ETOP 2007

Education and Training in Optics and Photonics 2007

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Ottawa Conference Centre

Ottawa, Ontario

Dr. Marc Nantel, Chair/Editor

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Ontario Photonics Education and Training Association

Welcome to ETOP 2007

Education and Training in Optics and Photonics 2007

Optics and photonics spawns increasingly important enabling technologies that are key to a variety of widely diverse fields. The telecommunications industry has fundamentally changed as a result of fiber optic communication and optical interconnect technologies. The biomedical field has changed with the expanding array of optical spectroscopy and diagnostic measurement techniques. Our fundamental understanding of physics and our natural environment has been improved as a result of the laser and its applications. Even the manufacturing industry has been revolutionized by lasers and photonics technology.

But any sector of the economy is nothing without its people, which is why the teaching of optics and photonics – critical fields at the core of today's worldwide technological infrastructure – must continually be upgraded and renewed in order to meet the growing demands of research, science and industry. This meeting will provide a forum for those who educate or are interested in education and training in photonics. Speakers from around the world will share methods and experiences relevant to this increasingly important and dynamically changing field. Innovative teaching methodologies and curricula from primary, secondary, post-secondary and post-graduate levels will be explored. Through presentations, panel discussions, workshops and exhibits, this important conference informs and teaches the professors, students, teachers and professional trainers how to teach for the future.

This conference represents the primary international forum for the exchange of ideas and experiences related to education and training in optics and photonics. It is an honour to be able to welcome you to ETOP 2007.

Marc Nantel
Chair – ETOP 2007
Ontario Centres of Excellence

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The Ontario Centres for Excellence is a not-for-profit corporation that delivers the Ontario Centres of Excellence program, made possible through the financial support of the Ontario Ministry of Research and Innovation. OCE supports research and development in Ontario's university, colleges, teaching hospitals and institutes; the commercialization of industry and academic collaborations; and the development and deployment of the next generation of talent in specific technologies across a range of market sectors including communications and information technology, earth and environmental technologies, energy, materials and manufacturing and photonics.

OSA®
Optical Society of America

The Optical Society of America, headquartered in Washington, DC, is an international scientific society dedicated to increasing and diffusing the knowledge of optics and photonics in all its branches, pure and applied, through its world-renowned publications and education forums. Founded in 1916, the OSA comprises nearly 16,000 individual and over 250 corporate members encompassing scientists, engineers, and technicians from the United States and nearly 90 other countries. OSA brings together the worldwide optics and Photonics community of scientists, engineers, educators, technicians, and business leaders.

SPIE

The International Society for Optical Engineering is an international technical society dedicated to advancing scientific research and engineering applications of optics, photonics, imaging, and optoelectronic technologies through meetings, education programs and publications. The Society comprises more than 16,000 individual, 1,750 student, 370 corporate, and 5,000 technical group members in 80 countries. A core mission of the Society is to provide a full range of continuing education, professional development, and student/educator resources and services, including the award of $250,000 annually in scholarships and grants.

INTERNATIONAL COMMISSION FOR OPTICS
COMMISSION INTERNATIONALE d'OPTIQUE

The International Commission for Optics was created in 1947. It is an Affiliated Commission of the International Union of Pure and Applied Physics (IUPAP), and as such part of the ICSU family (ICSU is the International Council of Science). As it is clear from its name, its objective is to contribute, on an international basis, to the progress and diffusion of knowledge in the field of optics.

IEEE LEOS
THE SOCIETY FOR PHOTONICS

The IEEE (Eye-triple-E) is a non-profit, technical professional association of more than 360,000 individual members in 150 countries. The full name is the Institute of Electrical and Electronics Engineers, Inc., although the organization is most popularly known and referred to by the letters I-E-E-E. Through its members, the IEEE is a leading authority in technical areas ranging from computer engineering, biomedical technology and telecommunications, to electric power, aerospace and consumer electronics, among others. The Society for Photonics (LEOS) advances the interests of its members and the laser, optoelectronics, and photonics professional community.

NATIONAL ACADEMY OF SCIENCES

The National Academy of Sciences is an honorific society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare.

ETOP 2007 would also like to thank OPETA, which is the official organizer of the conference, and which lent its webpage and member resources to make this conference possible.

OPETA

The Ontario Photonics Education and Training Association (OPETA) was founded in June 2001 to regroup members of the education, industrial and governmental sectors in Ontario who take an interest and care in the provision of top-quality optics and photonics talent in the province. OPETA and its members – now including some from outside Ontario – have expanded the education and training offerings to cover the whole education pyramid, from grade school to grad school.

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POSTERS

I.

ACTIVE LEARNING IN PHYSICS A WAY FOR RATIONAL THINKING - A WAY FOR DEVELOPMENT

Z. Ben Lakhdar [1]*, N.Derbel [1], Z. Dhaouadi [1], H.Ghalila [1], R.Miled [1] , S.Lahmar [1]. K.Berrada [2], R.Channa [2] and A.Outzourhit [2]
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ABSTRACT: Science Development leads to new concepts, new tools and new techniques. It leads to a society development with new Truth. This Truth is shared by the Society which development is built on Knowledge, on rationality thinking and scientific behavior. This takes its origin in the experimental approach introduced by Ibn Al Haythem in optics at the Xth century.
By the end of the last millennium, this approach-known as Active Learning in Physics- has been adopted in most developed countries in physics education programs. Active Learning in Optics and Photonics- ALOP- is extended actually to some developing countries through a UNESCO program.
A French edition of ALOP takes place through many workshops over Morocco and Tunisia. It aims to build Truth on evidence and not on intuition or personal authority.

1. THE WAY OF SCIENCE FUNCTIONING

Man looks for Truth. What is Truth?
Truth is defined in Encyclopedia by Diderot and d'Alembert as " *a confirmity of our judgments with what are things* ".
This means: there is possibility of many truths-*upon once judgments*- for the same subject!
This jugements is personal, depends on Knowledge, on own initial disposition and life experiences, on human progress.
Then how do we find the "limit" between once believes and Truth which is established? Between once opinion and scientific knowledge?
Human progress: the elimination of ignorance, superstition and prejudice; and the promotion of understanding and awareness is built on education on Science and its methodology.

Development of Scientific knowledge is based on rational thinking based on old knowledge and new experiments , with codes of behaviour.
Scientists in their quest for new knowledge do not know what is relevant. Scientists believes are "Tentative, not dogmatic; they are based on evidence, not on authority or intuition." B. Russell (1910). That evidence is given by experiment. ".... The test of all knowledge is experiment. Experiment is the sole judge of scientific Truth." (Richard Feynman Nobel price1965)

2. SOCIETY DEVELOPMENT

The experimental approach is as "……a symptom of a wider conceptual revolution that lies at the heart of what has happened to the world along the second millennium" (R. Power-1999); The father of t*he rise of the experimental method* is Abu Ali al-Hassan Ibn al Haythem (965 - 1040), who is considered as the Scientist of the second millennium (R.Power 1999).
He solved a scientific debate (Euclide, Ptolemy, ..) that had remained deadlocked for more than 800 years about the mystery of vision and its interpretation that light necessarily travels from the eye to the observed object (M.Serres). He invited observers to stare at the sun and the result was: the eye can be burned. The conclusion was *shared* by all participants that light starts outside the eye and reflects into it, removing, with a *single observation,* the very well Systematic theory. Direct observation, controlled looking, experiment, remain the best ways leading to Knowledge. Sharing the experiment, will lead different persons to the exact same understanding.

At the start of this second millennium, Society culture was yet subject of Astrology, Miracles , ... In 1633, Earth is yet the Centre of the World with Sun moving around and Galileo, has been condemned by Church of Rome because he disturbed this beleive and, experimentally, established the Copernicus Heliocentric system!
The scientific method leads, when new evidence comes to light, to accommodation of the theory to that new evidence. Gravity, relativity, and quantum mechanics are concepts which have changed the way we think. This change is *shared* because it was *tested experimentally.*
For a scientist, the truth –for the material world- evolutes with the advancement of science "la vérité est fille de son temps (The truth is daugthter of its Time)" said V. Hugo.

3. KNOWLEDGE SOCIETY

At the start of the 3rd millennium, life depends more and more on science, on technology based on physics development (laser systems, computer science, mobile phones, …). The culture is mainly Science.
Science is present anywhere in our environment! and is at the heart of the functioning and the future of our society :

-a hand-held Global Positioning System satellite receiver can pinpoint its owner's location anywhere on the face of the globe!

-Atom can be seen, its dynamics controlled and new matter is created.

-DNA blueprint of life is decoded; we learn to manage the deployment and expression of genes; ..

-More than 100 exo-planets are discovered;.

-We look for extraterrestrial

-etc…..

This Culture, developed by scientits, is supposed to be universal, without frontiers and with Global dimensions.

4. STATE OF PHYSICS EDUCATION

While modern life depends increasingly on science transferred in technology (mobile phones, telematics and informatics, laser systems in medicine and industries, ...c'est déjà dit ci-dessus), at the end of the second millennium :

-The number of students – was decreasing in mathematics, physics and engineering through the developed countries. As an example, fig1- shows the percentage of student evolution in US given by National Science Foundation (NSF).

-The students choose *modern branch* activities which are close to their environment, connected with life, actual (telecommunication, informatics, microelectronic, biology,.)., and connected with money (fig2).

-The statistics has revealed that Physics suffer in the developed world institutions (A.M.Levy, T. Feder). On figure 3, NSF gives an example of this decrease students enrolment in physics between ~ 1950 and 1990 in US.

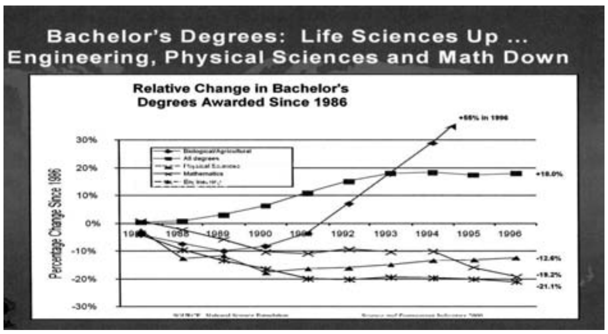

Fig 1: percentage of student evolution in –US in mathematics physics and engineering given by National Science Foundation (NSF).

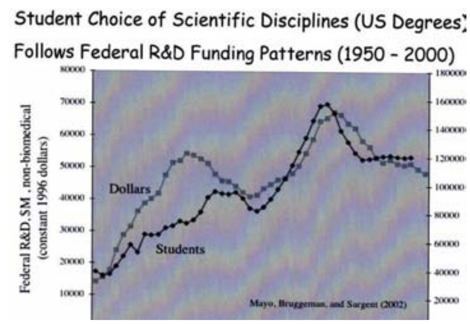

Fig 2: Choice of Scientific Disciplines is correlated with Dollars.

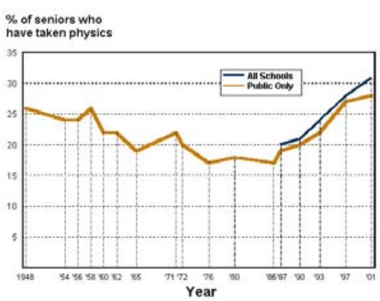

Fig 3: Enrolment School: percentage of senior who have chosen physics (1948-2001)(Statistical Research Center)

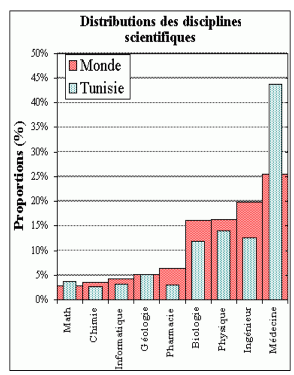

Fig 4:Tunisian scientific research productivity compared to the mean rate productivity of the world

This is dramatic: '*No physics today equals no technology to morrow tomorrow*'. The Scientific community (US National Academies of Science, National Research Council, CNRS in France...), tends to resolve this situation in crisis resulting principally from the old educational system which not ou don't follows the new technologic development.. New and innovative attention was paid to education:

- the work life of a physics teacher may be 40 years in which time physics is changing and developing . Continuous professional training and updating are required.
- Physics education and research should be popularised as well as other science disciplines. Physics should be connected to other disciplines with connexion of University to local

industries, to schools , to scientific societies, to Society.

In Developing Nations, science (mathematics, physics, chemistry) is relatively learnt at an early age (in Tunisia ~6 years old for mathematics, ~14 for physics) but science and particularly physics is more in crisis than in developed countries. Physics is seen by most people as a tedious experimentation in the laboratory and not a creative and cultural activity, not a source of development.

In Tunisia, almost the total students suffer from physics studies. After "Baccalaureat", a diploma which closes the high school studies, each student can access to University but his studies choice is depending of his results in Baccalaureat and places offered by institutions. Students, in Tunisia, as in developed countries, choose *modern branch* activities which are close to their environment (medicine, telecommunication, informatics, biology,.)., and connected with money. One of the best choice is also mathematics.
Physics carrier is among the last choice!
On figure 4 , we give the rate of research science productivity of Tunisia compared to the mean rate for research science productivity in the world.(H.Condé). While in mathematics, for which there is no need for experimental activities or in medicine where studies are followed by the best students and connected to the environment (hospitals), the Tunisian rate productivity is greater than the mean rate in the world, for physics , the world mean rate is larger than the Tunisian one. This is largely due to a severe shortage both of material facilities (schools, laboratories, equipment) and of well qualified physics teachers.

In a world where the progress of Society, the economic and cultural development is increasingly dependent on the science, this situation is no longer acceptable. We should try to bring an understanding of science.

The challenge requires a new *methodology* of teaching like: "**Active learning**" (inspired by L.C. Mc Dermott) or "Main à la pâte", inspired by Nobel price G.Charpac.

4. NEW METHOD FOR EDUCATION: ACTIVE LEARNING IN PHYSICS

Active learning in Physics-ALP- is an innovative mode of physics teaching, developed over the last decade. It has demonstrated in the US and other developed countries its capacity to enhance student's understanding of basic physics concepts (D.Sokoloff). This approach leads at the beginning of the 3rd millennium to a sensible increase Physics enrolment of student (fig.2, 3).
In this learning strategy, students are guided to construct their knowledge of physics concepts by direct observations of the physical world with Hands on – activity. This scientific method is based on *activities in groups* following the *steps PEDS*: predictions, experiments, discussion (qualitative or quantitative description of the observed phenomenon), synthesis. The experimental observations generally lead to questions, questions leads to tentative answers and over all these questions the teacher guides the students to construct their knowledge.
ALP is also, a way for *keeping the teaching of physics -which changes continually- up to date*

.

In 2003 UNESCO under its Physics Programme Division of Basic and Engineering Sciences, launched a Project: "Active Learning in Physics in Developing Countries". This project, made up by M. Alarcon, aims to promote innovations in physics education in developing countries. It is developed for the benefit of universities and senior high school physics teachers. It aims at training teachers to use innovative approach of *active learning* in teaching physics through a series of workshops.

After one preparing workshop in Manilla –Philippines, the 2 twwo first workshops (2003-2004) took place in Ghana,. The fisrt one was about mechanics then and the second one was about optics-photonics.

Tunisia (2005), then Morocco(2006) asked UNESCO for ALOP (Active Learning in Optics and photonics) workshops.

Why ALOP?

The project is then focused on optics and photonics because it is an area of experimental physics which is relevant and adaptable to research and educational conditions in many developing countries. We notice an explosion of work in optics. Optics has been termed as "enabling science" because it constitutes the basis of many modern advances in diverse and high technologies (communication, information, transportation, manufacturing, environment control, monitoring, health, medicine) and the new century is entitled the "age of photonics".

The project is developing an activity based on teacher training curriculum on the themes: Introduction to Light and Geometrical Optics; Optics of the Eye; Interference; Diffraction and Spectroscopy; Environmental Optics; Optics in Communication. Modules with activities and appropriate instrumentation are developed under each theme. Inexpensive materials and local fabricated ou made materials have been used. A team of 6 resource persons (from 5 continents) prepared modules, material and lead the workshops.

The workshops are organized via an international working group consisting of representatives from UNESCO, ICTP*, SPIE*, OSA* and ASPEN * and mainly funded by UNESCO with support from ICTP, SPIE and OSA.

5. IMPACT OF ALOP IN MOROCCO AND TUNISIA

Participation in the ALOP Workshops was open to different levels of trainers: technicians; high school teachers, researchers and professors at the university- Participants- ~40- coming from around 10 different countries in each workshop, with big enthusiasm! worked -during the sessions -*in groups* with not expensive materials and following the *steps PEDS(* Predict, Experiment, Discuss and Synthetize).

The ALOP workshops provided the trainers with the real difficulties that may encounter our students in physics concept understanding and explained the importance of sharing knowledge. It enhances- for the participants coming from différents regions in Africa (South Africa, Cameroon, Ethiopia, North Africa, Tanzania) how Knowledge is personal, and depends on our own initial disposition and life experiences and how sharing experience enhances or leads to the concept understanding.

Participants appreciated the choice of ALOP modules: the mixture of basic physics modules (geometric and physics optics) with modules connected to life science (eyes) , environment (atmospheric) and telecommunication.

The connexion of differents disciplines with physics behind is absent in our education system, and the program and the teaching way of physics, in secondary schools as well as in universities, seems far from our environment and boring .ALOP enhances this failure, and participants realize also that each teacher must have some basic understanding of connections of one field with other disciplines.

The active learning workshops led to the conclusion from all participants, technicians or who are also researchers in different fields (computing science, solid state physics, atomic and molecular physics,..) coming from Faculties or Engineer Schools, that this approach is the process of training people's mind and abilities so that they acquire knowledge and develop skills. They asked to extend that activity to other modules in Physics. They also realised the need of multidisciplinarity and that local fabrication of materials is feasible.
ALOP workshops success led to development of local resource persons for training of trainers, to development of others ALOP workshops over different Universities and secondary schools in Tunisia as well as in Morocco.

New programs, new approach of teaching and policies, high qualified students should be implemented for science physics achievement in our developing countries to lead development of science culture and to lead to a Knowledge Society.

Acknowledgements

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*ICTP: International Centre for Theoretical Physics; *SPIE: International Society for Optical Engineering; *OSA: Optical Society of America; *ASPEN: Asian Physics Education Network.

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II.

Post-Graduate Program in Optics & Photonics

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Abstract
An optics and photonics post-graduate degree program is described that was organized, offered, and presented, at the Royal Military College of Canada between the years of 1976 to the present. While the author retired in 1998, one or more of the courses: Fundamentals of Photonics, Fourier Spectroscopy and Fourier Optics, Electro-Optical Systems, Radiation Heat Transfer, and/or Advanced Instrumentation, continued to be offered/given in the Division of Graduate Studies and Research. The most recent PhD thesis was completed this past year. The history, together with the problems and successes associated with the program at RMC are described. Recommendations are made.

Introduction

Arriving at RMC, Department of Mechanical Engineering, ME, in the in the Fall of 1976, after 14 years in optics and photonics[1, 2], it seemed unlikely that an opportunity for optics and photonics research would be possible. To propose nothing would achieve nothing; there was little time available for networking, an application for a grant to develop liquid-crystal, LC, light valves was made to CRAD, Chief Research and Development, Department of National Defense, DND. It had potential since one of the contracts while working in industry had involved LC's. CRAD was the only possible source of research funds for RMC engineering and science faculty unless a connection had been established with one or more colleagues at a civilian university. In the latter case, NRC, MRC, or private sources, could be addressed, the other colleague(s) could then "farm out" aspects of a successful proposal to RMC.

By the time the LC work had been completed, a satellite experiment was being considered. A reservation that used a Get Away Special, GAS, package carried on the Space Shuttle was obtained in 1979[3]. My experience with ISIS B[2] and high altitude spectrosopic measurements[4] were references. (The satellites: Alouette and ISIS B had been built down the hall from my laboratory). It turned out that the venue had minimal value for PG research—each shuttle flight was to spend only a few days in orbit as well as being problematic for the launch—and costs were significant. No other faculty members were interested to participate. The GAS did have value for undergraduate projects. Nine engineering projects in different departments stretched over several student generations between 1979 – 835[5]. NASA had requirements that had to be satisfied, the most stringent being "space-qualifying" an observation window. DIT was not interested in providing a minimum $125K that was needed to move ahead, the efforts were dropped. The reservation was relinquished, but visibility had been achieved. Telesat Canada donated space-qualified lithium batteries together with the two surplus traveling wave amplifiers from Anik C[6].

It took two years before a PG student was found. The graduate student, Capt(then) Paul Allen, was courtesy of Dr. D. Rogers, Physics Department. The suggestion had been made that an engineering thesis would have greater interest for the DND sponsor. Demand and supply determined a change in direction. Here was the premier and still greatest hurdle (see below) for research at RMC; the interest of the sponsor is paramount, not the desire of the student, nor the interests of the supervisor.

Organization & History

PG uniformed students come to RMC via a sponsor, the sponsor is the commanding officer of the unit to which a "posting" is directed. An SBQR, a requirement designation, is established within National Defense Headquarters; NDHQ, a search is undertaken to try to satisfy the requirement with a PG program. The sponsor opens a "window" of 22 months to complete that program; keeps the post open, and administers the salary. When the time is "up", the participant must report to the post.

Time extensions, when necessary, have to be negotiated with the sponsor. RMC being part of DND can mitigate this by extending the stay, but the sponsor ultimately controls.

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An incomplete thesis at the end of the 22 months sometimes results in the PG student making several short return visits to complete the thesis rather than have a direct extension of time.

Potential PG students for optics and photonics were drawn from graduates with bachelor's degrees in: electrical engineering, physics, engineering physics, chemistry, science applied, or engineering management. In the main, they were posted to RMC after two or three years work in their first job after graduation. RMC maintains its minimum acceptance level to any program. The PG students who entered the optics and photonics program were registered in different departments. Sponsors can insist that their candidate be registered in a given department. Depending on marks, a PG student from a different background may be asked by RMC to take several under-graduate courses in the new department. Created by the sponsor, this situation adds a year to the degree program; because of the time restriction, the result is often that the student goes elsewhere for the optics and photonics degree.

As much as desired, there was never an attempt made to organize this program as a distinct discipline(7). From time to time, the Dean of Engineering was apprised of the movements within the professional societies: OSA, IEEE, and SPIE, towards making optics and photonics a distinct discipline, but such a delineation was never given serious consideration at RMC. After all, Engineering Physics and Engineering Management were dropped in 1993 because their populations were small. The critical mass for optics and photonics was never going to be achieved. RMC, until recently, draws its PG students exclusively from uniformed graduates. The supply is limited.

Queen's University and RMC had earlier organized reciprocal arrangements, put in place because RMC had (has?) no mechanism to charge fees. Uniformed students did(do) not have sponsor's funds for tuition. RMC PG students were accepted freely into given courses at Queen's and qualified Queen's PG students were accepted in kind into given courses at RMC.
.

A specific problem was that the optics and photonics program was "hidden" inside ME. Cautious sponsors tend to follow a traditional path as they know it. An optics and photonics program buried inside ME may be "normal" for an Asian or European university, but not for North America. Optics and photonics is seen as necessarily attached to EE or Physics Departments.

Curriculum

PG students for a master's degree in science and engineering take five courses of three periods per week, plus a thesis. The course work is spread over two Terms. The initial courses(8) for optics and photonics were: Radiometry, and Remote Sensing. Although the title was meant to be generic, the Remote Sensing course did include satellite content. Eventually, the core of the program was refined to three courses(9) :

ME581, Fundamentals of Photonics: radiometry, reflection & refraction, electro-magnetic wave theory, photons, detectors—thermal & quantum, atmospheric transmittance, coherent & incoherent sources—natural, artificial, laser, FOV, FOR, optical crystals

ME583, Fourier Spectroscopy & Fourier Optics: spectroscopy review, diffraction, prism & grating instruments, Fourier Transform review, correlation, convolution, central limit theorem, Michelson interferometer, Fabry-Perot interferometer, imaging, filtering

ME587, Electro-Optical Systems: information control—chopping, reticles, phase sensitive techniques, spectral filters, scanning, detector arrays, figures of merit—D* & NETD, IFOV, image intensifiers, contrast, OTF, thermal imaging systems, low-light level TV, satellite observation, hyperspectral systems, synthetic apertures, MAWS, laser designators, laser aiming

These courses attracted students from Queen's as well as from other RMC departments and DND locations. Their average number was 2 per course. Occasionally, this meant that lectures had to be given one night per week per Term to accommodate out-of-town participants. An unexpected need was the time for the Queen's students to commute the four km distance between campuses; the institutions were out of step by ½ hour in their timetables. Two-hour slots had to be set aside for one period. In 1995, ME581 was presented via a video link between CFB Kingston and NDHQ, Ottawa.

An Electro-Optics Short Course(10) was voluntarily developed for people who lacked a fundamental understanding of optics and photonics. A course variation, ME580, soon became necessary(11), it was an amalgam of ME581 and ME587 for individuals who had participated in the Short Course who wanted academic credit. It added mathematical rigor and assignments. ME580 was given on demand, about 15 extra periods, depending on the routine for individuals who commuted from distant locations.

ME589, Advanced Instrumentation[12], was voluntarily developed, originally for ME students, but it became useful for the optics and photonics program for students who lacked background in measurement techniques. It included some electronics and sensor theory, signal processing, A/D and D/A techniques, electronic filters, and displays. A significant part of the content included fibre-optic sensing. Remaining courses needed for degree requirements were chosen from the EE Department, Computer Science, Mathematics, or Physics Department, either at Queen's University or from a different department at RMC.

One may ask, given my background in detector and semi-conductors[2], why a distinct detector course was not included. There is some detector analysis included in ME581. The answer is given through the experience of one PG student with a different supervisor; a thesis topic in new detector materials was chosen. The sponsor declared the officer to be "useless" on return to the "post"; this despite a satisfactory thesis! The operative content obviously had to be electro-optic systems.

Summary

The degrees awarded at RMC for the PG candidates in optics and photonics were from the disciplines in which they were registered: EE (4), Phys (2), and ME (7); one withdrew after a month into the program, and one did not complete the thesis nor all the course work. All theses resulted in publications.

There were 14 males and one female. There was one civilian, of the 14 uniformed participants—one was from the land element, one maritime, the remainder were air. Six remain in the CF, five continue to do optics and photonics work (only 3 within the CF); unfortunately information about four has been lost. Eight arrived married, two were with children, there was one divorce, and one birth, during their programs.

Among the thesis topics are: spectroscopic UV measurements on a rocket-motor exhaust (1), laser anemometry studies at λ514 & λ488 [nm] (1), diffractive element design and blur measurements at λ10.6, and λ1.064 [μm] (7), passive ranging using a diode array (1), detector fabrication studies (1), resolution capability of a fibre optic integrated spectrometer[13] at λ4.7 [μm] (1), and phase diversity astronomic studies in the visible (1).

Recommendations & Conclusions

Professionals often say that their "current work" is far removed from their original degree program. Any degree is less an indication of utility and more a measure of capability. Too often, sponsor and student look only at immediacy. They need to look beyond the department residence of a program, beyond the program detail to judge its utility. It is education that must be the goal, not training for a particular "slot". Education paves the way to greater understanding.

There is a reluctance, or perhaps an inability, to understand the effort and the hours spent in developing such courses and research, as well as in administrative and organizational matters associated with the PG programs. One has to be willing to work long hours to bring about any PG program when there is minimal recognition of the commitments. RMC gave (gives?) no credit or bonus to its faculty for time spent preparing and presenting graduate courses. Setting up the optics and photonics program was an exclusive volunteer responsibility. In the words of one department head: "It's like shooting yourself in the foot." All faculty members present two undergraduate courses as a minimum, three or more periods per week, per Term, as well as supervising undergraduate laboratories, and projects. Each PG course adds a commitment of a further three periods per week per Term. Credit for time spent preparing PG courses must be given to encourage the effort. Individual department heads are keen to see the effort, but have to balance the undergraduate work loads.

All uniformed PG students are paid to attend class. They also have military duties. There are no teaching or laboratory assistants; these duties were handled by the RMC faculty.

This added a further two to three hours per week for each faculty member. This had to change; the Dean of Engineering, Dr WC Moffat, negotiated the use of PG students for these tasks with potential sponsors, but it took several years until 1991 to achieve.

A research program must be carried out by the thesis supervisor to gain credibility. Credibility means the chance to expand. The research, funded through CRAD, may not necessarily be in the direction that a PG-student and sponsor would like. A "Catch-22" arises. The sponsor is willing to support the PG student, but has no financial support for the research; CRAD finances the proposed research, but the sponsor is not particularly interested in its direction. If the research is widely divergent from the sponsor's interest, the faculty member never gets a PG student. As a consequence, the research activity is not freely chosen.

By 1997, Dean R. Weir, Graduate Studies and Research, had negotiated accessibility to NSERC. This was no small task since RMC, being a part of DND, had always been denied this access by the Treasury Board; access was deemed to create a precedent allowing for the transfer of budgeted funds between government departments. With the change, research at RMC at last could attempt to find funding in directions that: could become independent of a sponsor's interests, could have more peer visibility, could give the possibility to hire research associates on long term contracts, and could generate a healthy competition with all universities. The sponsor still had (has) to be "sold" on the utility of the potential graduate—but the research became independent.

The 22-month arrangement between sponsor and supervisor gives RMC a slight advantage over a civilian university. Being part of DND, the detachment has a bit more flexibility if delayed for the time may be marginally extended . Geographically, RMC is close to NDHQ, a commute is feasible for short work periods.

The hurdle in getting uniformed PG students to RMC has always been the struggle between sponsor and supervisor. There is also the normal struggle between departments for more graduate students at any university. When a separate discipline is not identified, the result can be a greater struggle. The RMC program within ME had visibility only through the trickle of graduates, through the sponsor who had familiarity, through the RMC PG Calendar listing of courses, and through word of mouth. A wide ranging PR effort was missing.

Given a choice, the sponsors would like a course-only master's program. This is identified as having a fixed time. The interest seems to be to have the degree, not necessarily an independent thinker. RMC did (does?) not have the resources for such a program. There were several efforts to nudge RMC to offer a course only degree; it was faculty resources that prevented it. Today, a nine-course master's program with no thesis is offered in some departments. When the argument was presented that a thesis forces the candidate to use initiative to learn more, there was disbelief.

The individual efforts have been successful, the program has not been. Because RMC is a university that comes under the "training umbrella" of DND, there is a struggle between the academic requirements and the sponsor's requirements. The sponsor wants the candidate to be immediately useful on his or her return, "to hit the ground running", pronounced "full", ready to go. There is disinterest from the sponsor in the research; the focus is on the waiting job that has been kept open.

It is clear that the formal optics and photonics program will not revive. Of course there will be individual optics and photonics theses, but not a focused program. The author was not asked, nor able to steer a successor into the department to carry on work in optics and photonics. The circumstances that brought optics and photonics to the RMC ME Department were unique, but the condition did not have to be abandoned.

Acknowledgements

DASP (now defunct) encouraged this PG program through contracts, donations of equipment, and the sponsorship and posting of candidates to RMC over a 22 year period.

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III

An Optics & Photonics Program: Buried

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Abstract
Buried in the Land Forces Technical Staff Program, a one-year program within Applied Military Science, AMS, at the Royal Military College of Canada, is a set of 27 lectures in optics and photonics. The lectures, spread over 1½ months, are organized and presented to 22 participants each year, Captains and Majors, to give an appreciation of: thermal imagers, image intensifiers, laser designators, atmospheric characteristics, and many of the basic concepts associated with the detection, identification, and recognition, of targets. Discussion is provided of the difficulties associated with this program.

Introduction & History

The Land Forces Technical Staff Program, LFTSP, was organized within the AMS Department at RMC to repatriate a program for CF personnel, previously offered at the Royal Military College of Science, RMCS, Shrivenham, UK. RMCS offers many programs of interest to participants from the UK as well as other countries. One of these courses offers instruction on: armaments, artillery, explosives, "fire control" equipment, data and characteristics of different vehicles and their operating technique and tactical use.. There are two 'streams' or Divisions—one for degree granting purposes, the other much shorter program, is non-degree granting.

The LFTSP, within AMS, is a one year program organized to prepare officers for new roles in the Canadian Forces, CF. It is a clone of the RMCS course, but emphasizes equipment that is used by CF land elements. The course provides the opportunity to obtain a master's degree in Applied Military Science. The participants come as senior Captains or Majors; their average age is about 28; most are married with families; many have had experience serving in hostile environments.

Since there are many weapons and vehicles that make use of optics and photonics systems, lecture time was made available for this subject. The Electro-Optics Short Course had been presented by me many times at RMC(1) ; it was natural to volunteer to modify it for a shorter series of lectures in 1994.

There were similarities between the two programs:

i) The lectures and demonstrations were designed to bring the participants from a limited (or forgotten) background in optics and photonics to an overview of electro-optical systems that operated actively or passively in the ultra-violet, visible, and infrared.

ii) There was a night session about ½ way through the program to demonstrate and contrast: binoculars, telescopes, aiming devices, image intensifiers, and thermal imagers, under atmospheric conditions that included scattering from smoke. There was one two-hour afternoon session to demonstrate laboratory equipment: polarizers, lasers, LDA, Bragg modulation, detectors, and spectrometers.

iii) Like the Short Course(1), it was a rare year that there were one or two who had a science or engineering degree. Lectures had to avoid reliance on mathematics. The lectures had to show "why" rather than "how". Power capture was the crux(1) to appreciate the developments.

There were also differences:

a) The main difference was that there were only a limited number of periods available for optics and photonics. That number originally was 29, scattered within the LFTSP; the number were reduced over vigorous objection to 27 after the first year.

b) The participants had a defined purpose in the LFTSP, a focus on land-element equipment.

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The participants in The Electro-Optics Short Course had a general purpose; they were drawn from all elements; land, maritime, and air[1]. Examples illustrating optics and photonics that were not associated with the defined purpose of the LFTSP were deemed less important and by inference less interesting.

c) The LFTSP is built on the RMCS model that organizes participants into syndicates or groups. Each syndicate works together as a unit; co-ordination is through a syndicate director. The optics and photonics instruction had to include an assignment for each syndicate. Three assignments were developed: one for thermal imaging, one for an image intensifier, and one that varied from year to year that was either a directed weapon scenario or a different thermal imager to operate at a different spectral wavelength.

d) The LFTSP has a requirement for year-long projects for teams of two or three. Participants choose projects (with sponsor[2] input?) at the start of the program. Most projects are overly sophisticated, inappropriate in my view for any of the syndicates.

e) Marks were required for the projects based on a team written report and oral presentation, for the team assignments, and for exercises to be done by individuals that were added (see below).

Course notes: <u>The Electro-Optics Short Course Notes</u>[3], were provided to each participant.

Difficulties

There were(are) a good number of unique difficulties:

First. A Term at university has the courses presented with distinct identity, three periods per week until perhaps 11 or 12 weeks complete the program. Professors complain about compartmentalization, but isolation for optics and photonics would have been an asset with the LFTSP. University courses come with prerequisites; without the isolation identity, the implied prerequisite is the LFTSP itself, but there is nothing else of an optics and photonics nature in the program. Without the identity, the participants questioned the fit.

Second. Lectures were presented when time was available from “normal” LFTSP matters. Optics and photonics lectures commenced in the fifth month and ended in the sixth month. The lectures were spread: perhaps three in the first week, then four, then three in one day in the third week, then six, then two, then six, until completed. Because of other duties, presentation time was also constrained by my own availability. The impression was that of disorganization. Invariably discussions and questions brought concepts to the fore that needed far more time to explain than was available. The periods together were not lectures in the traditional university sense; they were more like instructions that became repetitive—returning many times to concepts associated with assignments.

Third. The participants who had chosen optics and photonics projects at the start of the LFTSP would show up early at my office asking for help. Enthusiasm and willingness were obvious, initiative needs to be rewarded, but a zero background causes much “spinning of wheels”.

Fourth. Optics and photonics lecturers from outside RMC could not be invited before the fundamental lectures had been given. Such visitors’ lectures[4] were not part of the 27.

Fifth. Occasionally, based on misinformation from outside the program, a participant would challenge me. Misinformation is difficult to dislodge. Such participants were the product of the classic: “someone who has just enough information to make him or her dangerous”! One participant believed that: “… optical fibres have to have mirror coatings along their length to reflect the *em* wave passage.” *TIR was a foreign concept*. Another asked: “ … where do audio waves appear on the *em* spectral chart?” *A wave is a wave is a wave?* Others were overly concerned about laser reflections from the class-room pointer! *Lambert’s law and irradiance were not obvious.* Difficult concepts to isolate are the differences between diffraction and aberrations. Correcting misinformation is not easy within short time constraints and lack of background.

Sixth. The Notes[3] were organized for the presentation of data over 85 periods; most were made available to the EO Short Course participants to read ahead of time. Only parts were used in the 27 periods for the LFTSP participants; the participants had little time for advance reading. Furthermore they were used to having “hand-outs”, not used to take notes, or consult references. The lecture overheads were photocopied, but created confusion because there was little time to tie them to sections in the notes.

Seventh. The participants had no difficulty accepting that general input functions: the step, the ramp, the impulse, and the periodic, can be applied to transducers and "control boxes" in order to find their general response. There was difficulty in understanding that these functions could be combined to make any generalized polynomial input. Without mathematics, there was difficulty accepting the output responses to the inputs from the transfer function characterization of the devices and systems. The transfer functions used are either zero, first, or second order. The concepts of: time constant, rise time, decay constant, amplification and responsivity, were repeated, often using graphical depictions. The 27 periods did not allow time for review.

Conclusions & Recommendations

It is expensive to educate personnel in optics and photonics; there are no short cuts. As with any discipline, without the education, the options are limited. The equipment is 'thrown away', to be replaced, or 'sent back' for repair(1). Without the education, personnel become knob turners, panel openers and viewers, screw fasteners, or component replacers—the same as "fetchers of water and hewers of wood". Until the proper education is achieved, the personnel remain at worst over-the-shoulder onlookers, and at best followers of action by rote.

Usage follows a recipe, understanding needs the background. Optics and photonics is a discipline that requires a lot of background for mastery. For example, one can train an individual how to use a laser, but understanding how it works requires considerable chemistry, physics, and engineering. To understand a laser's limitations, detail is needed. There are many types of laser: gas, semi-conductor, solid, dye, DFBL, tunable, quantum dot, VCSEL, etc, not to mention LED's. Each has unique characteristics. In addition, laser safety requires study of the physiology of the eye. The difference between cw and pulsed signals needs the understanding of the difference between energy and power. The differences between cw and pulse lasers need a firm understanding to appreciate eye protection.

Because the optics and photonics lectures are buried without identification or "highlighting", the impression is given that they are "fill in". The lecture pattern leaves the impression that their content is peripheral, yet the systems carried by soldiers and on military vehicles are crucial to the success of the operations. The participants appear to have little faith that their goals are kept in focus. It is a strong visibility for optics and photonics inside LFTSP that is lacking.

There was bitterness about the assignments because of the inordinate amount of time required (in the opinion) of the participants. The assignments were difficult for those who had little interest in simple mathematics understanding. The concepts of radiance, emittance, power, and intensity, gave difficulty. Group work was done within each syndicate which made it difficult to identify individuals having trouble understanding. Only once in seven years was help asked.

With reference to marks: in the first year, there was a debacle at presentation time, a public event with visitors from NDHQ. Presenters had not submitted their efforts ahead and too many fundamental errors were noted! Later years saw previews before the "official" presentation. Because there were only one or two projects in optics and photonics, it was awkward to be harsh in judgments, even though harsh might be deserved. Marks were listed in "order of merit". Marks meetings degenerated into positioning candidates according to the opinions of the syndicate directors.

An impression was given that the projects were related to future postings of the participants; that both the participants and the sponsors were looking for "a leg up", perhaps some free advice, on their coming work within NDHQ. The guests invited to the presentations were from some industries, as well as from NDHQ. Were they invited because of an interest in the projects or because of a general interest in the program? Their presence and contributions were unclear.

Because of the marks requirement, and the group mark only being available for optics and photonics, two or three problem sets were added to be responded individually. This was unpopular, but it was the only way to get a clear distinction between participants.

Generating a proper understanding of optics and photonics in those with little or no background is an impossible task. The best that can be hoped is a rudimentary appreciation rather than understanding.

In my view, treating these lectures as education is incorrect, a waste of effort and time. The short number of lectures on optics and photonics buried in the LFTSP should emphasize training on specific systems. Training does not require a PhD. The conclusion must be made that the PhD lecturer was used for "window dressing" perhaps for credibility for the program? These periods should make use of manuals, brochures, and catalogues[5, 6]. It is obvious that the participants look on the lectures on optics and photonics as an inconvenient truth that has to be endured. The CF understand training, use and need training for specific equipment and machines, and for tactics and strategy. The CF requirements are for now, not for the future. There is little patience for research. This is understandable given the required tasks.

Given the optics and photonics lectures, they need to be spread over six to eight months for a proper education. There is no time during the lecture interval for "reflection time" or a "soak time". It is a disservice to the participants who choose their project in optics and photonics to have to wait for over ½ the elapsed time of the LFTSP before to receive lectures in their subject.

If one takes the LFTSP lectures as being 8 months (remaining time being establishment visits) of 25 periods per week, the result is about 800 hours of instruction. A course-only master's degree of nine courses spread over two Terms (each university level course being 4 hours per week) is about 400 hours. There is more than enough time for a course-only program. If such is to be the case, care has to be exercised to establish that such a program is still education, not training, if it remains at RMC.

Because the purpose of the LFTSP is to study military vehicles, artillery, and weapons, the optics and photonics lecturer becomes the last to know about changes to the schedule organization and time table. Visiting lecturers deserve notice also that fundamental material has already been presented. There was repetition of a number of concepts by visitors. The visitors are invited to discuss special equipment, perhaps classified, or unique in some way, and should not have to discuss or repeat fundamentals. There was little or no direction for visitors; significant time is lost in repeating basic concepts already discussed.

The optics and photonics lectures for the LFTSP were a volunteer activity within RMC. Because of my personal commitments to the under-graduate[7], graduate[2, 8] (also volunteer) and the Electro-Optics Short Course[1] (also volunteer) programs, the LFTSP did not get all the attention it might have needed. When I retired, a modest stipend was paid for the last three offerings of mine, until 2002. Optics and photonics lectures continue to be presented as a part of the LFTSP by several others, using, I believe, "The Electro-Optics Short Course Notes"[2]. I hope that optics and photonics within LFTSP gets its proper attention.

Acknowledgements

Mr K Stefanski, Head EO Section (now retired), LETE (now defunct), was instrumental in providing much extra equipment useful to the program. Capt C Frost, DND, ensured that it was delivered to RMC.

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IV.

Photonics Education Program at California Polytechnic State University

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Abstract: California Polytechnic State University (Cal Poly) has an active photonics-related program. The thrusts of the program are coursework, extensive photonic educational laboratories, an SPIE student branch chapter, and a new Project-Based Learning Institute (PBLI) to promote joint projects with industry. This paper will describe our program for a multidisciplinary approach to photonics education at the undergraduate and master's degree level.

OCIS codes: (000.2060) Education

1. Introduction

1.1 About Cal Poly. California has two university systems: the University of California (UC) system and the California State University (CSU) system. The UC system provides for undergraduate programs as well as advanced degrees and major research programs at all graduate levels. The CSU system offers Bachelors and Masters degrees in most of its departments but in general does not offer Ph.D. programs except in education.

California Polytechnic State University (Cal Poly) is a member of the California State University (CSU) system. The CSU system has 417,000 students at 23 campuses around the state. Cal Poly has a full time enrollment of about 18,000 students. The engineering college is the largest on campus with 4,500 students. Cal Poly is located in San Luis Obispo, CA. This location is equidistant (4 hour drive) between the major metropolitan areas of San Francisco to the north and Los Angeles to the south. Cal Poly attracts approximately equal numbers of students from the northern and southern halves of California.

The authors of this paper are from the department of electrical engineering (EE) and the department of Physics at Cal Poly. This paper will focus on major photonic education and research activities in these departments. The EE department has approximately 650 students enrolled and its sister Computer Engineering (CPE) department has 450 full-time students. There are 28 full-time professors in the EE department with 5 full-time equivalent lecturers. Within the electrical engineering department, there are four professors who are active in photonics education and research. The Cal Poly Physics department has an enrollment of approximately 120 undergraduate students. About a quarter of the twenty two full-time tenured/tenure-track faculty have research and professional development activities in the area of photonics.

1.2 Key Issues for Photonics Education at Cal Poly. Cal Poly as a university has advocated the philosophy of "learn by doing" and has used this phrase in its marketing program for incoming students for several decades. A visit to the campus web site, www.calpoly.edu, will find the words "learn by doing" in the very center of the main page. It is part of this university's culture to advocate a hands-on approach to learning.

There is continuing debate among engineering faculty and administrators on how we continue to innovate and improve our student's educational experience and educational outcome. The college of engineering has chosen to further invest in project-based learning programs for our undergraduate and graduate students as one of its key initiatives. A key action has been to establish a Project-Based Learning Institute (PBLI[1]) on campus. The goal of this program is to facilitate interaction between the university and industrial collaborators in order to create more multidisciplinary team-based opportunities for our students and faculty.

The photonics area is a broad field that requires technical knowledge in quite a range of sub-disciplines. It certainly is a prime example of a field where contributors can come from a wide range of backgrounds. Photonics applications in communication, scientific, commercial, biological, and defense areas are all important to the California economy. A major challenge for Cal Poly is then to make sure our graduates interested in the photonics area have the multidisciplinary and team skills necessary to work in the diverse areas of photonics applications. Our photonic education program at Cal Poly emphasizes four main educational tools; **A.** Lecture Classes, **B.** Photonics Laboratory Classes, **C.** Student Photonics Club, and **D.** PBLI design projects. In this paper, we will describe these four items with emphasis on our new initiatives for part B and D.

2. Photonics Lecture and Laboratory Course Innovations at Cal Poly

This section describes the lecture courses and laboratory courses that are offered in Cal Poly's photonics program. Special emphasis is given to contents of several of the laboratory courses to highlight some of the changes that have been made to improve our laboratory educational experience. Table 1 gives a summary of the lecture and laboratory courses offered in photonics at Cal Poly.

Table 1: Photonics Courses Offered at Cal Poly.

Course Number	Course Title	Credits
PHYS 315	Introduction to Lasers and Laser Applications	3
PHYS 323	Optics (With 1 Credit Lab)	5
PHYS 423	Advanced Optics (With 1 Credit Lab)	4
EE 403	Fiber Optic Communication	3
EE 418	Photonic Engineering	3
EE 443	Fiber Optics Laboratory	1
EE 458	Photonic Engineering Laboratory	1
EE422	Polymer Optoelectronics Laboratory	1
EE520	Solar-Photovoltaic System Design. (graduate course)	3
EE 530	Photonic Systems (graduate course)	4

2.1 Photonics Lecture/Laboratory Offerings in Electrical Engineering: The EE department offers 3 undergraduate lecture/lab courses and 2 graduate lecture courses in the photonics area. Cal Poly has a 600 square foot photonics laboratory that is used both as a teaching and research facility. Figure 1 shows a photograph of one of three identical teaching optical benches that are used for undergraduate education. This laboratory was first established in 1986. A major upgrade occurred in 1995 to track some of the innovations in the fiber optic communications field. Laboratory equipment was financed primarily through generous equipment donations. We are also supported from the University for space, utilities, and equipment maintenance. Approximately 100 students take these EE undergraduate elective courses in photonics over the duration of a year. A second major upgrade of these laboratories is in progress. A brief description of each of these courses follows.

Figure 1: Undergraduate photonics teaching laboratory station. This is one of three identical benches used in two of our undergraduate laboratory courses. The room is 600 square feet. It also accommodates a photonics research bench. In this particular exercise the students are measuring the modal dispersion-limited bandwidth of a multimode optical fiber at 850nm.

2.1.1 EE403 Fiber Optic Communication (3 credit lecture)

This course offers an introduction to fiber optic communication. The topics covered include propagation of light in optical fibers, attenuation and bandwidth, LED and laser diode sources for use with optical fibers, optical sources, detectors, and receivers. Design of optical communication systems with applications in telecommunications and local area networks (LANs) is covered. One of the prerequisites to this course is the Physics optics course, PHYS 323.

EE 443 Fiber Optics Laboratory (1 credit)

This laboratory course is a concurrent and companion course to EE 403. The topics covered in the experiments include experimental investigation of the properties of optical fibers, sources, and detectors. Measurement of numerical aperture, attenuation, bandwidth of optical fibers, and coupling of light into optical fibers are part of the experiment set. The specific experiments are:

Experiment 1: Handling Fiber, Numerical Aperture. This involves cutting, stripping, and cleaving of fiber. Several fiber types are mounted on a bare fiber connector adapter and the numerical aperture is measured. A customized motorized scanner/detector was developed as a part of an earlier senior design project exercise.

Experiment 2: Fiber Attenuation, Splicing, and the OTDR. In this experiment, fiber attenuation is measured using the cut-back technique. The Optical Time Domain Reflectometer (OTDR) is then used to measure loss of the fiber and of optical connections. The students also learn how to join optical fiber ends with a fusion splicer.

Experiment 3: Single Mode Fibers, Source Output Characteristics. This experiment concentrates on the spectral characteristics of optical sources. Optical spectrum analyzer measurements are made for various sources such as LEDs, Distributed Feedback (DFB), and Fabry-Perot (FP) laser sources.

Experiment 4: Sources, Coupling to Optical Fibers. In this experiment, the students couple the output of a laser component to a single mode fiber using an XYZ coupling adjustment stage. This enables students to fully appreciate the alignment difficulties associated with single-mode fiber components.

Experiment 5: Bandwidth of an Optical Fiber. In this experiment, students measure the dispersion-limited bandwidth of multimode optical fiber. Both frequency domain and time domain measurements are made.

In the last two years, additional experiments and upgrades were made to the EE443 fiber optic communication laboratory.

A. An Erbium–doped fiber experiment was added to the experimental list. A senior project was initiated to construct an amplifier assembly to be used in the laboratory. The result was an EDFA constructed in such a way that the students could see each component that made up the amplifier (in comparison to a commercial Er-doped amplifier tightly packaged in a box). The student controls the level of optical pumping and temperature of the pump laser. An optical spectrum analyzer is used to measure the amplified spontaneous emission spectral density in both the forward and reverse directions of amplification. The results are compared to computer simulations using the freely available "OASICS" optical fiber amplifier simulation program (courtesy of OFS). The output of the amplifier is then connected back to the input in order to demonstrate construction of a fiber laser (but with poor frequency selectivity). A tunable optical filter will then be connected between the output and the input to control the lasing frequency more precisely. Non-linear optical behavior is also demonstrated by observing the "green glow" emitted from the pumped Erbium doped fiber (third harmonic generation in the Er-doped fiber). Figure 2 is a photograph of the Erbium doped fiber amplifier assembly used in the laboratory exercise.

Figure 2: The Erbium-doped fiber amplifier assembly used in the EE443 fiber optic communication lab is shown. The students adjust the bias conditions of the pump laser. Experimental measurements on the amplifier are compared to computer simulations.

B. The EE443 laboratory as initially constructed used an instrumentation laser source manufactured by HP for introducing signals on to the optical fiber. The laboratory now uses a combination of instrumentation sources and the SFP[2] (small form factor-pluggable) transceivers. SFP TX/RX transceivers are now the most commonly used optical source assemblies in the telecommunication and data communication industry. The use of SFP sources in this laboratory setting offers tremendous versatility for experimentation. The pluggable SFP card cage allows the experiment to be quickly changed between multimode or single mode components. SFP transceivers are also available at all of the major communication wavelengths and the DWDM wavelength grid. The development of the SFP+ multi-source agreement will allow data rates up to 10 Gb/s in this form factor. This change provides the students exposure to current transmitting and receiving solutions.

C. An RSOFT Photonics CAD program[3] is being introduced so that hardware experimental results can be compared to simulations. This is especially useful for comparing measurements of signal impairments such as chromatic dispersion to those predicted by the computer simulation.

2.1.2 EE418 Photonic Engineering (3 credit lecture)

This course covers classical optics topics including electrooptic, accoustooptic and magnetooptic modulation and other interactions of light with materials. Modern optical design methods with emphasis on the use of computers to design simple optical systems and evaluate existing optical designs are part of the coursework. Paraxial and exact ray tracing through thin and thick lenses, mirrors and prisms, radiometry and photometry are covered during lecture. As part of the homework exercises, students use the Z-MAX ray tracing program installed in the photonics laboratory to design simple photonic imaging applications.

EE458 Photonic Engineering Laboratory (1 credit)

This laboratory course is a concurrent and companion course to EE 418. The topics covered in the experiments include experimental investigation of the techniques used in processing of optical signals. Examples are experiments on electro-optic modulation and acousto-optic modulation, construction of an RF spectrum analyzer, analog processing of optical signals, and charge-coupled array devices. Acoustooptic modulators are also used to make a simple scanning spectrometer. Many of the experiments span two weeks. Specific experiments include:

Experiments 1: Acousto-Optic Modulator. In this two-week experiment, students explore the intensity modulation and beam deflection properties of an acousto-optic device (Bragg cell). They measure some parameters of an acousto-optic modulator, including Bragg angle, modulation bandwidth, and diffraction efficiency.

Experiment 2: PIN Photodiode. In this two-week experiment, students investigate the properties of a PIN photodiode. Students determine the PIN responsivity, bandwidth, RC time constant, the noise equivalent power dark current, rms shot noise due to dark current, and signal current. Useful receiver circuits are constructed using this device.

Experiment 3: CCD Photodetector Array. In this two-week experiment, students investigate the properties of a 2048x1 linear CCD array, and measure some of its important parameters. Some of the parameters of the CCD measured include the linearity and dynamic range, the dark current and noise, the charge transfer efficiency, bandwidth, etc. The students also use the CCD to measure the size of a very small object such as the diameter of an optical fiber.

Experiment 4: Acousto-Optic RF Spectrum Analyzer. In this experiment, students simulate the design of an acousto-optic RF spectrum analyzer using the optics lab design software. The design is then constructed. Finally the students evaluate its performance using a linear CCD array, and a collimated Helium Neon laser beam.

2.1.3 EE 422 Polymer Optoelectronics (1 Credit, Laboratory)

This undergraduate laboratory offers students the chance to fabricate an organic polymer light emitting diode (LED). Simple photolithography and spin-on polymers are used to construct a working polymer LED. The same laboratory includes complete characterization equipment for the LEDs that each student constructs.

2.1.4 EE520 Solar-Photovoltaic System Design (3 Credits, Lecture)

This graduate course introduces the student to system design and applications of photovoltaic systems. It is open to senior undergraduates with the permission of the instructor. Topics covered include solar cell and storage battery theory, examination of insulation, variability and optimization techniques, principles of grounding protection and control, a survey of power conditioning equipment, and system integration techniques.

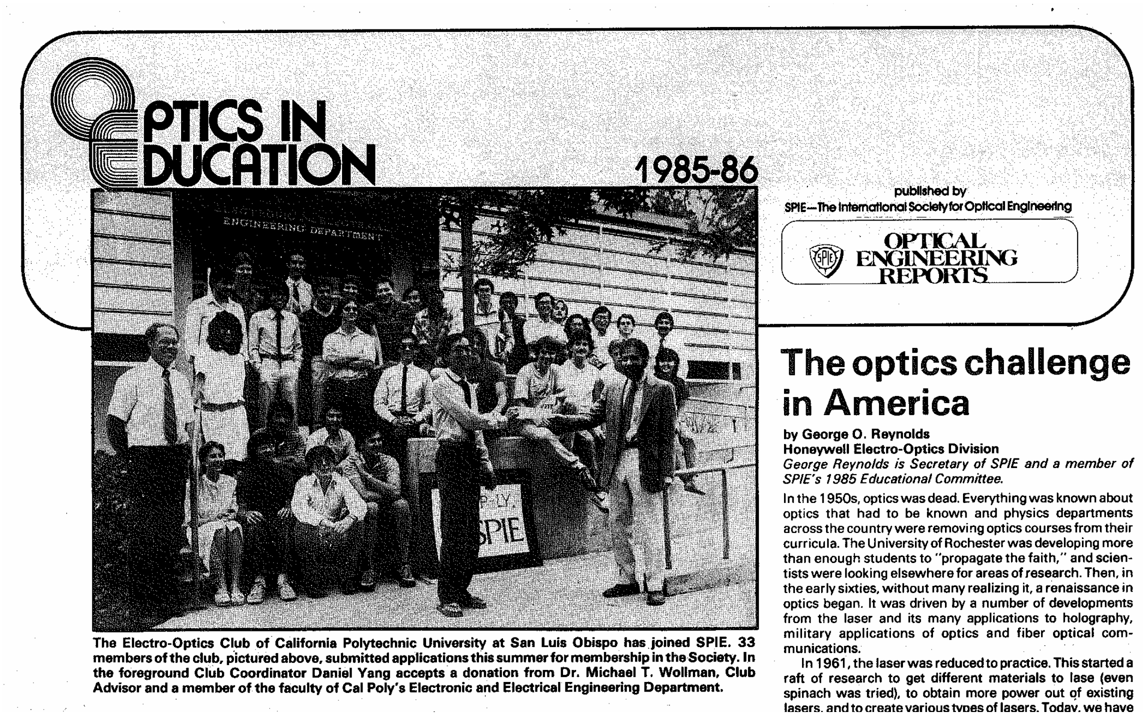
2.1.5 EE530 Photonic Systems (4 Credits, Lecture)
This graduate course employs a systems approach to photonics. Topics covered include design of radiometric information optics and imaging systems, remote sensing, guidance and tracking; fiber optics and laser communications; component modeling, optimization of systems for detection of radiant flux with maximum signal-to-noise ratio, modeling of sources, and optical systems; signal conditioning, and output display.

2.2 Photonics in the Physics Department. Unusual for a Physics Department, Cal Poly has a required junior-level optics course (Physics 323). This course, which includes a lab, covers the basics of physical and geometrical optics. An elective junior-level course in laser physics (Physics 315) is also offered. A senior level course in optics (Physics 423) is offered once every two years and is taken by anywhere from eight to twenty students from various departments. It also has a laboratory component and within the constraints of the curriculum can cover a wide variety of topics at the instructor's discretion. Recent topics have included Fourier optics, dielectric waveguides, computer generated holography and optical trapping. Although the Physics Department has no graduate students, this latter course often includes graduate students from Engineering. Exposure to other optical topics in the curriculum takes place in other courses. For example, in the year-long sequence of "quantum labs" (Physics 340-1-2) taken in the junior year students carry out experiments in photon counting, optical pumping, and high-resolution spectroscopy.

3. Student Photonics Club

It has been our experience that it is important to give students a group identity. A student photonics club was formed in 1986 so that students who had an interest in photonics could have a common forum to talk about the subject and bond together as an entity. Figure 3 shows a picture of the initial group of students that formed the club in 1986. Several national and international professional organizations are available for student club affiliation. Our student club chose to be affiliated with SPIE. A major reason is the generous funding that SPIE offers for its student organizations. This funding is key for providing food at meetings and paying for event expenses throughout the year. SPIE also offers 2 major conference events that are within driving distance of Cal Poly each year. Photonics West is in San Jose (3 hours north) each January and the SPIE annual meeting is held in San Diego each August. Both of these events offer great opportunities for students to observe first-hand the diversity of the photonics field. We have recently chosen the on-campus name for this club as the RF, Microwaves, and Photonics club (RMAP). This broader title allows us to attract a wider range of students and encourage a better understanding of the diverse range of photonics and its applications. Student trips to industrial sites are provided about once per quarter. The group meets bi-weekly and often features guest speakers on a range of photonics related topics.

A major focus of the club each year is to provide a display at Cal Poly's open house celebration. Annual crowds of over 25,000 people gather together on campus to see activities from the departments and student clubs. The entire event is student managed. This activity again helps form an identity for those students interested in the photonics field and offers new students, parents, and their siblings a chance to see photonics in a fun-filled hands-on display.



OPTICS IN EDUCATION 1985-86

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SPIE—The International Society for Optical Engineering

OPTICAL ENGINEERING REPORTS

The Electro-Optics Club of California Polytechnic University at San Luis Obispo has joined SPIE. 33 members of the club, pictured above, submitted applications this summer for membership in the Society. In the foreground Club Coordinator Daniel Yang accepts a donation from Dr. Michael T. Wollman, Club Advisor and a member of the faculty of Cal Poly's Electronic and Electrical Engineering Department.

The optics challenge in America

by George O. Reynolds
Honeywell Electro-Optics Division
George Reynolds is Secretary of SPIE and a member of SPIE's 1985 Educational Committee.

In the 1950s, optics was dead. Everything was known about optics that had to be known and physics departments across the country were removing optics courses from their curricula. The University of Rochester was developing more than enough students to "propagate the faith," and scientists were looking elsewhere for areas of research. Then, in the early sixties, without many realizing it, a renaissance in optics began. It was driven by a number of developments from the laser and its many applications to holography, military applications of optics and fiber optical communications.

In 1961, the laser was reduced to practice. This started a raft of research to get different materials to lase (even spinach was tried), to obtain more power out of existing lasers, and to create various types of lasers. Today, we have

Figure 3: This photograph was from the first student photonics club at Cal Poly in 1986. The picture shows a funding check from the SPIE being handed over to the student leadership from Professor Wollman.

4. Project-Based Learning and the Project-Based Learning Institute

This section of the paper will describe what Cal Poly and the photonics group is doing to support the "learn by doing" label of the University. First a description of our long-established senior-project program and master thesis program is given. The college of engineering is embarking on a formalization of the use of projects as a learning tool. The Project-Based Learning Institute has been established to facilitate the linkage of industry with the college of engineering. These collaborations offer a wider range of student projects including interaction with industrial sponsors.

4.1 Senior Design Projects at the Undergraduate Level

Each senior is required to have a two quarter long senior design experience as a requirement for graduation. Students can bring in their own vision for a project. They can also work in conjunction with projects sponsored by professors. A senior project handbook has been developed to guide the student on the expectations for completing a senior project. The results of the senior project program in terms of an educational outcome have been positive but highly variable. For the student who has a high degree of motivation and self-discipline, professors are often surprised at what can be accomplished over such a short period of time. On the other hand, there are students who are distracted in their focus and feel that the senior project program is an obstacle that must be overcome rather than an opportunity. The desire for a more uniform senior project experience has been an issue that has been discussed at the college of engineering level. It is also desired to bring in more projects that can directly impact relevant problems from industry. Several program changes have been made to address the need for a uniform experience in a multidisciplinary and team-based environment. The electrical and mechanical engineering programs are advocating cross-program teams to work together and receive senior project credit in their respective departments. The photonics team has recently completed their first joint senior project with mechanical engineering utilizing a 4 person optical, mechanical, and electrical design team to construct an optical coherence tomography subsystem. A wide variety of photonics related senior projects are active each quarter.

The Physics department has a senior project requirement for graduation and students work closely with a faculty member for two quarters. This feeds into the faculty professional development requirements and the optics projects are usually well subscribed. There are a variety of research projects ranging from computational studies of pattern formation to experimental investigation of optical methods for fluid flow measurement. Several interdisciplinary projects are also underway including the use of optical tweezers for measuring bacterial adhesion (in collaboration with Dairy Science) and fluorescence measurement of phytoplankton in the ocean (in collaboration with Biological Sciences).

4.2 Photonics Projects at the Graduate Level

As a large undergraduate university, we continue to develop a variety graduate research projects through five major channels:

- Joint projects between university departments to establish interdisciplinary research projects with a common photonics theme.
- Collaboration with national laboratories such as Lawrence Livermore National Laboratories for joint Masters Degree projects each year.
- Collaboration with major research universities for joint projects. The faculty works with Ph.D. granting research universities nationally and internationally to keep Cal Poly's photonic research current in the field.
- Industrial direct project sponsorship through research grants is an area of special interest to us. Recent examples are a research grant on photodetector modeling and chromatic dispersion measurements on multimode fiber. Figure 4 shows a photograph of this multimode fiber dispersion characterization project.
- Traditional sources of funding such as NSF and DARPA.

A large group of our Master's degree students take advantage of Cal Poly's 4+1 program. In this program the student forgoes the senior project and replaces it by a three quarter research program and graduate coursework.

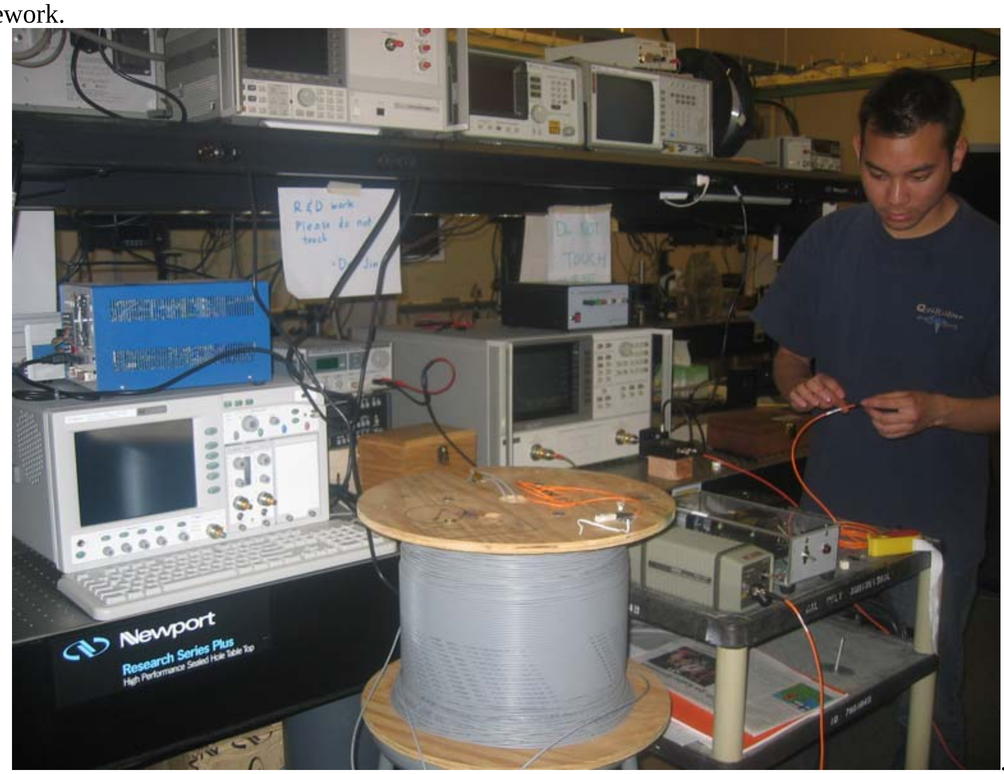

Figure 4. James De Leon standing by his master thesis setup of multimode fiber characterization for an industrial partner.

4.3 Formalization of Project-Based Learning Through the Project-Based Learning Institute (PBLI). Many professors have established direct relationships with industrial partners in order to provide interesting problems and research topics for undergraduate students. It takes a significant effort to cultivate these relationships. Once a track record of success has been achieved with the industrial partner, both groups see the benefits of working together and future projects become easier to maintain. The photonics group has worked to establish on-going industrial relationships. Lawrence Livermore National Laboratories has established a yearly project internship program with Cal Poly that has resulted in several Master's degree dissertations as an example.

The project based learning institute (PBLI) at Cal Poly was formed in the fall of 2006. The PBLI has a goal of formalizing the interface between the university and industry for project-based collaborations. A company that would like to work with the university now has a clear path to establish a project-based relationship with Cal Poly. The PBLI consists of permanent staff, established departmental project and research facilities, and the new Bonderson Student Project Center (see Figure 5). A major milestone in the establishment of the PBLI was the construction of an 18,000 square foot building for student projects. Paul. Bonderson (the building donor) was inspired by some of his senior project work and the path of success it gave for him in his career. The Bonderson Project center is 100% dedicated to project-based learning. Emphasis is given to multidisciplinary projects in conjunction with industrial sponsors. The building opened to students in March of 2007. The facility is being opened to students 7 days a week and 24 hours a day. The first Photonic-content project associated with this new project based learning institute is a prototype integrated small-scale air defense system using laser-based tracking of targets. The PBLI maintains a list of departmental competencies and individual professors' interests that can be used to locate areas of potential interest overlap with industrial sponsors. The photonics area is highlighted as a featured area of competency to perspective industrial partners. PBLI also helps establish agreements on intellectual property ownership. The PBLI is funded by membership in the institute. A membership fee is charged for each participant. For this membership fee, a designated set of projects can be done in cooperation with the Cal Poly.

Figure 5: The Bonderson Project Center of the Project-Based Learning Institute. This photo was taken in the March of 2007. The facility has become available for student projects as of March 2007. The facility is 18,000 square feet and is available 24 hours a day 7 days a week for undergraduate and graduate project work. Emphasis is given on multidisciplinary projects sponsored by industrial partners.

5. Conclusion

This paper gives an overview of the photonics program offered at Cal Poly. Specific coverage is given on how our photonics group has structured its undergraduate and masters level photonics programs. The laboratory contents and some of the recent upgrades are described in detail. Our view of photonics education emphasizes the importance of multidisciplinary project-based learning efforts as an educational tool. Student photonics organizations have been established to help forming a bond between students with a common interest. Finally, the photonics program is utilizing the college-wide project based learning institute to facilitate project-based learning interactions with industrial partners.

Acknowledgements: Authors wish to acknowledge contributions from Dr. Zahed Sheik, director of the project-based learning institute.

References:

[1] More information on Cal Poly's project based learning institute can be found at www.pbli.calpoly.edu.
[2] Information on optical transceivers can be found at optical component supplier web sites such as www.finisar.com
[3] Rsoft design Inc. application notes of LaserMOD are found at the RSOFT web site, http://www.rsoftdesign.com/

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Applied Electro-Optics Educational and Training Program with Multiple Entrance and Exit Pathways

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Abstract: This paper presents an innovative hands-on training program designed to create a pipeline of highly-skilled technical workers for today's workforce economy. The 2+2+2 Pennsylvania Integrated Workforce Leadership Program in Electro-Optics prepares students for a career in this new high-tech field. With seamless transition from high school into college, the program offers the versatility of multiple entrance and exit pathways. After completion of each educational level, students can exit the program with various skill levels, including certificates, an associate's degree, or a bachelor's degree. Launched by Indiana University of Pennsylvania (IUP) in partnership with Lenape Vocational School (Lenape), the 2+2+2 educational pathway program was implemented to promote early training of high-school students. During the first level, students in their junior and/or senior year enroll in four Electro-Optics courses at Lenape. Upon completion of these courses and an Advanced Placement Equivalency course with an appropriate exam score, students can earn a certificate from Lenape for the 15+ credits, which also can be articulated into IUP's associate degree program in Electro-Optics. During the second level, students can earn an associate's degree in Electro-Optics, offered only at the IUP Northpointe Campus. After completion of the Associate in Applied Science (A.A.S.), students are prepared to enter the workforce as senior technicians. During the third level, students who have completed the Associate of Science (A.S.) in Electro-Optics have the opportunity to matriculate at IUP's Indiana Campus to earn a Bachelor of Science (B.S.) degree in Applied Physics with a track in Electro-Optics. Hence, the name 2+2+2 refers to getting started in high school, continuing the educational experience with an associate's degree program, and optionally moving on to a bachelor's degree. Consequently, students move from one educational level to the next with advanced credits toward the next degree. This program was made possible by two grants from the Pennsylvania Department of Community and Economic Development (PA DCED). The intent of the grant is to foster partnerships that will develop programs in high-tech fields, such as biotechnology/life sciences, information technology, opto-electronics, and advanced manufacturing and materials. Topics of discussion will include program development, curriculum development, course descriptions, course sequencing, outreach and recruitment efforts, and program challenges.

1. Introduction

The 2+2+2 Workforce Leadership Grant Program (WLGP) was designed to establish unified curriculum across two-year vocational programs and two- and four-year post-secondary educational programs in information technology, biotechnology, and advanced manufacturing career clusters. Administered through the Pennsylvania Department of Community and Economic Development (DCED), the program provides funding to high schools as well as colleges and universities to help them prepare high-technology programs where students can continue their education by using credits earned in advance toward their next degree. With a seamless transition from the secondary school into college, the program offers students the versatility of multiple entrance and exit points. After completion of each educational level, students can exit the program with various skill levels including certificates, an associate's degree, or a bachelor's degree.

Established in January 2003, the 2+2+2 WLGP fosters the development of school, community college, university, and business partnerships that will ensure that Pennsylvania emerges as a national leader in the development of industry-focused partnerships that will train a workforce capable of competing in the global economy.

Indiana University of Pennsylvania (IUP) received $200,000 in 2005-2006 to establish a 2+2+2 Workforce Leadership Program in Electro-Optics in Armstrong County. With the financial assistance from the DCED, IUP partnered with Lenape Technical School and all four school districts in Armstrong County: Apollo-Ridge, Armstrong, Freeport, and Leechburg. The program established integrated and seamless curriculum development that was designed to support education and training, beginning in high school/vocational technical school, progressing to a two-year degree, and culminating in a four-year degree in the emerging field of Electro-Optics. As the lead institution, IUP provides collaboration among the partners by establishing curriculum design and program implementation in addition to preparing the articulation agreement that will be used for transferring credits. The university also works closely with the regional Electro-Optics industry to facilitate job opportunities for students when they graduate from the program.

Typically applicants for the 2+2+2 WLGP include a career/technical school, a two-year community college, and a four-year institution. However, in this instance IUP serves both as the two-year and four-year components as it offers a two-year degree program in Electro-Optics only at its Northpointe Regional Campus in Freeport, PA, and a four-year degree in Applied Physics with a track in Electro-Optics at its Main Campus in Indiana, PA. The regional campus is a recently built state-of-the-art, commuter campus located approximately 38 miles southwest of Indiana. It is located immediately off Route 28 at Exit 18 just 35 minutes from downtown Pittsburgh.

The program was designed so students could enter IUP from one of the seven sending high schools from the four school districts or from Lenape, which is a comprehensive career technical school.

In Fall 2002, IUP introduced a two-year Associate's Degree in Electro-Optics. The program was established by faculty members from the Physics Department who traveled to other colleges and universities that offered comprehensive Electro-Optics programs designed for industry. They took the best practices from the programs that they visited and developed a hands-on training program that would create a pipeline of highly-skilled technical workers for this new industry. Once the curriculum was in place, administrators at IUP sought the input of local Electro-Optics leaders. The curriculum was presented to the Chief Executive Officers of area Electro-Optics corporations and members of the Electro-Optics Alliance (EOA) for their review and suggestions. The EOA is comprised of industrial, academic, and government affiliates. It is a component of the Penn State Electro-Optics Center (EOC), a manufacturing center of excellence sponsored by the U.S. Navy Manufacturing Technology (MANTECH) Program and the Office of Naval Research. It is located in the same Technology Park as the IUP Northpointe Regional Campus, and it also serves as an industry partner for the 2+2+2 WLGP in Electro-Optics. The EOC plays a vital role in advancing Electro-Optics capabilities nationally, while advancing local economic opportunities in Armstrong County. Companies moving into the area can tap into the center's expertise, finding not only technical support but educational advantages.

Concurrent with IUP's Electro-Optics degree program development, Lenape developed two Electro-Optics courses for its Adult Evening Program. These courses were developed to prepare displaced workers for entry-level positions in this new high-tech industry. The intent was that the IUP and Lenape initiatives would support each other. However, there was no academic connection or partnership between the Lenape courses and the IUP degree program until the 2+2+2 WLGP was established. The grant allowed IUP to work with Lenape to create four entry-level Electro-Optics courses that would articulate into IUP's two-year degree program.

Funding from the grant allowed IUP and Lenape to offer release time to their faculty so they could work on curriculum and outcomes assessment for the new industry-focused program. Four courses were developed for articulation into IUP's program: EOPT 125—Introduction to Electronics (4 credits); EOPT 105—Computer Interfacing (3 credits); EOPT 110—Geometric Optics (3 credits); and PHYS 100—Prelude to Physics (3 credits). Students completing these courses with a C grade or above can transfer 13 credits into IUP's two-year degree program. If they also complete an Advanced Placement (AP) Equivalency course with the appropriate exam score (3), they can transfer 15+ credits toward the Associate's Degree in Electro-Optics, permitting them to earn one semester of college credits while they are still in secondary school as stipulated by the grant. This provides students with a substantial savings as they can complete one semester of college for free.

For many years Armstrong County thrived economically on such industries as brick, coal, and steel. However, in recent decades the emphasis on these industries has shifted, resulting in an economic decline and a demographic shift for this once prosperous region. In order to survive, this proud county had to undergo a paradigm shift and had to focus its attention on the revitalization of its economy and workplace. To accomplish these goals, the county has attracted a new high-tech industry—Electro-Optics—to the area. According to regional industry officials, technology industry sectors are key drivers of a region's economic growth. The 2+2+2 WLGP has provided IUP with the financial resources to create a workforce pipeline with multiple pathways for this new industry.

The objectives of the grant included:

- Design and establish an integrated industry curriculum with our partners
- Articulate a minimum of 15 credits from the secondary schools and Lenape into the Associate's Degree
- Articulate 63 credits from the Associate's Degree into the Bachelor's Degree
- Create and distribute career and marketing materials to recruit 15-20 students into the Lenape program
- Provide academic advisement to students to insure that all of the required coursework is taken in sequence
- Provide a summer Electro-Optics experience for students
- Familiarize students with Nanofabrication
- Create a 2+2+2 WGLP Electro-Optics Steering Committee

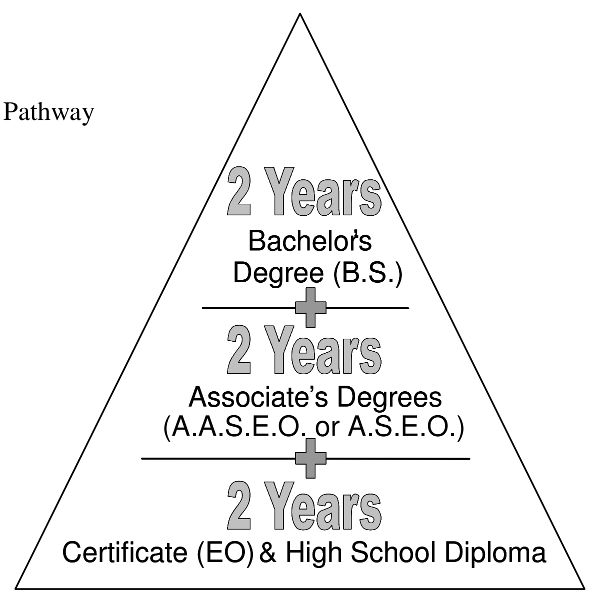
IUP and its partners accomplished their goals, and eighteen students were recruited into the program at Lenape for the Fall 2006 school year. In 2006-2007, IUP received an Extension Grant for $160,000 from the DCED to continue to further develop its Electro-Optics program in collaboration with its partners. The university has applied for a second Expansion Grant that would permit it to take its prototype program to Westmoreland County, a county that borders Armstrong County and is located approximately 20 minutes from the Northpointe Regional Campus.

2. 2+2+2 Educational Pathway

The 2+2+2 WLGP provides considerable flexibility with multiple entrance and exit points for students to pursue vocational training and academic education in Electro-Optics, as shown in Figure 1.

The first level of the 2+2+2 WLGP provides students with the opportunity to enter the program at the beginning of their junior year in high school. During their junior and senior years, students co-enroll in the appropriate math and science courses and four Electro-Optics courses offered at Lenape. The four courses are: Prelude to Physics (PHYS 100), Computer Interfacing (EOPT 105), Geometric Optics (EOPT 110) and Introduction to Electronics (EOPT 125). A faculty member at IUP who serves as the coordinator of the program received release time to align the Lenape courses with the courses offered by IUP. Upon completion of the Lenape courses and an AP Equivalency course with the appropriate exam score, students can earn a certificate for the 15+ credits which can be articulated into IUP's Associate's Degree Program in Electro-Optics. Students may exit the program at this point with a Certificate from Lenape. The training received during this phase of the program prepares students for entry-level technical positions in the Optics. At this point, they have the option of going directly into industry or to continue on to the second level.

Figure 1: 2+2+2 Educational Pathway



The second level of the 2+2+2 Program involves coursework offered by the Physics Department at IUP's state-of-the-art facility at the Northpointe Regional Campus. Students have the option of earning a Certificate in Electro-Optics from IUP by completing an additional fifteen credits of specified optics courses. Students may exit at this juncture or they may complete either an Associate in Applied Science in Electro-Optics (A.A.S.E.O.) or an Associate in Science in Electro-Optics (A.S.E.O). After completing the A.A.S.E.O degree, students are prepared to move into senior technical positions in the industry. Students may exit the 2+2+2 Program at this point or continue to the third level.

The third level of the 2+2+2 Program takes place at IUP's Main Campus in Indiana, PA. Students who have completed coursework for the A.S.E.O. have the opportunity to matriculate at IUP's campus in Indiana by transferring 63 credits toward a Bachelor of Science degree in Applied Physics/Electro-Optics Track. After completing this third level, students can enter the workforce into highly skilled positions in the field.

The Electro-Optics Industry is expected to grow from a $34 billion industry today to a $500 billion industry by 2010. The demand for workers in this field, especially at the technician level, has been acute and many companies will be offering finders' fees for Electro-Optics technicians.

3. Core Courses

IUP has collaborated with several local Photonics companies to gain a better understanding of their current staffing needs. Based on feedback from these companies, nine courses were developed for IUP's program. These courses provide students with the necessary background to move into related positions in Optics. The nine core courses for IUP's program are listed and outlined in Table 1.

Table 1: EO Program Core Courses

Number	*IUP Course Title and Number*	*Course Description*
1	Computer Interfacing in Electro-Optics (EOPT 105)	The first half of the course introduces the student to basic digital electronics and teaches them how computers interface with the outside world. These concepts are applied in the second half of the course. The Labview programming environment is used to collect experimental data and to control scientific instruments. The course assumes a basic background in electronics (equivalent to an introductory course, such as EOPT 125) and computers (windows environment, word processor and spreadsheet use) as well as knowledge of algebra.
2	Introduction to Electronics (EOPT 125)	This course is intended to be an introductory course requiring a minimum knowledge of mathematics. The course covers DC and AC circuits, resistors, capacitors, inductors, filters, diodes, power supplies, transistors, and operational amplifiers. Emphasis is be placed on both the principles and the "rules of thumb" used in everyday laboratory settings. A laboratory component is included in this course so students can gain practical experience in building electronic circuits and using electrical measuring devices with an eye toward lab applications.
3	Geometric Optics (EOPT 110)	Introduces the student to the principles and theory of light as a geometrical ray and gives an elementary treatment of image formation. This course will cover selected topics including reflection, refraction, optical components, optical instruments, and optical system design and evaluation. Students will learn how to apply matrix optics and the optical design software ZEMAX to simple optical components.
4	Wave Optics (EOPT 120)	Introduces the student to the principles of light as an electromagnetic wave and provides elementary treatments of light sources and important wave phenomena. The theory is applied to common devices used in the photonics field. Topics include properties of light, reflection, refraction, absorption and transmission, interference, diffraction, polarization, and holography.

5	Detection and Measurement (EOPT 210)	Introduces the student to the technology and techniques involved in making electro-optical measurements. Students will learn the basic theory and working mechanisms of optical detectors, interferometers, spectrometers, and imaging devices, as well as the optical components used along with these instruments.
6	Introduction to Lasers (EOPT 220)	Introduces the student to laser safety practices, basic laser physics, and measurements of laser properties such as divergence, mode spacings, polarization, and power. The student will align various laser cavities and be exposed to several CW lasers. Students will use optical instruments such as spectrum analyzers, power meters, and auto-collimators to align and measure basic laser properties.
7	Fiber Optics (EOPT 240*)	Covers basic concepts in fiber optics such as dispersion, attenuation, single mode and multimode propagation. Fiber optics test equipment such as optical spectrum analyzer and optical power meter are discussed and investigated. Sources, detectors, optical amplifiers and passive fiber components are covered.
8	High Vacuum Technology (EOPT 250*)	Presents the properties of gases and the concepts of fluid flow and pumping. Many different kinds of vacuum pumps are discussed in detail. The concept of measuring a vacuum is introduced through the discussion of vacuum gauges and gas analyzers. Covers the techniques of leak detection and thin film deposition.
9	Industrial Applications of Lasers (EOPT 260*)	The first half of the course introduces the student to semiconductors and solid-state lasers and associated technologies. The student will learn how to operate and perform basic maintenance on these lasers, as well as how to measure basic laser parameters. The student will then apply this knowledge, along with that developed in EOPT 220, toward laser applications in manufacturing, defense, medicine, and other important areas. The course assumes a background in basic laser theory, basic electronics, and wave optics as well as knowledge of algebra and right-angle trigonometry.

**The A.S.E.O. degree requires 2 of the following 3 courses: EOPT 240, EOPT 250 and EOPT 260.*

The suggested coursework offered during the first two years which will satisfy the A.A.S.E.O. Degree requirements is outlined below.

Semester I		**Credits**
PHYS 100	Prelude to Physics	3
PHYS 115	Physics I for Electro-Optics	3
COSC 101	Microbased Computer Literacy	
or		
COSC 201	Internet and Multimedia	3
EOPT 250	High Vacuum Technology	3
EOPT 110	Geometric Optics	3
	Sub-total	15

Semester II		
ENGL 101	College Writing	4
PHYS 116	Physics II for Electro-Optics	3
MATH 110	Elementary Functions	
or		
MATH 121	Calculus I	3-4
EOPT 120	Wave Optics	3
EOPT 125	Introduction to Electronics	4
	Sub-total	17-18

Semester III

	Humanities Elective	3
CHEM 111	General Chemistry I	4
EOPT 105	Computer Interfacing in E-O	3
MGMT 234	Introduction to Quality Control	3
EOPT 220	Introduction to Lasers	3
	Sub-total	16

Semester IV

	Social Science	3
EOPT 210	Detection and Measurement	3
SAFE 145	Workplace Safety	3
EOPT 240	Fiber Optics	3
EOPT 260	Industrial Applications of Lasers	3
	Sub-total	15

The program consists of a total of 63-64 credits.

Due to the rapid emergence and interdisciplinary nature of the field, teaching strategies in IUP's Electro-Optics Program give highest priority to activities that encourage creativity, critical thinking, and problem-solving skills. Furthermore, since the program is introduced early during the freshman and sophomore years, emphasis is placed on concept development and qualitative analysis rather than mathematical derivations. The focus has been purposely diverted from the study of "facts," which has been the pattern for physics textbooks for a long period of time, to problem-solving skills. In addition, emphasis is placed on synergy among different Electro-Optics core courses, reinforcing students' knowledge in this new field of study.

4. Hands-on Practical Skills Training

Due to the necessity of hands-on experience to succeed in the Photonics Industry, each Electro-Optics core course in IUP's program consists of hands-on lab experiments in addition to lectures. Since IUP is on a semester system, the 3-hour lab experiments are arranged once per week during each 15-week semester.

A. *Equipment*

Through these labs, students learn vital hands-on skills utilizing state-of-the-art Electro-Optics equipment and optical alignment techniques. Some of the instruments used by students in IUP's Electro-Optics Program are listed in Table 2.

Table 2: Equipment used in select Electro-Optics lab experiments

Course	*Equipment/Software*
Geometrical Optics (EOPT 110)	• Prism spectroscope • Optical power meter • Microscope and traveling microscope • Telescope and beam collimator/expander • Projector • ZEMAX Optical design software

Introduction to Lasers (EOPT 220) and Industrial Applications of Lasers (EOPT 260)	• He-Ne lasers: red, yellow and green • Argon laser with multi-wavelength output • Acousto-Optic and Electro-Optic modulators • Flashlamp pumped Q-switched Nd:YAG laser • 20W Fiber coupled semiconductor laser and power supply • Solid state green laser from a diode pumped Nd:YVO_4 laser with intra-cavity frequency doubling • Solid state blue laser from a diode pumped Nd:YAG with intra-cavity frequency doubling • Q-switched, frequency tripled, diode pumped Nd:YVO_4 laser • 3D laser imaging system
Fiber Optics (EOPT 240)	• Tunable light source and handhold power meter at 1550nm • Optical spectrum analyzers (OSA) • Optical fiber fusion splicer and fiber cleaver • Fiber Bragg gratings and other fiber optic components
High Vacuum Technology (EOPT 250)	• Vacuum pumps (rotary, diffusion, turbo and cryo) • Vacuum gauges • Thermal evaporator and Electron-beam evaporator • Vacuum leak detector • Residual pressure analyzer • 1000 grade cleanroom

B. Lab Experiments

The laboratory experiments developed for the Geometric Optics course (EOPT 110) are listed in Table 3. Students attend two hours of lecture and one three-hour lab per week. The semester course runs for 15 weeks, plus one week for the final exam. For each lab experiment, students use a lab manual developed by IUP's Electro-Optics faculty. Students are responsible for building the experiment without any preliminary setup. They select appropriate equipment available in the lab such as optical components (mounts and holders, etc.), light sources (lasers, light bulbs, etc.) and measurement instruments (optical power meter, etc.) to complete the experiment After completing the lab, each student has to submit a formal lab report, documenting the objectives, basic theory, procedure, data collected, results, discussion, and conclusions.

Table 3: Geometric Optics (EOPT 110) Lab Experiments

Lab	*Title of Lab*	*Objective*
1	The law of reflection	▪ To study the law of reflection ▪ To measure the incident and reflected angles made by plane and spherical surfaces
2	The law of refraction	▪ To study the law of refraction ▪ To measure the incident and refracted angles and determine the refractive index
3	Prism spectroscopy and refractive index measurement	▪ To learn how to use a prism spectroscope ▪ To measure the apex angle of a prism ▪ To determine the refractive index of a prism
4	Measurement of beam spot size, power and photometric light flux	▪ To learn how to use power meter ▪ To measure the laser beam spot size and divergence angle ▪ To estimate the refractive index using the reflection method
5	Image formation from spherical mirrors	▪ To determine focal length and the radius of curvature of a spherical mirror ▪ To study the image formed by a spherical mirror
6	Image formation with cylindrical mirrors and lenses	▪ To learn how to use a cylindrical optical component ▪ To study the properties of image formation with cylindrical mirrors and lenses

7	Spherical lenses – Images and object relationship, aberrations	▪ To understand the image formation by spherical lenses ▪ To measure the focal length of a lens ▪ To understand lens aberrations ▪ To study the depth of field ▪ To measure the radius of a spherical surface using a spherometer
8	Thin lens combination	▪ To study experimentally the image formed by multiple thin lenses in series
9	The projector and magnifier	▪ To understand the principle of a projector and a magnifier
10	The telescopes and beam collimators	▪ To understand the principle of telescopes ▪ To measure the magnification of a telescope ▪ To set up astronomical and Galilean beam expanding collimators ▪ To compare the laser beam property before and after the beam collimator
11	The compound microscope and its use in measuring refractive index	▪ To set up a simple compound microscope ▪ To measure the overall magnification of a compound microscope ▪ Learn how to measure the refractive index using a traveling microscope
12	Field stops and apertures	▪ To understand the concepts of the field stop and aperture stop ▪ To determine the entrance and exit pupils and aperture stop for the system of two lenses with an intermediate stop
13	Experimental study of a thick lens system matrix	▪ To understand the definition and learn how to use the basic matrices. ▪ To verify the basic matrices for a thick lens experimentally
14	Optical design using ZEMAX software	▪ To learn how to enter data into ZEMAX, set the system aperture, lens units, and wavelength range and then optimize the design ▪ To learn how to use ray fan plots, spot diagrams and other diagnostic tools to evaluate the performance of the design ▪ To design singlet and doublet lenses

In general, the Electro-Optics labs developed for this unique program emphasize general instrumentation and equipment used currently in the Electro-Optics Industry: basic optical alignment skills, experimental methods, and problem-solving skills. Table 3 also lists the objectives for each lab, reinforcing the basic theory introduced during class lecture. Students gain experience using numerous types of optical components. Furthermore, the basic alignment skills of these optical components are learned using both optical rails and optical breadboards.

C. Industry Collaborations

The collaborations among IUP, Lenape, and the Electro-Optics corporations have been strengthened by the creation of the 2+2+2 Steering Committee. The thirty-nine members represent the major Photonics companies in the region. The members are very supportive, and almost 100 percent of the membership meets twice a year to be actively involved with this unique program.

5. Outreach Efforts

Electro-Optics is a fairly new industry to Pennsylvania and, as such, it is ahead of the curve. Therefore, emphasis had to be placed on promoting awareness of this new initiative to students, parents, and the community in order to educate them on the various career opportunities created by this emerging industry.

To increase awareness in Electro-Optics, activities have been focused on a variety of areas: outreach activities geared toward middle- and high-school students, the establishment of parent information sessions, workshops for professional development for teachers and guidance counselors, and an aggressive media campaign.

A. Outreach to Area Students

The program's faculty and staff have interacted with 1,768 students from 1/1/2006 to 4/27/2007 throughout Armstrong, Allegheny, Butler, Indiana, and Westmoreland counties. The interactions included visits to the classrooms, career fairs, and field trips designed for the students to visit the campus. A survey is administered to the students after each visit. The information gleaned from the surveys is very informative. Approximately 50% of the students expressed an interest in Electro-Optics after the interaction. Many of the students who expressed an interest in the field after the interaction did not have previous knowledge of Photonics.

Primarily, outreach activities have included: the Electro-Optics Science Experience at Northpointe Regional Campus, classroom presentations, and the Electro-Optics Summer Camp. During classroom presentations, students learn about the emerging field of Electro-Optics through portable hands-on activities such as: diffraction grating glasses, night-vision scopes, and polariscopes. These experiences allow students to view stress and strain points within various transparent objects through crossed polarizers. The primary focus, however, is to promote the high-tech careers in the Electro-Optics Industry, as well as the necessity for preparation in mathematics and science.

The "Electro-Optics Science Experience" takes place in the Electro-Optics state-of-the-art labs at the IUP Northpointe Campus. It is comprised of an introductory session, highlighting an overview of the field of Electro-Optics, an employment outlook and Optical Jeopardy session; as well as a laboratory session, where the students gain a better understanding of such concepts as polarization, open-space communication, optical illusions, holography, laser diffraction, and fiber-optics through hands-on activities. Forty students can be accommodated at each visit. Funding from the grant pays for the busses and lunch for area students. The school districts would not be able to send students on these field trips if they had to pay for the busses.

Last year's Summer Camp was held from July 31–August 4, 2006. IUP at Northpointe partnered with the EOC to offer an exciting summer camp for high-school students. Eighteen students from local high schools participated in this week-long event which was designed to expose students to the new, high-tech career field of Electro-Optics and the educational opportunities available in this field. This year's Summer Camp is scheduled for June 18-22, 2007. The event will provide lessons and activities in wave optics, fiber-optics, electronics, and nanotechnology.

These outreach activities have resulted in the creation of the first 2+2+2 Integrated Workforce Leadership Program in Electro-Optics at Lenape. Eighteen students began coursework in the prototype program in Fall 2006—ten juniors and eight seniors. The Outreach/Career Coordinator has met individually with these students throughout the 2006-2007 academic year to discuss courses, future goals, and potential admission to IUP's Electro-Optics Program, creating an educational pipeline.

B. Parent Information Session

Area parents were invited to attend an Electro-Optics Information Session on March 13, 2007, at the IUP Northpointe Regional Campus. Thirty-five people attended and received information on Electro-Optics and its importance to Armstrong County. They also received information on careers in the field and educational programs. They participated in hands-on activities to gain insight into the nature of this emerging industry. The outreach activities, designed to introduce parents to this new field, are essential as they bring the knowledge of Photonics into the homes and reinforce the opportunities available to this area.

C. Professional Development Opportunities for Teachers

IUP also provides professional development activities such as workshops for local high school administrators and instructors. Area guidance counselors, teachers, and affiliated educational program leaders were invited to participate in IUP's *2+2+2 Electro-Optics Workshop for Teachers and Guidance Counselors*. Participants took part in hands-on Electro-Optics activities that could be used in their classroom. They also received activities with a corresponding curriculum guide to take back to their schools. Program speakers discussed the efforts and history of program development, an overview of the 2+2+2 Workforce Leadership Development Program in Electro-Optics, and educational curriculum and career opportunities.

D. Media Campaign

Electro-Optics students from IUP and Lenape have taken an active role in recruiting other students into the program. They participated in the development of a television commercial which advertised the program to area students. The commercial aired on ESPN, ESPN 2, MTV, VH-1, SPIKE, and TNT, stations that target the high-school/teen population. The commercial can be viewed on our website: *www.iup.edu/armstrong/222/index.shtm*. The goal was to expand awareness of the Electro-Optics field into the homes.

In addition, a roadside billboard advertising the 2+2+2 Electro-Optics Program partnership was developed by IUP and was displayed on Route 28 near Exit 18, the IUP Northpointe exit. Over 7,000 vehicles drive past this site every morning and evening, providing program visibility.

6. Challenges

Highly technical programs tend to be ahead of the curve. Consequently, the workforce is not up to speed. Electro-Optics emerged into Armstrong County a number of years ago, but the community is not aware of the career opportunities. Electro-Optics is not a subject in our schools at any level. Our most difficult challenge is the recruitment of academically prepared students, as these students are headed for four-year degree programs in computer science or engineering. When students think of technical programs, they do not think that they need to have knowledge of math and science. However, math and science preparation is a necessity for these types of programs. Finding academically prepared students is one of the challenges that this program faces.

Highly-technical programs also tend to be costly. A used Yag laser costs $30,000, while a used Tunable laser costs $90,000. Educational institutions do not have money for high-tech programs, especially if they have low enrollments.

Revise of the Undergraduate Program for Speciality in Applied Physics to Intensify Training in Optics and Photonics

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Abstract:

The Applied Physics program at Beijing University of Technology was designed to nurture innovative talent in modern applied physics, providing students both solid theoretical grounding and training for practical scientific research skills by offering 4-year BS degree. In order to fit in with the needs of the fast developing of our society, the education objectives and the program curriculum need to be correspondingly adjusted. This paper reviews the two revises of Applied Physics program, launched in 2003 and 2007 respectively.

1. Introduction

Beijing University of Technology (BjUT) was founded in 1960, and initially focused to high education of undergraduates in various engineering disciplines for Beijing, the capital city of China. At the beginning the main task of Physics speciality was only offering University Physics course to engineering students. As China launched the economy reform and opening to the outside world since late 1970s, the requirement of Beijing for highly-educated talent promoted BjUT to be a comprehensive university, and Applied Physics Department was built up. After thirty years developing, and especially since 1996 when the University entered the national 211 project[1], the faculty of applied physics nowadays not only provides fundamental physics courses to all the engineering students of the whole university, but also offers BSc degree in Applied Physics, MSc & PhD degrees in Physics. The undergraduate program for Applied Physics speciality was designed to nurture innovative talent in modern applied physics, providing students both solid theoretical grounding and training for practical scientific research skills. The graduates were supposed to be employed by high education and research institutions.

However, as the economy of the society developing, the situation of enrollment and employment changes quickly. In order to fit in with the needs of the fast developing of our society, we must revise the education objectives and the program as well. This paper describes the method and the results of two revisions of the undergraduate program in recent years.

2. Motivation and Method

In the late 1990s, the undergraduate course curriculum of the Applied Physics speciality was aiming at presenting traditional theoretical fundamentals, and after covering the necessary theoretical concepts, introduced several specialized course in Optics, Condensed Matter Physics, and Theoretical Physics. This was to prepare graduated students for work in high education and research institutions. The problem had arisen as the economy developing rapidly: the employment threshold of high education and scientific research went up; graduates with only BSc degree in Physics felt difficult in finding jobs. At the same time, there was a common view that photonics would be a key enabling technology in the 21st century, which would be applied to all industry and research fields. It is a crucial strategic technology demanded by Beijing. Since BjUT has been oriented to "Merging itself with Beijing, and Serving the development of Beijing", we should have more students educated and trained to work in photonics. On the other hand, optics has been one of the key disciplines in BjUT. The faculty of optics has made remarkable progress in research fields such as optical information processing, advanced lasers, fiber communication and sensing. In this situation several optics and photonics courses was added into the program during 1998-2002, and a systematic revision of the undergraduate program was conducted first in 2003.

The latest revision has been conducted in this spring. The purpose of this revision is to decrease the total credits and intensify the practical training, which would be beneficial to students to develop their creative thinking pattern and ability to solve real-world problems. Also, through the 4-year study students would have wider knowledge and more flexibility, and would more easily emerge into various industrial sectors.

Although the program is for undergraduate students, it should be implemented by the faculty members. So in each revision we organized a Teaching Steering Committee and called all teachers into action. The professors who were in charge of the course groups organized discussions in depth. Through discussions teachers took the responsibility for providing students with new courses both in curriculum classes and in laboratory.

3. Description of the course curriculum

The number of total credits is, in principle, decided by the university authority. The courses can be roughly divided into four domains: General Education (**G**) including social science, arts, and cross-disciplinary courses; Basic Courses of Disciplines (**B**) including advanced mathematics, general physics, four main mechanics, and optics; **S**pecialized Courses (**S**) including courses provided by teachers working in three main research directions (optics and photonics, condensed matter physics, and theoretical physics); and Practical Training (**P**) including laboratory experiments, workshop practice, course design projects, and final year projects.

4. Details of the revision

Firstly, the revision is to adjust the credit distribution of courses among the above four domains, which is listed in Table 1. It is obvious that in the 2003 revision the practical training was highly reinforced as the total credits increasing. This is because we slightly changed the educational objectives of the Applied Physics Speciality to meet the demand for highly-qualified personnel in high-tech fields with more practical skills. In the 2007 revision we maintained the proportion of practical training and increased the proportion of specialized courses, even though the total credits was reduced.

Table 1 Credit Distribution of courses for Speciality in Applied Physics

Classification	Program Version		
	1999	2003	2007
Total credits	192	217.5	190
General Education （Credits/Proportion）	62.5/32.6%	65.5/30.1%	50.5/26.6%
Basic Courses of Disciplines（Credits/Proportion）	83/43.2%	73/33.6%	68/35.8%
Specialized Courses （Credits/Proportion）	16/8.3%	18.5/8.5%	23.5/12.4%
Practical Training （Credits/Proportion）	30.5/15.9%	60.5/27.8%	48/25.3%

Then，the revision is to adjust the proportion that the optics-related courses have in the whole program, so that the program is most suitable for the education objectives. Table 2 gives the data showing that in these two revisions the proportion of optics related courses kept increasing, reflecting the fast developing of optics and photonics.

Table 2 Credit distribution of Optics & Photonics courses

Classification	Program Version		
	1999	2003	2007
General Education, elective	-	-	2
Basic Courses of Disciplines, required	7	7	7.5
Specialized Courses, required	7	8.5	8.5
Specialized Courses, elective (Total available)	2 (4)	2 (2)	6 (10)
Practical Training, required	2	15.5	13.5
Practical Training, elective			6
Subtotal/proportion	18/9.4%	33/15.2%	43.5/22.9%

Table 3 lists the details of courses designed for optics and photonics. In the 2003 revision, we incorporated fiber communication experiments and holographic data storage experiment[1] into the Specialized Physics Experiments course, and added Optical Industrial (workshop) Practice and Optical Communication Course Project in the program. Thus the training in optics and photonics was greatly reinforced. In the 2007 revision, more elective courses both in class curricular and in laboratory were added in the program. Moreover, we designed an interdisciplinary course, Stereography & Holographic Arts, not only for Applied Physics students, but also for all other disciplines at the University. This would be beneficial to open up new horizons for the students.

Table 3 Credit of Courses Designed for Optics & Photonic

Name of Course	Program Version		
	1999	2003	2007
Stereography & Holographic Arts （**G**, elective）	-	-	2
Optics（**B**）	3.5	3.5	4
Principles of Lasers（**B**）	3.5	3.5	3.5
Information Optics（**S**）	3	3.5	3.5
Principles of Fiber Communications（**S**）	2	2	2
Optoelectronics（**S**）	2	3	3
Principles of Holography （**S**，elective)	2	-	
Optical Communication Systems（**S**，elective)	2	-	
Optical Communication Networks（**S**，elective)	-	2	2
Crystal Optics（**S**，elective)			2
Fiber Sensing Technology（**S**，elective)			2
Applied Optics & Optical Instruments （**S**，elective)			2
Specialized Physics Experiments (**P**)	2	4.5	3
Optical Industrial Practice (**P**)		2	2
Course Project: Optical Communication (**P**)		9	4
Course Project: Optoelectronics (**P**)			4.5
Self-taught Course (**P**，elective)			2
Course Group for Creative Activities (**P**，elective)			4
Final Year Project (**P**)	14	18	16

5. Results

The revision has given good results as expected. The situation of recruitment greatly improved as more qualified students enroll in Applied Physics each year, showing that the undergraduate program satisfies the need of the students. In recent years more graduated students obtained jobs in the field of photonics, and the number of graduates who obtained the opportunity to pursue higher degree has been increasing. However, this reflects only success of the revision during 1998-2003. The effectiveness of the 2007 revision has to be demonstrated by our teaching practice in the following years.

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I.

Can classical optical superposition principle get us out of quantum mysticism of non-locality and bring back REALITY to modern physics?

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Abstract

We already know that in the purely technological frontier, photonics is going to play a leading role during this century riding on the shoulders of electronics-, bio- and nano-technologies. This talk will underscore that the fundamentals of photonics as has already been developed by classical optics, specifically, the Superposition Principle (SP) will play a profound role in bringing REALITY in physics while opening up many new paths to innovations by opening up new understandings behind SP. SP becomes manifest only when the detectors and the detectees are within each others range of interacting forces and can exchange energy allowed by the quantum restrictions to manifest the measurable transformations undergone by them. The deeper recognition of this fundamentally "local" SP will guide us overcome many conceptual bottlenecks, appreciate deeper realities hidden behind the current quantum formulation, remove the unnecessary non-causal interpretations of quantum mechanics, bridge classical and quantum optics and bring back conceptual freedoms for many new photonics innovations. One of the many specific examples is that the apparent spectrometric resolution limit $\delta\nu\delta t > 1$ is not a fundamental principle of nature. I will show mathematical and experimental work to establish this assertion.

1. It is generally accepted that photonics will lead the technology innovations of this century. Both science and religion converge on one common opinion that in the beginning of the creation there was light. Today's science continues to reveal the critical functional and facilitating role of light behind almost all the life and evolutionary activities. Without the Sun light there would be no life, period. Down to Earth, in our econo-sphere, the global economic competitive advantage is driven by the rate of innovation toward building intelligent, diverse device-based, multi-functional, micro systems. Micro systems must continuously evolve to higher intelligence through multiple feed-back loops. Inter connectivity required for these feed-back loops between the integrated diverse components will be a critical element to enhance this intelligence. What is going to serve these ubiquitous functions? Light will be the best inter connector and intelligence enhancer. Light can gather and deliver information; it can pick up and deliver energy through and between diverse materials, simply based on the choice of frequency of the radiation and the right light-matter interaction principle. Science of light is still continuing to make breakthroughs. Nano photonics (manipulating light in domains that are orders of magnitude less than the wavelength) is already developing many new technologies by integrating biological devices and functions. Optics is going to play the role of the critical technology enabler for decades to come riding on the shoulders of all the other matured technologies as their integrators and intelligence enhancer by giving them more "voices of intelligence" through many flexible feed-back loops..

The field of Electronics started only a century ago and it is already almost peaking in technology maturity (rate of patent submission). In contrast, the importance and the role of light as a profoundly important enabler of both science and technology have been recognized by modern human since many centuries past. However, it is as old as the beginning of the universe. The technologies behind galactic evolution has been started by nature with light (The Big Bang)! The Electronic chip owes its existence to very recent understanding of Solid State Physics, empowered by Quantum Mechanics, which itself was forced on us by Spectroscopy (discrete lines of gas discharge) and Black Body radiation. Stimulated emission gave birth to lasers, which is now ubiquitous in our every day life, whether they are technological devices (CD read-write) or industrial instruments (Raman spectrometers). Spectrometry is the most precise measurement tool ever invented by us. No major field of science or industry can thrive today without these tools. But these fundamental tools could not have been invented without the help of science of light at the fundamental level. We are now waiting to translate Bose-Einstein Condensates (BEC) into new technologies.

2. This century, photonics will also lead the way to bring reality in fundamental physics by giving 'active voice' to the Superposition Principle. Mathematical framework behind the classical superposition principle (SP) was well developed in the process of studying "interference" of light and other sinusoidally undulating phenomena like water and sound waves and various coupled mechanical pendulums and electrical oscillators and transformers. Quantum mechanics rightly co-opted and generalized SP to a higher level. All measurable (observable) transformations in this universe becomes

possible if and only when a detector and a detectee (i) are physically superposed within their range of interaction by an appropriate force and then (ii) the rules of constrained interactions allow the exchange of energy to manifest the sought-after transformation. Thus, SP is universal, but it is an active process. SP cannot become manifest (measurable) without real physical interaction.

2.1. Appreciating that EM fields do not interact with each other inspite of their linear superposition being accepted by Fourier theorem and Maxwell's wave equation. All wave phenomena propagate through each other unperturbed beyond the physical domain of interaction if not perturbed by inserting detectors. Water waves pass through each other; the superposition fringes are visible only in the region of physical superposition and because the medium that manifests the wave phenomenon is directly visible to us. Same is true for sound waves as one can validate by carefully listening to the voice of a friend from a distance in a rowdy party. Same is true for light 'waves'. Otherwise, the visual universe would have been full of space and time scintillating 'interference' patterns. Or, the hair-thin fibers that use WDM technology (wavelength domain multiplexing) would have converted the independent data bits all mixed up; we do know that light does produce beat signal when different frequencies are mixed. But, unlike water waves, the medium that manifests light waves is not directly visible to us. That is why we must insert photo detectors within the physical region of superposition of the light waves. Photo detectors being quantum mechanical (energy levels are quantized and frequency sensitive) and electrons themselves being discrete (quantized), we can only register discrete number of electrons in any photo detection process. This does not unequivocally prove that light constitutes propagating 'bullets' of indivisible energy hν [1, 2, 3].

That EM fields do not operate on each other is accepted in physics. Yet, somehow we have been overriding this daily observed fact by claiming that there is 'interference' of light even in the absence of detectors as if the superposed fields by themselves can re-distribute their energy in space and/or time. Detectors are atomic size entities. For them to respond to single or superposed multiple beams, they must experience all the fields simultaneously present on themselves before they can absorb energy from the fields and undergo any measurable transformation. Thus any and all measured superposition effects must necessarily be local (within the range EM force of interaction).

It is true that Fourier theorem is mathematically correct in showing the linear superposition relation between multiple sinusoids. We also know that Maxwell's wave equation accepts any single sinusoid or their all possible linear combinations. However, the correctness of mathematical linearity cannot override the real world's necessity of real physical interaction between detector and detectee to generate measurable transformations in the real world. The summation implied by the SP is actually carried out by the detectors while they respond to all the filed amplitudes simultaneously as electric dipoles. Susceptibility (polarizability) takes care of this part of the physics. This is also well known calculation recipe in classical and quantum mechanics. Giving the "active voice" to the SP opens up the door to understand the actual physical processes behind the generation and absence of SP effects based on the quantum restrictions of the detecting dipoles. Coherence theory should be re-written in terms of correlation of dipole stimulations [3].

3. Re-visiting classical spectrometry through "active" Superposition Principle. Is elevating SP as an active interaction process purely semantics? We will summarize the derivation of a generalized theory of spectrometry based on the real physical superposition of light pulses and then show that the classical results are particular case along with better understanding of the physics of (processes behind) spectroscopy. It will also be obvious that spectral super resolution for short pulses can be obtained with precision many orders of magnitudes better than the classical limit set by Fourier's corollary $\delta\nu\delta t>1$.

Causally speaking, all light signals are pulsed; only the duration may be very short or very long. High resolution spectrometers like gratings and Fabry-Perots (FP) are beam or pulse replicator with a temporal periodicity given by the $\tau = m\lambda/c$ where m is the diffraction order for gratings and the interference order $(2d/\lambda)$ for FP, d being the plate separation. Then an incident pulse $a(t)\exp[i2\pi\nu t]$ with a carrier frequency ν will produce a partially superposed train of pulses [3]. We are presenting the formula for the time varying intensity for a grating only:

$$|\, i_{out}(t)\,|^2 = \left|\sum_{n=0}^{N-1}(1/N)a(t-n\tau)\cdot\exp[i2\pi\nu(t-n\tau)]\right|^2 \quad (1)$$

The corresponding time integrated energy distribution recorded by a photographic plate is:

$$I_{pls}(\nu,\tau)\Big| = (1/N) + (2/N^2)\sum_{p=1}^{N-1}(N-p)\gamma(p\tau)\cos[2\pi p\nu\tau] \quad (2)$$

We have written $\gamma(|m-n|\tau)\equiv\gamma(p\tau)$; this normalized autocorrelation function is defined as:

$$\gamma(p\tau) = \int d(t-n\tau)d(t-m\tau)\ dt \Big/ \int d^2(t)\ dt \tag{3}$$

It is interesting to recognize that the total stretch of the pulse train is $\tau_0 = N\tau$, where N is the total number of the grating slits. So, whenever the width of the incident pulse a(t) is longer than τ_0, the spectral fringe pattern given by the generalized spectrometric Eq.2 becomes identical to the classical text book formula derived under CW condition:

$$\underset{\delta t \to \tau_0 = N\tau}{Lt.} I_{pls}(\nu,\tau) = \frac{1}{N} + \frac{2}{N^2}\sum_{p=1}^{N-1}(N-p)\cos[2\pi p\nu\tau] \equiv \frac{1}{N^2}\frac{\sin^2 \pi N\nu\tau}{\sin^2 \pi\nu\tau} \equiv I_{cw}(\nu,\tau) \tag{4}$$

We now have two new physical insights from the Eqns.1-4. Classical spectrometers have a characteristic time constant τ_0. When the incident pulse is longer than τ_0, we get the classical CW formula. When the pulse width is shorter than τ_0, the broadened spectral fringe width is given by Eq.2. But, if we can separately determine $\gamma(\tau)$ through an autocorrelation instrument, we can determine the value of the carrier frequency with arbitrary precision from Eq.2; we are not limited by $\delta\nu\delta t>1$; it is not a fundamental limit of nature because Fourier theorem is not a principle of nature. It comes from the correct mathematical assumption that numerically the spectral fringe width for a pulse is given by the convolution of the CW fringe pattern of Eq.4 with the mathematical Fourier intensity spectrum $\tilde{A}(\nu)$ due to the time function a(t). Using Parseval's theorem of conservation of energy, one can mathematically demonstrate that our generalized Eq.2 can be found equivalent to classical assumption:

$$I_{pls}(\nu,\tau) \approx \int_{-\infty}^{\infty} |\, i_{out}(t)|^2 dt = I_{cw}(\nu) \otimes \tilde{A}(\nu) \tag{5}$$

We believe that this amthematical equivalency of the convolution of Eq.5 with our generalized formula of Eq.2 has constrained us in believing that the Fourier corollary $\delta\nu\delta t>1$ is a limiting principle of nature. The experimental paper that demonstrates super resolution by heterodyne spectroscopy can be found from Ref.3.

4. Future of "active" Superposition Principle in fundamental Physics. Active SP clearly implies that the "dominant part" of the quantum-ness of photo detection process is determined by the quantized photo detectors themselves. That EM fields do not operate on each other is accepted in physics. Yet, somehow we have been overriding this daily observed fact by claiming that there is 'interference' of light even in the absence of detectors as if the superposed fields by themselves can re-distribute their energy in space and/or time. Detectors are atomic size entities. For them to respond to single or multiple superposed beams, they must experience all the fields simultaneously present on themselves before they can absorb energy from the joint-fields and undergo any measurable transformation. Thus any and all measured superposition effects must necessarily be local (within the range EM force of interaction) [4]. It also strengthens us to reject un-supportable non-causal assertions like "non-locality" and "teleportation" in SP experiments. Consider more down to earth observations that contradict accepted physics assumptions. Fourier transform spectroscopy works because Michelson assumed that different optical frequencies do not interfere with each other. His assumption was correct for slow detectors of his time. Today we routinely carry out heterodyne spectroscopy by superposing different frequencies on a fast detector; different frequencies do give SP effects. We still claim that orthogonally polarized light do not interfere with each other. But EM fields do not interfere (interact) with each other, no matter what. The physical reason is that the same detecting molecule, once responded to the stronger EM fields upon them as a dipole, it cannot simultaneously respond as a dipole in the orthogonal direction; so it cannot sum the effect of both the fields and hence there are no fringes when the fields are orthogonally polarized.

5. Acknowledgements. Past support for some of the activities presented here was provided by the Nippon Sheet Glass Corporation.

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II.

The first steps for learning optics: Ibn Sahl's, Al-Haytham's and Young's works on refraction as typical examples

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Abstract: Optics scholars did not only discover optical phenomena and laws governing them. Some of them also invented impressive optical systems and instruments or offered us techniques to juggle with optical signals and rays. One typical example of the impressive optical systems is the *camera obscura* invented by Ibn Al-Haytham. For techniques enabling us to easily handle optical rays, one can mention Young's method to handle rays put into play by refraction. Nine centuries before him, Ibn Sahl proposed an elegant method to manipulate refraction related rays. These three examples will be handled in this paper, together with a historical overview inviting the reader to be in the context of this fascinating works.

1. Introduction

We cannot be grateful enough to optics scientists, during the running wheel of history, who enabled us to rapidly understand optics and to tackle specific research tasks in optics or to design particular optical components or systems. They did discover a huge number of optical phenomena. They elaborated and formulated the laws associated to these phenomena in such a way we can use them. Some of them also invented impressive optical systems and instruments or offered us techniques to easily handle optical signals and rays. In this paper we will focus on three findings of those scholars, which are strongly related to learning optics. We will treat Ibn Al-Haytham's *camera obscura*. For techniques enabling us to easily handle optical rays, we will take the case of Young's method to handle rays put into play by refraction. This famous scholar was preceded, nine centuries before, by Ibn Sahl who proposed another elegant technique to manipulated refraction related rays. These three examples will be handled in this paper, together with a historical overview inviting the reader to be in the context of this fascinating works. The remainder of this paper is organized as follows. Section 2 presents a historical review of achievements in Optics. In this review, we will focus on Al-Haytham's contributions as well as previous and subsequent works to emphasize the continuity of achievements through the link between scientific observations, interpretations and criticisms during the turning wheel of history. While section 3 briefly addresses the medieval Islamic achievement in optics, section 4 focuses on Al-Haytham's contributions from which optics scientists profited widely and for a long time and are still profiting. In relation with learning optics, we take the *camera obscura* as an example. This fascinating experiment is in our opinion one of the most exciting and motivating examples to teach optics and to make it readily understandable by laypeople. Results are presented in section 5. Finally, section 6 presents some concluding remarks.

2. Brief historical overview of achievements in optics

Historically, light was a center of interest for numerous inquisitive people: the philosophers who were interested in its nature and the scientists who wanted to interpret its associated phenomena. In antiquity, the Egyptians attempted to discover the mystery of light and to know its structure [1]. From a philosophical point of view, their attempts were fruitless. However in practice, they implemented impressive mechanisms mainly based on reflection. The Greeks also attempted to decode the enigma of light and considered it a continuous phenomenon propagating in the form of a substance current called the "visual ray". Nevertheless, based on the work of the Egyptians, they established rules for light deflection [2]. One of the most impressive legacies of the Greeks in optics is the mirror of Archimedes. Aristotle [3], interested in the sensation in general, refused to admit the existence of the visual ray and believed in the analogy between light and sound whose vibratory nature was already known [4]. In the XIth century, the thesis of the visual ray was definitively abandoned by the Iraqi Ibn Al-Haytham [5] whose work revolutionized the optics [6,7]. He detached Optics from its philosophical envelope and embedded it in the framework of physics and mathematical sciences [5]. He dealt at length with the theory of various physical phenomena like shadows, eclipses, the rainbow, and speculated on the physical nature of light. Al-haytham's optics entered Spain in the XIIth century and was adopted by Grossteste [8], who affirmed the analogy between light and sound [9,10] and thoroughly investigated the matter of geometrical optics.

After the contributions of the geometro-opticians, Snell and Descartes [11] studied the refraction phenomenon and stated that the speed of light is as high as the covered medium is dense. This hypothesis was contested by Fermat [12], who attributed indices to the media. Foucault in the XIXth century came out in favour of Fermat. This more modern progress still dealt only with geometrical optics which considered that the behavior of light with respect to obstacles is expressed uniquely in terms of absorption, reflection or refraction. However, in the XVIIth century, Grimaldi, using a simple experiment, had observed the progressive transition between light and shadow and regarded the corpuscular theory, supposing the rectilinear propagation of light, as insufficient to explain such an effect [13]. Despite Newton's support of the corpuscular theory [14] (He believed that the light propagation is a movement of corpuscles that respects the rules of mechanics and notably that of the universal gravitation), Huygens advanced the ondulatory theory based on Grimaldi's observations. He explained Grimaldi's observation by a purely intuitive postulation, in which he regarded light propagation as an incessant creation of elementary spherical light sources [15].

At the beginning of the XIXth century, after some experiments on the colors of thin plates, T. Young came to the conclusion that the interaction between light rays may produce darkness, thereby discovering a wonderful phenomenon which he called "interference" [16]. Like Huygens, Young supported the ondulatory theory. He also developed an elegant technique to handle refraction (it will be treated in the experimental part). His belief in the analogy between light and sound leads him to state that light vibration is longitudinal [17]. The famous A. Fresnel was of the same opinion. However he considered that Huygens' postulation did not explain the non-existence of waves that have the same specifications propagating backwards. He combined Huygens' principle of the "envelope" building, with the interference principle of Young and, for the purpose of putting forward a coherent theory, he made some supplementary hypotheses on the amplitude and phase of the new elementary waves. At the end of the XIXth century, G. Kirchhoff gave a deeper mathematical basis to the diffraction theory introduced by Huygens and Fresnel, and considered Fresnel's hypothesis as a logical consequence of the ondulatory nature of light. Kirchhoff's work was subjected a few years later to criticisms made by Sommerfeld who considered the Kirchhoff formulation as a first approximation. He advanced with Rayleigh what was later called the "Rayleigh-Sommerfeld diffraction theory". Hence, a supplementary phenomenon called "diffraction" is added to those concerning the behavior of light when coming across obstacles, namely absorption, reflection, refraction, diffusion and dispersion. Sommerfeld defined this phenomenon conveniently as follows [18]: "Diffraction is any deviation of light rays from the initial path which can be explained neither by reflection nor by refraction".

Because medieval Islamic contributions in optics are not commonly known by optics community, we will devote a separate section for this era.

3. Medieval Islamic contributions in optics

As stated by Lindberg [19], the Islamic contribution to the science of optics within the medieval Islamic world should be measured not by the number of practitioners, which was small, but by the quality of the contributions, which was great. Let us briefly recall some scientific contributions in optics and limit attention to six scientists in chronological order. A separate section will be devoted to the famous scientist Ibn Al-Haytham.

3. 1. Al-Kindi

Yaqub Ibn Ishaq Ibn Sabah Al-Kindi (c. 801-873), popularly known as the "Philosopher of the Arabs" in the Middle Ages, was one of the earliest important optics scientists in the Islamic world. His theory of the active power of rays, stating that any luminous object emits rays in every direction, influenced several European scientists like Grosseteste, Bacon and Watelo [20,21]. In other words, he pointed out the incoherent behavior of light and therefore challenged the ancient assumption that light emanates from luminous objects as a single, holistic unit [19]. Al-Kindi's observations and interpretations influenced the course of thinking for centuries. Moreover, he defended Euclid's theory of visual power issuing forth from the eye and suggested some corrections. It was necessary to wait for Al-Haytham's revolutionary theory, two centuries later, to abandon the assumption of radiation moving out of the eye in favour of the statement that light moves in.

3. 2. Ibn Ishaq

The trilingual Nestorian Christian, Hunayn Ibn Ishaq (Isac), contemporary and neighbour to Al-Kindi in Baghdad, was one of the most illustrating examples of the peaceful and fruitful multi-cultural and multi-religious cohabitation in Baghdad. He wrote ten Treatises on the Eye and claimed that the sensitive organ of the eye is the crystalline lens, located in the center of the eye. He was a leading administrator of the translating enterprise and translated several works from Greek to Arabic with Syriac as a probable intermediate step. He supervised Jewish, Christian and Muslim translators [22].

3. 3. Ibn Sahl

In the same place, Baghdad, but in the next century (10^{th}), another scientist, called Abu Sad Al Alla Ibn Sahl, excelled in Optics. Author of a treatise on Burning Mirrors and Lenses, he was an optics engineer associated with the court of Baghdad. He wrote his textbook in 984 where he set out his understanding of how curved mirrors and lenses bend and focus light (see Figure 1). R. Rashed credited Ibn Sahl with discovering the law of refraction [23], usually called Snell's law and also Snell and Descartes' law. It worth noting that Snell's law, discovered in 1621 in Holland, was not well known until Descartes (1596-1650) published it in 1638. Even then he did not make it clear that he was following Snell, so for some time Descartes was regarded as the originator of Snell's law. Similarly, Ibn Al-Haytham is the inventor of the pinhole camera, but the idea was later credited by Della Porta for redescribing how the camera works.

We recall this law: $n \sin(i) = n' \sin(i')$, where n and n' are the refraction indices in the first and second medium and i and i' are respectively the incidence and refraction angles. For small values of i (expressed in radian and not in degree), the law can be approximated as follows: $n\, i = n'\, i'$

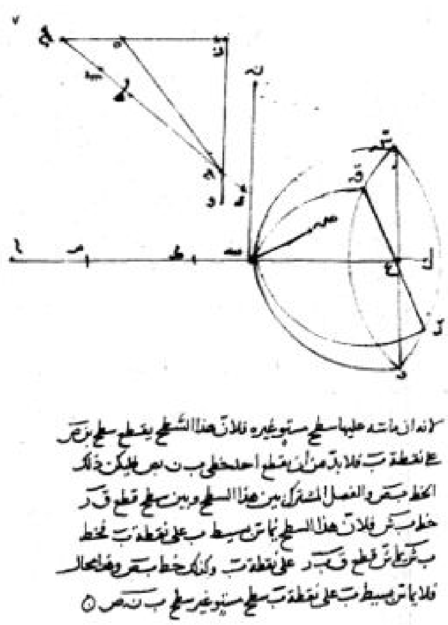

Figure 1: Reproduction of a page of Ibn Sahl's manuscript showing his discovery of the law of refraction [23].

Figure 2: Ibn Al-Haytham's symbolic photo in an Iraqi 10,000-dinar note.

By examining Figure 1, Rashed's thesis looks very defendable. Let us have a close look at the top-left part of the Figure, where we see two right angles. The inner hypotenuse stands the path of an incident ray. Let us say that its length is h and the incidence angle with respect to the horizontal line is i. The outer hypotenuse, with length h' and angle i', shows an extension of the path of the refracted ray. Here, the incident ray meets a crystal whose face is vertical at the point where the two hypotenuses intersect [24]. According to R. Rashed [23], the ratio of the length of the smaller hypotenuse to the larger is the reciprocal of the refractive index of the crystal. In mathematical terms, $h/h' = 1/n'$ or $h/h' = n/n'$ with (n=1 the refraction index of the air). Because $h/h' = \sin(i')/\sin(i) = n/n'$, we find the law of refraction mentioned above. Ibn Sahl's treatise was used later by Ibn Al-Haytham. R. Rashed reassembled the manuscript parts, dispersed over two libraries, and translated it into French [25].

3. 4. Al-Quhi

In the same century (10^{th}) and in addition to geometrical mathematics, the Persian, Abu Sahl Waijan Ibn Rustam Al-Quhi, also known as Abu Sahl Al-Kuhi or just Kuhi, studied optics and investigated the optical properties of mirrors made from conic sections. His renown came also from his skills in the manufacturing of optical observation instruments [26].

3. 5. Ibn Al-Haytham

Because a special section is devoted to Ibn-Alhaythm, let us just mention two of his followers.

3. 6. Al-Shirazi

Qutb Al-Din Al-Shirazi (1236-1311) continued the optical studies of Ibn Al-Haytham. Georges Sarton considers Al-Shirazi to be one of the prominent scientists in mathematics, astronomy, optics and philosophy [21]. His main contributions in physics was his "unprecedented comprehensive explanation of the rainbow, as he demonstrated that the rainbow phenomenon occurs when sun rays fall on the small water drops that prevail in the air when it's raining. The sun rays then undergo an internal reflection and become apparent to the eye" [27]. He was the first scientist giving a correct explanation for the formation of the rainbow.

3. 7. Al-Farisi

Kamal Al-Din Al-Farisi (1260-1320). He was concerned by light, colour and the rainbow [28]. His work was discussed in the Dictionary of Scientific Biography [29]. Al-Farisi was a pupil of Al-Shirazi. His work on optics was prompted by a question put to him concerning the refraction of light. Al-Shirazi advised him to consult the Ibn Al-Haytham's work. Al-Farisi made such a deep study of this treatise. The professor, Al-Shirazi, suggested to his student, Al-Farisi, to write what is essentially an amendment of Al-Haytham's major work, which came to be called in Arabic the "Tanqih".

4. Ibn Al-Haythm's attempts and achievements

Abu Ali Hasan Ibn Al-Haitham (c.965-1039), known by Europeans as "Alhazen" (Al Hasan), was born in Basra, where he received his education. Sir Thomas Arnold considers that "the field of optics reached its peak with Ibn Al-Haytham" [30]. Sarton says "Ibn Al-Haitham was the best scientist to have existed in the Islamic world in the middle ages in the field of natural science. He was one of the few most outstanding figures in optics in all times. He was also an astronomer, a mathematician and a doctor" [21]. The Encyclopaedia Britannica considered him as the leading figure in optics after Ptolemy [27].

4.1. Scientific experimental method

Ibn Al-Haytham is one of the very early founders of the scientific method. Ibn Al-Haytham rejected Aristotle's theory (384-322 B.C.) claiming that there is a difference between the laws governing events on earth and those pertaining to celestial bodies. He considered that light is traveling with respect to well defined physical laws, regardless of its source and where this source is. In this sense, he anticipated the universal laws of seventeenth century scientists. Light coming from the sun, reflected by the moon, emitted by fire, reflected by a mirror or focussed by a lens, is light and it undergoes the same effects and phenomena. Light, used in the *camera obscura* setup, is identical to light causing the rainbow effect. In other words, light is universal. If one allows oneself to do the parallel to the universal gravitation, Ibn Al-Haytham, mainly concerned by optics, anticipated the universal laws of seventeenth century scientists. He opted for an experimental approach (optical observations) to prove his scientific interpretation. For example, he implemented, the *camera obscura* to experimentally prove that rays travel in straight lines and that the image is reverted like the retinal image. He also concluded from his various experiments that light weakens as it travels from its source. His writings clearly point out a scientific method including the systematic observation of physical phenomena and their linking together into a scientific theory. Ibn Al-Haytham's influence on physical sciences in general and optics in particular, has been held in high esteem at the level of both theory and practice.

4.2. Human eye

Where do the names of the optical components of the eye come from? They are indeed Ibn-Haytham's appellations: *cornea* (القرنية), *retina* (الشبكية), *Vitreous Humor* (السائل الزجاجي), *Aqueous Humor* (السائل المائي), etc. [31]. Ibn Al-Haytham is the founder of the Psychology of Vision. In his anatomy, he was able to identify the eye layers with great precision and to define his lens system as comprising of the aqueous and vitreous humors and the lens. In addition, he identified the neural components of the visual system including the retina, the optic path and the optic chiasma (part of the brain where the optic nerves partially cross). His Psychophysics was based on a clear understanding of the optic mechanisms of the convex and concave layers of the eye, the visual angle and the reversal of the visual image. He provided explanation of the visual constancy's, perception of distance, form and orientation. His explanation cannot be distinguished from the one retained in the psychology of vision today. Al-Haytham work in optics in general and in vision in particular hugely influenced western scientists such as Bacon, Witelo, Pechan and ultimately Kepler who provided an improvement of the understanding of the eye five centuries later.

4.3. The first spectacles

Ibn Al-Haytham is one of the scholars often credited with inventing spectacles [32], although that credit is more commonly given to Roger Bacon. It is well known that Ibn-Haytham proved the magnification ability of convex lenses. Islamic history revealed that when he became old, he designed a convex lens to continue reading scientific treatises. He realized that each eye requires a specific correction (binocular vision) and used two convex lenses with different powers.

4.4. Light dispersion

He also carried out the first experiments on the dispersion of light into its constituent colours. Indeed, the rainbow incited the Ibn Al-Haytham's curiosity. By exposing water-filled glass globes to sunlight, he discovered that rainbows are caused by refraction not by sunlight reflecting off raindrops, as Aristotle had claimed. Ibn Al-Haytham mage the first experiment in history showing how to disperse light, to break white light into its constituent colors. He made a close look at sunlight passing through his water-filled globes; he could see the beams of light refracted at measurable angles. He realized that each band in the resulting multi-colored beam had been refracted at a different angle, and that each color always occurred at the same angle. Ibn Al-Haytham demonstrated that the prism made the colors visible by refracting rays of different colors in varying amounts, thus producing the familiar spectrum.

4.5. Sun and the atmosphere

Ibn Al-Haytham gave a correct explanation of the apparent increase in size of the sun and the moon when near the horizon. Ibn Al-Haytham has discussed the density of the atmosphere and related it to altitude. He also studied atmospheric refraction. He discovered that the twilight only ceases or begins when the Sun is 19° below the horizon and attempted to measure the height of the atmosphere on that basis. For Ibn Al-Haytham and his contemporary scientists, the fact that the earth is spherical is not debatable. Their experiments do not leave the slightest doubt about the spherical shape of the earth. We believe that this kind of knowledge belongs to laypeople at that time. Cartographers and geographers, like Ahmad Ibn Rustah (died in 903), Abu Al-Hasan Al-Masudi (died in 956) and Abu Abdullah Muhammad Al-Idrisi (c. 1100-1165), mentioned the spherical shape of the earth in their books of traveling.

4.6. Camera obscura

In its simplest form the first camera in history, the *camera obscura*, is a shuttered room with a narrow aperture that admits light. The first recorded use of this optical system is in an optical treatise written by Al-Kindi. Decoding the nature of light was his concern in his attempts to setup a camera and therefore did not go much far in imaging systems. While the image forming ability of the camera was of little interest for Al-Kindi, this quality was of huge importance for Ibn Al-Haytham. The latter rapidly went beyond the scope of issue of the nature of light to investigate one of the most important behaviors of light, namely propagation. With determination, he defended the thesis of rectilinear propagation of light. His *camera obscura* was implemented to provide experimental evidence for this statement.

4.7. Refraction

In addition to his studies of reflection, he also studied refraction, a phenomenon in which light rays bend when traveling from one medium to another, such as from air to water. The effect causes an object to appear to be in a location other than where it actually is, making him the first scientist to test a property of refraction that seems so obvious today. He demonstrated that a ray of light arriving perpendicular to the air-water boundary was not bent at all and showed that this was true for light passing through not just two, but several media. Ibn Al-Haytham's explanation of how a lens works enabled him to implement spectacles. He contended that magnification was due to refraction, the bending of light rays at the glass-to-air boundary and not, as thought before, to something inside the glass. He made the link between glass curvature and magnification. He is then credited with discovering that the magnifying effect takes place at the surface of the optical element rather than within it.

It is quite surprising that Ibn Al-Haytham, who gave an outstanding explanation of the working of the optical system of the eye, who manufactured and used the first spectacles in history, who attempted to measure the thickness of the atmosphere, who worked on many others refractive components and systems, did not suggest a law for refraction. Our interpretation privileges two possibilities. First, he may actually have made this suggestion, but his writing was lost during wars and by negligence. Second, he may did not write it explicitly because it is well known before him and commonly used by Islamic scientists, like the fact that the earth is spherical (no one in the Islamic word debate on this issue).

5. Experimental results

An applet was designed to illustrate a very likely interpretation to Ibn Sahl's method to handle refraction [33]. Three rays are put into play: the incident, refraction and the extent rays. The extension ray (extension of the refraction ray into the incidence medium) is represented in dashed line. The incident and extension rays are considered as hypotenuses forming two rectangle triangles. The ratio extension to the incidence hypotenuse is constant and is a characteristic of the refractive medium (in the bottom in the applet). For simplicity, one can keep both hypotenuses constant as the case of the applet. This ratio is nothing else than the refraction index *n'* of the refractive medium if the incidence medium is air. As a consequence, the two extremities of the two hypotenuses move along a vertical line if one changes the incidence angle of the ray that meets a plane surface. We invite the reader to manipulate the applet [33], which presents our interpretation to Ibn Sahl's technique.

We propose a mechanical approach that enables illustrating the analogy between the refractive system and a mechanical equivalent [33]. The two rays (considered as hypotenuses previously) in the incidence medium 1 (top) are replaced by two sliding bars hanging on the application point, also moveable in the applet. Because the bars are solid and therefore their lengths are fixed, if we want to move one of the bars, the second one and also the vertical bar must move correspondingly. In summary, we need a mechanical system with three sliding bars. The special case, where the lengths of both hypotenuses are set to the values of the refraction indexes *n* (1 if air) and *n'*, is interesting. In this case, the method becomes similar to Young's method. Here also, we invite the reader to manipulate the applet developed for this purpose [34]. The lengths will be taken as the two radii of Young's scheme. Thus Young's method is covered by Ibn Sahl's method.

We also organized in Tunisia two photographic workshops [35,36] including conferences. Among others, the workshops offered us a valuable opportunity to open up to Ibn Al-Haytham's attempts and achievements. The *camera obscura* that he thoroughly studied was the theme of a training where more than twenty participants set up and used this basic camera. The training was designed for any photographer just starting out. The adopted training approach, based on active teaching and learning, allowed achieving interesting results in spite of the heterogeneity of the group of trainees. The training includes for major experimental lessons on how to set up and to use a *camera obscura* by means of only sheets of paper. The first two lessons were dedicated to the history of the *camera obscura* and on how to devise it in its most simple way. The next step was to initiate the group to implement their own *camera obscura*. It is worth noting that the group was heterogeneous. Moreover, the subject was very new for the trainees. Thus, the lectures were asked to popularize the experiments by avoiding forbidding mathematical formulas and simplifying complex concepts so that it can be easily understood by laypeople. The training approach has been chosen to incite trainees to be active and to efficiently improve their skills in optics and photography. Prior to experimentation, the trainees received theoretical instructions in a comprehensible way. They learn the photographing conditions to fulfill, and go through the process of photographing their favorite objects from start to finish on their own. Through interaction with the mentors, trainees were better able to understand the scientific way of thinking and doing things.

Figure 3: Photos of the workshop organized in Tunis in 2004.The boxes are the cameras oscura that the participants implemented by hand.

6. Conclusions

Through simple examples, daunting formula and forbidding aspects may be popularized. Al-Haytham's attempts to understand challenging natural optical phenomena, like the rainbow, and to model complex and delicate systems, like the human eye, present start points to teach optics and especially geometrical optics. If Ibn Al-Haytham with some primitive tools, not to say with no tools, could implement the first camera in the world, our students can easily rebuild this system in our relatively sophisticated laboratories. The idea is to come close to geometrical optics laws by observing the travel of the image forming rays through a hand made system.

As for the law of refraction, our interpretation to Ibn Sahl's technique offers an easy tool to manipulate the rays put into play by the phenomenon of refraction. By providing a material dimension, the mechanical approach further simplifies the refraction phenomenon. Because of the wave nature of light, optical rays do not exist actually and present a convenient fiction to illustrate that light travels in straight lines. In the same spirit, the mechanic approach may present a further fiction to illustrate refraction of light.

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III.

Orbital Angular Momentum of Light in Optics Instruction

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Abstract: We present an introduction to the orbital angular momentum of light for use in optics instruction. This type of angular momentum is a new fundamental concept discovered fifteen years ago. It arises in optical beams with helical wave-fronts. We introduce it as part of a fundamental discussion of the momentum of light. We also present inexpensive demonstrations of transfer of linear and angular momentum of light using optical tweezers.

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1. Introduction

Orbital angular momentum of light is a new fundamental concept in optics discovered only fifteen years ago [1]. Since then this form of angular momentum has been the subject of numerous studies [2]. It arises when a light beam is in a spatial mode with a helical wave-front. The transfer of orbital angular momentum has opened new applications in manipulation of matter with light using optical tweezers [3]. Orbital angular momentum has also been studied at the single-photon level [4], where it has created new possibilities in quantum information.

It is becoming an increasingly important omission that optics textbooks, even modern ones, do not have discussions of orbital angular momentum. The purpose of this article is to start the process of filling this vacuum in optics instruction. Since orbital angular momentum appears in its purest form in high-order Laguerre-Gauss beams, it is logical to start by expanding the coverage of Gaussian beams in high-order modes [5]. The general topic of Gaussian beams is not dull. Quite contrary, it is rich with useful concepts and interesting wave physics. In this article we describe a way to introduce orbital angular momentum. We complement the theoretical description with laboratory experiences using optical tweezers. In Sec. 2 we give the conceptual narrative and in Sec. 3 we present laboratory demonstrations using optical tweezers.

2. Teaching methodology

Orbital angular momentum appears due to an azimuthal component of the linear momentum of the light present in beams with a helical wave-front. The transfer of orbital angular momentum to an object is easily observed using optical tweezers. Since optical tweezers can be explained in terms of momentum transfer of the light, we can incorporate a discussion of optical tweezers as a method to demonstrate momentum interactions between light and matter. This method may be also suitable to use in introductory physics.

2.1 Momentum of light

Within the framework of electromagnetic theory the linear momentum density of a light beam traveling in vacuum is

$$\boldsymbol{p} = ?_0 \boldsymbol{E} \times \boldsymbol{B} = \boldsymbol{S}/c^2, \tag{1}$$

where $\boldsymbol{E}$ and $\boldsymbol{B}$ are the electric and magnetic field vectors of the light, $?_0$ is the permittivity of vacuum, c is the speed of light, and $\boldsymbol{S}$ is the Poynting vector. It is convenient to express these quantities as time averages. The time average of the magnitude of the Poynting vector is also known as the irradiance I, so the average momentum per unit area is $I/c^2 = ?_0 E_0^{\,2}/2\mathrm{c}$, with E_0 being magnitude of the electric field amplitude. The total power of the beam P is the integral of the irradiance over the transverse profile of the beam.

If a beam of light is incident on an absorptive object the force exerted by the light is given by $F = P/c$. Although the phenomenon can be explained fully in terms of electromagnetic theory, we can also appeal to the simplicity of the photon picture to explain light forces. If the instructor desires he or she can keep this description entirely from a classical electromagnetic perspective without invoking photons. However, so many optical phenomena are explained by electromagnetism that not taking the chance to talk about photons can be a missed opportunity. We must not fall prey to oversimplifying the photon as a spatially confined particle, as the quantum mechanical description is more sophisticated and rich.

It is well accepted that light is composed of quanta or photons of energy $E = hc/\lambda$ and momentum $p = E/c$. The momentum of a photon is very small compared to the momentum of macroscopic objects. For example, a 500-nm photon traveling in vacuum has a momentum $p = 1.3 \times 10^{-27}$ kg m s^{-1}. This is small even compared to the momentum of a single atom moving at thermal velocities. However, a light beam contains a large number of photons. A beam of 500-nm light with a power of 1 mW carries $N = P/E = 2.5 \times 10^{15}$ photons per second. When such a beam of light is absorbed by an opaque object, the object experiences an average force $F = Np = 3.3$ pN. This is a small force compared to macroscopic forces. However, it is larger than the weight of common microscopic objects. For example, a cube of size 5 μm and density 10^3 kg/m^3 has a mass of 125 pg and weight of 1.2 pN. Thus, at this microscopic scale light can exert forces that can significantly affect the dynamics of an object.

An optical tweezer is a microscope designed to send an intense beam of light from a laser to the sample being observed on the microscope slide. Objects are normally immersed in a liquid medium. Thus the force of light acting on a fully absorptive particle is $F = Nnp$, where n is the index of refraction of the medium. Our model object, a fully absorptive cube, is hardly realistic. Microscopic objects may have any shape and may reflect and refract the light. A more realistic object is a semi-transparent sphere. The force that light exerts on a latex sphere of 5-μm in diameter is only a fraction of the value that we calculated for a fully absorptive object. Ashkin studied this case and another more interesting situation: the forces due to a converging beam of light [6]. He found the very interesting result that the light focused towards spherical objects displaced from the center of the focal spot received a momentum recoil force toward focal point of the light. When the size of the object is larger than the wavelength of the light we can explain the force simply in terms of the recoil kicks that light exerts on the object. Thus, focused light exerts a trapping force on a spherical object. Ashkin showed that the maximum trapping force can be expressed as

$$F = QnP/c, \qquad (2)$$

where Q is a parameter that depends on the geometry. Typical values of Q range between 0.01 and 0.5 [6-8]. Thus, trapping forces of the order of a few pN are very feasible [7]. This allows three-dimensional trapping of latex spheres of a few micrometers in diameter with not much difficulty.

2.1 Angular Momentum

A light beam can have two types of angular momentum. Spin angular momentum is due to the polarization of the light. It is specified by the parameter s, where $s = \pm 1$ for circular polarization, $s = 0$ for linear polarization, and $0 < |s| < 1$ for all other states of elliptical polarization. Orbital angular momentum is present in wave-fronts with helical shape. In particular, Laguerre-Gauss beams are a class of beams with wave fronts with ℓ-intertwined helices. The orbital angular momentum of these beams is proportional to ℓ [1]. Figure 1 shows the wave-front of the Laguerre-Gauss beam with $\ell = 1$. This beam has a characteristic "doughnut" profile owing to a phase that depends on

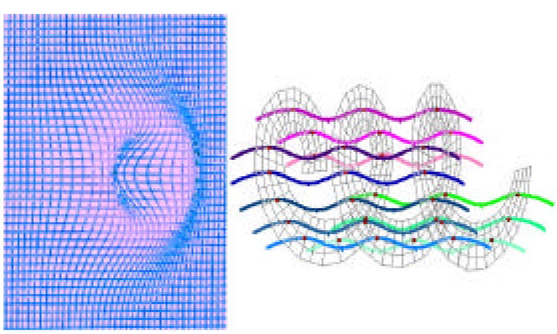

Fig. 1 A drawing showing on the left the intensity profile of a Laguerre-Gauss beam, and on the right, the helical wave front of the lowest order mode carrying orbital angular momentum.

the transverse angular coordinate. These types of beams can be introduced in an optical course as part of a treatment of Gaussian beams [5].

The angular momentum density of the light is given in terms of the linear momentum by

$$\boldsymbol{j} = \boldsymbol{r} \times \boldsymbol{p}. \tag{3}$$

The beam has angular momentum if it possesses an azimuthal component of the linear momentum p_f.. The component of the angular momentum density along the propagation direction z is then $j_z = rp_f$ given by [9]

$$j_z = e_0 w \left(\ell |u|^2 - \frac{1}{2} s r \frac{\partial |u|^2}{\partial r} \right), \tag{4}$$

where w is the angular frequency of the light and u is a complex scalar function proportional to the electric field amplitude. It is interesting to note that for paraxial Gaussian beams the angular momentum has two independent contributions. The first one depends on ℓ and is the orbital angular momentum of the light. Notice that it depends on the square of the field amplitude, which means that the angular momentum is provided by the field of the wave-front. It is also provided by the amount of tilt of the wave-front, which is proportional to ℓ. The second term in Eq. (4) corresponds to the spin angular momentum. Thus a linearly polarized beam has no spin angular momentum, while right (s = +1) or left (s = -1) circularly polarized light have the largest magnitude of spin angular momentum. Note also that the spin angular momentum depends on the gradient of the field, so an infinite plane wave carries no spin angular momentum [9].

It is also interesting to note that the total angular momentum of the beam J_z divided by the total energy of the beam W yields [9]

$$\frac{J_z}{W} = \frac{\ell + s}{w}. \tag{5}$$

One photon would thus carry an angular momentum

$$J = \ell\hbar + s\hbar . \tag{6}$$

This result has prompted numerous studies of the angular momentum of single photons [4]. It also underscores how the effective angular momentum of a beam of light can be increased by using helical beams with high values of ℓ [10].

3. Experimental Demonstrations with Optical Tweezers

The optical tweezer is a laboratory tool that can be illustrative for demonstrating the momentum of light. Manipulating objects with light is so far removed from our everyday life that this experience can be quite fascinating as well. Optical tweezers are excellent for qualitative demonstrations. Quantitative experiences are difficult due to many experimental parameters that are hard to obtain accurately, such as friction with surfaces, intensity distribution of the light, etc. Optical tweezers are relatively easy to set up. A detailed description of many aspects of this device for use in undergraduate laboratories has been given before [7]. Here we describe the details of our setup, which is slightly different. On the left side of Fig. 2 we show a schematic of the apparatus. Key ingredients are a laser, a 100x microscope objective and a camera. The inverted configuration is the most desirable one because it allows easy trapping in the longitudinal direction.

A picture of the apparatus is shown on the right side of Fig. 2. The laser that we used was an argon-ion laser operating at 514.5 nm, with a maximum power of about 100 mW. Trapping can be attained with much lower power, but the extra power helps when setting up the optical tweezer for the first time. High power levels are now easily

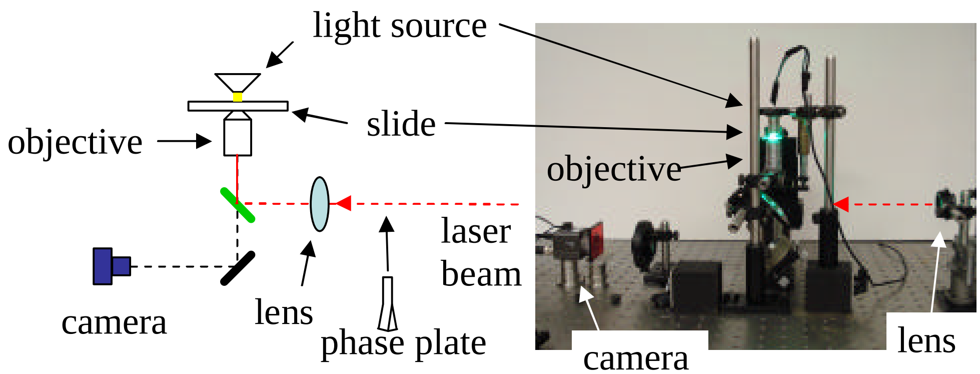

Fig. 2 Schematic of an optical tweezer. It is an inverted microscope with a 100x objective and arranged so a laser beam is inserted to be focused at the sample on the slide.

reached by other smaller lasers, such as diode-pumped solid state and diode lasers. We use a bright light emitting diode (LED) with a 10x microscope objective as a compact light source. The sample consists of polystyrene spheres of a few micrometers in diameter immersed in water. The sample is contained in a cell formed by a microscope slide, a layer of paraffin and a cover-slip.

3.1 Linear Momentum Demonstrations.

The trapping forces can be obtained by measuring the terminal velocity of the trapped sphere and using the viscous drag force

$$F = 6\, p\, h\, a\, v, \tag{7}$$

where h is the viscosity ($h_{water} = 10^{-3}$ Pl), a is the radius of the sphere and v its velocity. For a 5-µm sphere moving at a velocity of 5 µm/s the drag force is 0.24 pN. A few qualitative examples of trapping are shown in Fig. 3. In the first row, frames (a, b, c) show transverse control: as the sample slide is moved one can see that the trapped sphere (5 µm in diameter) remains in place while the background spheres move to the right. Maximum speeds of about 60 µm/s with this setup yield a trapping force of about 3 pN and a trapping Q (Eq. 2) of about 0.01. Frames (d, e, f) show longitudinal control: as the slide is moved up the trapped sphere remains in place at the same focus. The focusing of the spheres in the background changes as they move in and out of the focal plane of the camera. This type of demonstration is straight forward to perform.

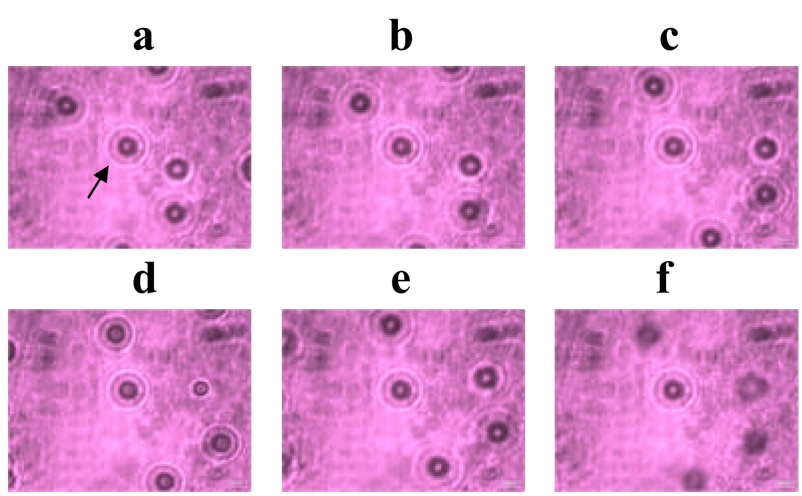

Fig. 3 Images of objects in an optical tweezer showing transverse (frames a-c) and longitudinal trapping (frames d-f). The object singled out by the arrow is the trapped 5-µm sphere.

3.2 Angular Momentum Demonstrations

If the light carries angular momentum it can rotate the trapped object via momentum exchange. The torque produced by the optical beam can be related to the rotational frequency of the rotating object immersed in a viscous medium. When the object is a sphere the torque is given by [11]

$$t = 8\; p\; h\; a^3\, \omega, \tag{8}$$

where ω is the angular frequency.

To rotate objects via the spin angular momentum the light beam needs to be circularly polarized and the sample objects need to be either fully absorptive [12] or birefringent [13]. The latter has interesting physics: if the birefringent particle acts as a quarter-wave plate it can take spin angular momentum from a circularly polarized beam. This experiment was recently reported as an undergraduate laboratory [13]. We have been able to reproduce the experiments of Ref. [13] with not much difficulty. We used crushed calcite crystals immersed in water and put a quarter-wave plate in the path of the laser beam to change its linear polarization to circular.

Inexpensive demonstrations of transfer of orbital angular momentum are difficult to perform because the inexpensive methods to produce beams carrying orbital angular momentum use inefficient binary forked gratings [5]. Efficient gratings in the form of phase holograms used in the early demonstrations [3] are not easy to make. An expensive alternative that is very popular today is to use of spatial light modulators [10]. Spiral phase plates are starting to become available, but in most cases they have to be special ordered.

In an effort to try a new inexpensive method we followed the recent suggestion of making a phase plate from a wedged piece of Plexiglas [14]. We made a cut on a 1-mm thick square piece of Plexiglas (5-cm on the side), wedged the material at the cut, and passed the light through the wedged plate centered at the end of the cut, where the dislocation starts. Figure 4(a) shows a drawing of the wedged plate. Figure 4(b) shows an image of the beam after passing through the phase plate at a maximum wedge angle of about 13°. In order to diagnose the phase dislocation carried by the beam we sent the laser beam through a Mach-Zehnder interferometer, with the phase plate placed in one of the arms. We then imaged the resulting interference pattern. Figure 4(c) shows an image of the interference pattern. By the spiral shape of the pattern it is clear that the beam has a helical wave-front. From this and other patterns we estimate that the beam has an ℓ-value of between 4 and 5. From the shape of the beam we also gather that the value of ℓ is probably not an integer. As reported earlier, the helicity of the beam could be reduced by decreasing the wedge angle [14].

The frames on Fig. 5 show a demonstration of transfer of orbital angular momentum to a 10 μm sphere. The frames are separated by a time interval of about 30 s. The sphere was partially absorptive so the momentum transfer was not very efficient. We estimated a torque of 4 aN-m.

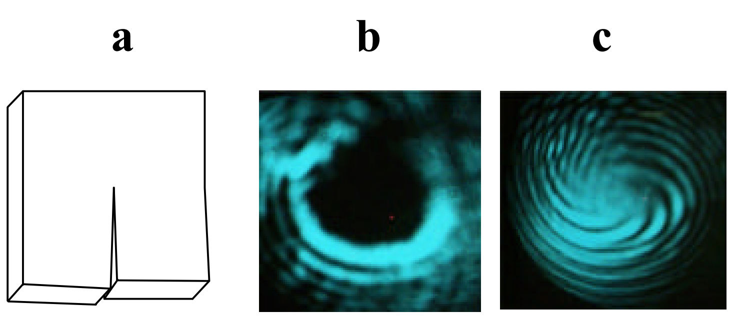

Fig. 4 Images related to the phase plate. Frame (a) shows a sketch of the wedged phase plate. Frame (b) shows a laser beam profile after passing the phase plate. Frame (c) shows an interference pattern of the beam in (b) with a portion of the beam that did not go through the phase plate.

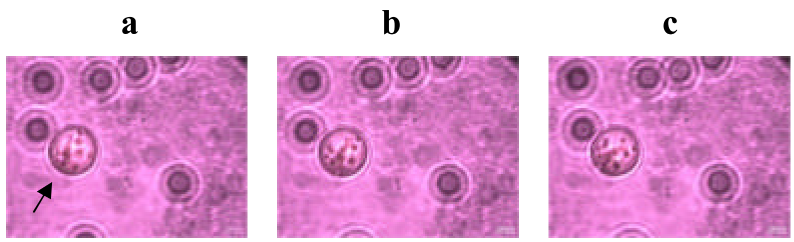

Fig. 5 Demonstration of transfer of orbital angular momentum using a phase plate. The sphere singled out by the arrow is the one trapped and rotated.

4. Conclusions

Fifteen years ago a new form of angular momentum of light arising from the spatial mode of a light beam was discovered. This new form of angular momentum, called orbital angular momentum, has started new lines of research and found numerous applications. The fundamental character of orbital angular momentum demands that it be incorporated in optics instruction, even at the introductory level. Unfortunately modern textbooks have not yet incorporated these concepts. Following the lead of recent article [5], here we present ways in which the concept can be introduced. In addition, we present inexpensive undergraduate-level laboratory demonstrations of transfer of linear and angular momentum.

5. Acknowledgments

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IV.

Understanding the characteristics of gain saturation for homogeneously broadened laser medium from the point of view of the bandwidth

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Abstract: It is very important to understand the characteristics of gain saturation for homogeneously broadened laser medium. Assuming a Lorentzian lineshape function with a linewidth of $\Delta\nu_{H,}$ we have derived the analytical functions of the gain coefficient under three different conditions: 1) a small and 2) a large signal incident on the medium respectively, and 3) a small signal accompanied by a large signal simultaneously incident on the medium. We have found that the bandwidth $\Delta\nu$ of the gain coefficient is equal to the linewidth $\Delta\nu_H$ for condition 1) and 3) while it is $\Delta\nu = \sqrt{1 + I_{\nu_1} / I_s}\Delta\nu_H$ for condition 2). Here, I_{ν_1} and I_s are the intensity of the large signal and the saturation intensity at the center frequency ν_0, respectively. The reasons are also presented for such results. For condition 2), gain saturation effect is strongly dependent on the frequency of the large signal: the more the frequency deviates from the center frequency, the weaker the gain saturation effect. This results an increase of the bandwidth. For condition 3), the intensity of the large signal only changes the distribution of populations on the upper and lower energy levels. Hence, the shape of the gain coefficient does not change with the gain reduction of the small signal, thus, its bandwidth remains the same.

OCIS codes: (140.3430) laser theory, 000.2060 Education

1. Introduction

When populations between two energy levels of an atom are inverted, the medium can act as an amplifier. Therefore, as an optical signal passes through it, the signal intensity I_{ν_1} grows more or less exponentially with distance along the length of the amplifier. However, when the signal intensity increases to a certain value, I_s, the population difference and hence the gain coefficient in the laser medium decreases[1]. This behavior is often referred to as gain saturation. Where I_s is the saturation intensity at center frequency ν_0.

Gain saturation is the primary mechanism that determines the power level at which a laser will oscillate. When a laser oscillator begins to oscillate, the oscillation amplitude grows first until the intensity inside the cavity is sufficient to saturate down the laser gain. The steady-state oscillation then occurs when the saturated laser gain becomes just equal to the total cavity losses, so that the net round-trip gain is exactly unity.

The saturation behavior is different for homogeneously and inhomogeneously broadened laser media. In this paper, we will analyze the characteristics of gain saturation for homogeneously broadened system from the point of view of the bandwidth.

2. Analysis

The radiation emitted by the spontaneous transition from energy level 2 to level 1 in a medium is not strictly monochromatic (that is, of one frequency) but occupies a finite frequency bandwidth. The function describing the distribution of emitted intensity versus the frequency ν is referred to as the lineshape function $\tilde{g}(\nu, \nu_0)$ (of the transition 2→1) and its arbitrary scale factor is usually chosen so that the function is normalized according to

$$\int_{-\infty}^{+\infty} \tilde{g}(\nu,\nu_0)d\nu = 1. \quad (1)$$

The separation $\Delta\nu$ between the two frequencies at which the lineshape function is down to half its peak value is referred to as the linewidth[2].

Assuming the Lorentzian lineshape for a homogeneous broadening laser medium, the lineshape function is given by[3]

$$\tilde{g}_H(\nu,\nu_0) = \frac{\Delta\nu_H}{2\pi}\frac{1}{(\nu-\nu_0)^2 + (\frac{\Delta\nu_H}{2})^2}, \quad (2)$$

where $\Delta\nu_H$ is the linewidth, ν_0 is the center frequency of transition $2\rightarrow1$, i.e., $\nu_0=(E_2- E_1)/h$.

Here a laser medium is considered, in which two energy levels, E_2 and E_1 are inverted by feeding in energy. Based on rate equations in the steady-state, when a weak signal with frequency of ν_1 incident on the laser medium, its gain coefficient is given by[4]

$$g_H^0(\nu_1) = g_H^0(\nu_0)\frac{(\frac{\Delta\nu_H}{2})^2}{(\nu_1-\nu_0)^2 + (\frac{\Delta\nu_H}{2})^2}. \quad (3)$$

Note that the bandwidth of the curve $g_H^0(\nu_1) - \nu_1$ is equal to $\Delta\nu_H$.

When a strong signal with intensity of I_{ν_1} incident on the laser medium, its gain coefficient is expressed as[5]

$$g_H(\nu_1,I_{\nu_1}) = g_H^0(\nu_0)\frac{(\frac{\Delta\nu_H}{2})^2}{(\nu_1-\nu_0)^2 + (\frac{\Delta\nu_H}{2})^2[1+\frac{I_{\nu_1}}{I_s}]}, \quad (4)$$

where $g_H^0(\nu_0)$ is the small-signal gain coefficient at frequency ν_0. Note that the gain is reduced, that is, saturates as the strength of the amplified signal increase. The bandwidth can be expresses as

$$\Delta\nu = \sqrt{1+\frac{I_{\nu_1}}{I_s}}\Delta\nu_H. \quad (5)$$

Note that the bandwidth of this large signal is wider than that of the weak signal. In order to explain this phenomenon, we define the function $f(\nu_1)$ as

$$f(\nu_1) = \frac{g_H(\nu_1,I_{\nu_1})}{g_H^0(\nu_1)} = \frac{(\nu_1-\nu_0)^2 + (\frac{\Delta\nu_H}{2})^2}{(\nu_1-\nu_0)^2 + (\frac{\Delta\nu_H}{2})^2[1+\frac{I_{\nu_1}}{I_s}]}, \quad (6)$$

It describes the degree that large-signal gain drops from its initial or small-signal value $g_H^0(\nu_1)$, as shown in Figure 1[6]. The reduction depends on the frequency of the input signal; hence the gain saturation effect is a function of the frequency. When the frequency of incident signal equals to the center frequency, the saturation effect is the strongest, with the greatest drop of the gain coefficient. The more the frequency deviates from the center frequency, the weaker the gain saturation effect. Therefore the large-signal lineshape is flattening down of the gain at the middle of the line, resulting in a larger bandwidth.

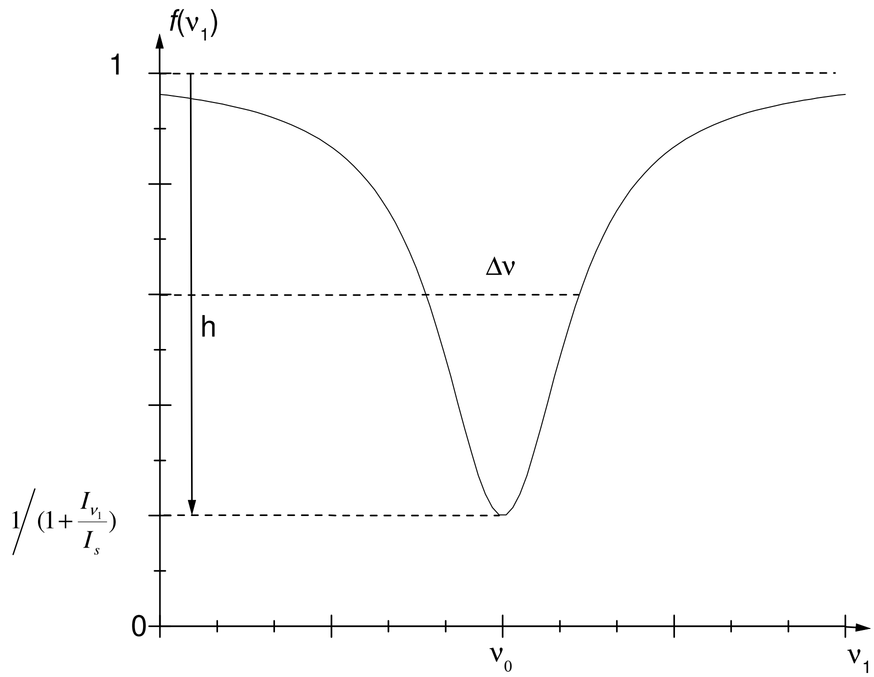

Fig.1 The ratio of the large-signal gain to the small-signal gain versus the input frequency

If a large signal with frequency of ν_1, intensity of I_{ν_1} and a small signal with frequency of ν are simultaneously incident on the medium, the gain coefficient for the small signal can be expressed as [7]

$$g_H(\nu, I_{\nu_1}) = g_H^0(\nu)\frac{(\nu_1-\nu_0)^2+(\frac{\Delta\nu_H}{2})^2}{(\nu_1-\nu_0)^2+(\frac{\Delta\nu_H}{2})^2[1+\frac{I_{\nu_1}}{I_s}]}. \quad (7)$$

The bandwidth of the gain $g_H(\nu, I_{\nu_1})$ is also equal to $\Delta\nu_H$.

In order to explain this, we rewrite the Equation 4 as

$$g_H(\nu_1, I_{\nu_1}) = g_H^0(\nu_1)\frac{(\nu_1-\nu_0)^2+(\frac{\Delta\nu_H}{2})^2}{(\nu_1-\nu_0)^2+(\frac{\Delta\nu_H}{2})^2[1+\frac{I_{\nu_1}}{I_s}]}. \quad (8)$$

In contrast to Eq. 7, we note that the large signal saturates not only its own gain, but also the gain at other frequencies. When the atomic system is used as laser medium, the gain decreases with increasing field intensity. This is because all atoms have identical line shape peaked at the same frequency, thus are indistinguishable, in a homogenous broadening system. Each atom contributes to the gain at all frequencies and the reduction of gain is uniform across the whole gain profile. The intensity of the large signal only changes the distribution of populations on the upper and lower energy levels. Hence, the shape of the gain coefficient does not change with the gain reduction of the small signal, thus, its bandwidth remains the same as illustrated in Figure 2.

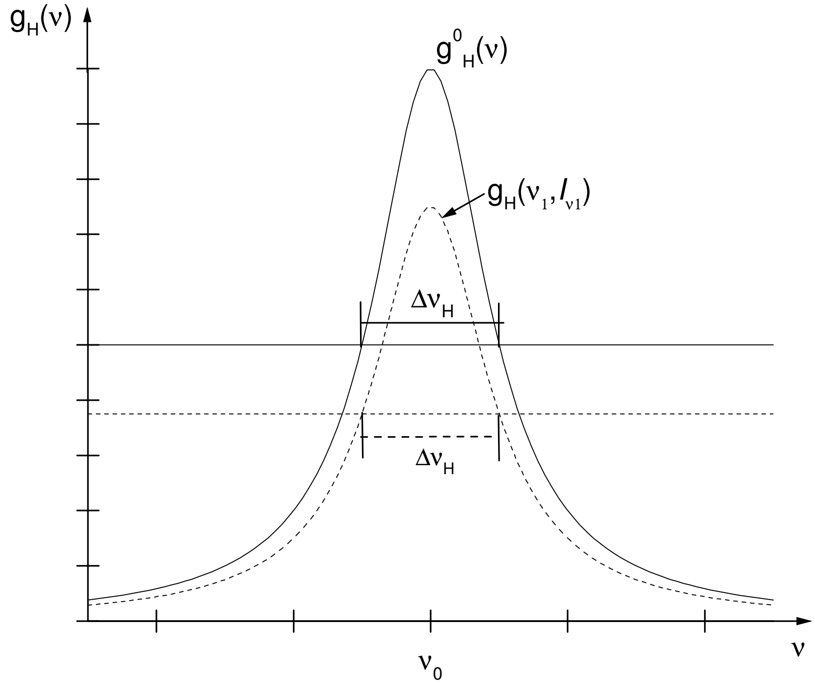

Fig.2 The variation of the bandwidth of the small-signal gain when the small signal accompanied by a large signal simultaneously incident on the medium

3. Conclusion

We have gained a deeper understanding of the gain saturation effect by analyzing the gain bandwidth of the homogeneous broadening laser medium. When a large signal passes through the inverted laser medium, it not only saturates its own gain, but also saturates the gain at other frequencies. Furthermore, the gain saturation effect is strongly dependent on the frequency of the large signal: the more the frequency deviates from the center frequency, the weaker the gain saturation effect. It is also helpful to understand in a homogeneously broadened laser, oscillation only occurs at one longitudinal mode frequency.

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Back To Index

Draft-1 (July 30, 2007)

A proposal to organize

i^2-EPR

(International Institute for Exploring Physics with Reality)

How can we promote *discovery* of actual *realities* in nature driven by *cosmic logic* rather than staying limited to *invention* of realities that are esthetically pleasing to our *human logic*?

by

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Executive Summary

Mission

•**1. Research:** Our objective is to discover, visualize, understand and some times gainfully emulate (to advance our technologies) the real physical processes behind diverse interactions that are at the root of incessant cosmic and biospheric evolutions. Our focus is on discovering actual realities in nature driven by cosmic logic rather than inventing the ones that are aesthetically pleasing to our human logic. Our responsibility is to facilitate continuous evolution in our epistemology of modeling natural phenomena simultaneously exploiting the current tools of reductionism and emergence-ism that are helping us to discover rules of interactions between stable but simple (some times irreducible) entities and between complex assemblies that emerge from simpler entities.

• **2. Education:** Promote an educational philosophy that encourages the students to persistently enquire to visualize and understand the processes behind all interactions in nature while being conscious of their scientific epistemology. Everything that we "see" is nothing but a creative interpretation of the chain of transformations experienced by the sensor (or assemblies of sensors) that we use to observe nature. Science has so far formulated an array of working rules to model nature none of which can be declared as inviolable laws as yet. We have generated several "solved" jig-saw-puzzles which are not yet unifiable into one coherent puzzle to map the indivisible cosmic system.

• **3. Outreach:** Organize local and international seminars and conferences disseminating (i) the results of research, and (ii) the evolving & effective model of research (scientific epistemology).

• **4. Economic wellbeing:** Disseminate new technology innovation potentials to attract enhanced economic support through proper local channels.

Structure

• **1. A Virtual Global Institute:** A limited number of agreeable institutions from several countries will organize their own local centers (i-EPR) at their own cost, congruent with their institutional mission and local governance. The local centers will adhere to the core vision and mission of the i-square-EPR constituting representatives from the local centers.

• **2. Organizational principles:** The interactions between the local centers should be driven by (i) symbiosis, (ii) synergy and (iii) food-chain (iv) eco-driven (v) competitions, which are behind the successful and sustainable evolution of our organic biospheric system.

Approach

• Nature being a creative **system engineer** we should be humble but creative ***reverse engineers*** to extract the ***working rules*** behind natural ***processes*** in nature and aid to technology advancements that are congruent with our sustainable evolution, for we need a long long time to understand the ***purpose of the cosmic evolution*** and our role in it.

Proposer's demonstrated organizational successes

Acknowledgements

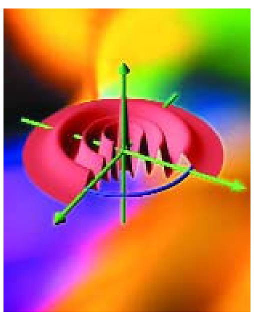
1. OSA & SPIE – for providing the platforms to raise the following question even though the main stream physics community believes that it is no longer an issue!

2. NSG & OTRR – for financial sponsorship for related publication and conferences.

The Nature of Light: What Are Photons?

Recent references

2003

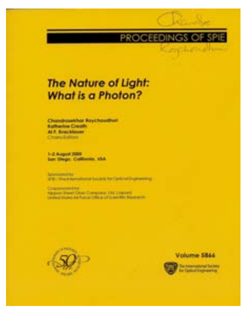


Optics and Photonics News

Special Issue; October 2003

Guest Editors:
C. Roychoudhuri and R. Roy

2005



SPIE Proc. Vol.5866

Conference Editors:
C. Roychoudhuri, K. Creath & A. Kracklauer

2007

The Nature of Light: What is a Photon? - II

Part of the SPIE International

26-30 August 2007 • San Diego

Conference Chairs: **Chandra Roychoudhuri**, Univ. of Connecticut; **Al F. Kracklauer**, Consultant (Germany) **Katherine Creath**, Optineering and Univ. of Arizona

SPIE Proc. 6664

Background & Justification

Why seek reality?

Manifest and emergent material universe is real and causal. It is subtle, complex and *elusive*, but it is neither mystical nor *an a-causal illusion* !

We need to understand the real physical processes behind the emergence of both the irreducibly stable elementary particles as well as the most complex systems out of these elementary particles. Then we can emulate the processes to assure our sustainable evolution, which will give us time to understand the meaning & purpose of the universe and our role in it !

Photons do not have any colors! Neither are the water droplets colored inside the fountain ! [Photo taken from the web.]

If you go inside the fountain, you will not find the rainbow.

Yet, it is a reality in nature & not an illusion,. It can be observed only by color-interpreting frequency sensitive sensors and only at the focal plane of an imaging system looking at the fountain and only when the Sun is behind the imaging sensor (observer).

There is no real rainbow inside the fountain. That is why nobody goes to dig out the “pot of gold at the end of the rainbow”.

The emergence of the mystical beauty of a rainbows is elusive but causal, and definitely not an illusion! Understanding the processes behind its formation help us understand the local weather conditions, besides enjoying its esthetic beauty, while advancing the optical sciences by validating a good number of optical principles through a single emergent phenomenon!

Why another research organization?

• **Deviation from Reality:** While technologies have been advancing successfully, the fundamental understanding of actual processes in nature has not only stalled for almost 50 years, it has seriously deviated into justifying mysticism by promoting non-causality, non-locality, teleportation, multi-universe, etc., which are hard to experimentally invalidate.

• **"Nobody understands Quantum Mechanics" even though it works!:** If nobody understands QM even after 82 years' of developing the formalism and its successful predictions, then we ought to acknowledge that there is some serious flaw with our epistemology to map or understand nature. Interpretation of QM and its successes to predict observations are not mutually congruent in seeking actual reality in nature. Classical physics, by being faithfully congruent to seeking reality in nature, gave birth to QM. But QM has failed to give birth to its progeny due its assumption that it is "complete".

• **From Geocentric to Homocentric:** After overriding Ptolemy's Geocentric vision, we are back on imposing Homocentric vision on all the enquiring minds by re-directing them to model nature as dictated by our human mathematical logic, instead of seeking actual reality. Being stifled by the quantum philosophy, we are emulating the 'invention culture' from our technological successes and imposing that on to physics. We are now deeply engaged in inventing realities rather than discovering the actual realities behind nature's evolutionary processes.

• **Cosmic vs. Human logic & CC-LC-ER epistemology :** Our cumulative experience indicates that nature's evolutionary processes consist of logical patterns & organizations. Although only partial, our consistent successes have been based on applying limited human logic to reach out to unknown cosmic logic. Our efforts to refine and elevate human logic to possible cosmic logic has been advancing based on the model of CC-LC – pro-actively extend *Conceptual Continuity* among as many diverse natural phenomena as possible by imposing *Logical Congruence*. Our *belief* in this CC-LC epistemology and intuitive *faith* in one continuous and logically functioning universe have been paying off enormously. Current physics has been developed based essentially on reductionism, matter into elementary particles and radiations into photons. We have neglected to incorporate formalism that articulates emergence of properties and rules of interactions in and between complex systems that constitute our regular observable universe. We now need to add another iterative feed back loop of *R*eductionism and *E*mergence-ism, CC-LC-ER epistemology, which should enhance the unifiability of our separate models or maps of nature.

• "**Did the tree fall?":** We now know that all advanced specie contain large assembly of diverse symbiotic and some non-symbiotic organisms. Our 10 trillion-cell human body carries 100 trillion diverse symbiotic microbes. To what extent our human thought processes are influenced by the convergent-divergent self interests of these two groups of co-habiting cells? In the absence of any human being in a forest, the fallen trees are properly taken care of by trillions of local microbes and more "advanced" organisms! Homocentric philosophies are counter to our healthy evolution.

• **Conscious Epistemology:** Do we really understand how our thinking process evolves? Can we identify & understand how all the factors that influence our conclusions after collating diverse observations? Epistemological awareness is crucial for us.

Some organized global minorities are restless to bring changes!

They are catalyzing changes in scientific epistemology!

• **Status-quo of the main stream:** Existing basic (working) theories must not be challenged! All the main stream institutions and journals around the globe pro-actively rejects that progress in physics is being stifled by accepting that all the current theories are correct as they are within their respective domains. They agree that the universe is one continuum. Yet they ignore the message of failure over many decades of intensive attempts to unify the separate little maps ("solved" jig-saw-puzzles) into one coherent structure.

• **NPA:** Founded in 1994, this group has just finished their 12^{th} conference at the University of Connecticut. NPA nurtures the enquiring minds of their members who are seeking reality in nature

• **"Nature of Light: What Are Photons?":** In 2003 we initiated this organized questioning about photon, first, by publishing a special issue on the topic through the OSA-OPN (Optics & Photonics News) issue of October. Then, in 2005 we organized an international conference on the same topic under the auspices of the SPIE Annual Conference with explicit intention of nurturing out-of-box thinking about photon and their consequences in physics and engineering. It has now become a well-accepted biannual conference; the 2^{nd} conference is about to be held in San Diego during Aug.26-27.

• **Individual well-known authors challenging the status-quo:** The following recent books are beginning to draw attention to the lack of progress in physics: (i) Roger Penrose, "The Road to Reality" (2004) (ii) Nobel Laureate Robert Laughlin, "A Different Universe" (2005), (iii) Lee Smolin, "The trouble with Physics" (2006).

• **Individual web sites:** Many individuals, rejected and disenchanted by the main stream academia, have opened their personal websites explaining their alternate opinions about all the currently accepted physics theories.

• **Role of i-square-EPR:** We hope to synergize the energy of all these brave souls by facilitating their collaborative interactions through a virtual global institution respecting individual independence & freedom..

Proposed philosophy behind i^2-EPR

• **Vision:** The grand vision is to nurture the emergence of a global culture that accepts the responsibility of pro-active conscious designing of our future as the basis for our sustainable evolution within the biosphere.

The scientific vision is to re-establish physics as a discipline that is firmly engaged to discover the objective reality of nature as it happens, rather than inventing mathematically self-congruent model of homocentric reality and impose that on the nature. The idea is to continuously explore visualize and imagine the actual ***processes*** that are going on behind all the various interactions leading to incessant evolution of the biospheric and the cosmo-spheric evolutions.

Pragmatic dimension: Sustainable evolution is the prime desire evident form the genetic coding of all the specie. We need continuous expansion of our knowledge of various organizational structures in nature to develop newer technological tools products and engineering for our well being that are congruent with the rules of interactions in nature. Thus looking at nature as a creative system engineer and behaving ourselves as reverse engineers to emulate nature's ***processes*** is the best successful model for us. Science engineering economics and politics are inseparable social enterprises for our survival.

• **Spiritual dimension:** What are the meaning and ***purpose*** of our lives? Can we control and design our fate? The emergence of the spiritual dimension out of our scientific (reverse engineer) thinking started taking shape as we slowly started to appreciate the ever harmonizing organizations behind diverse processes in nature. We realized the dialectical state of our fate in nature – we are simultaneously the masters of our well being and yet insignificant 'pawn' in the evolutionary scheme of things in the "infinite" cosmos.

• **Approach, the p-cubed methodology:** The ultimate ***purpose*** of the scientific enterprise is to become the best possible creative reverse engineers, extract the organizational rules behind ongoing ***processes*** in nature and then emulate them as beneficial technologies that are congruent with our sustainable evolution, since we need a long long time to understand the real ***purpose*** of the cosmic evolution and our role in it. Nature is our best peer. Sustainable engineering activities will keep us anchored to nature's reality.

All major organized human enterprises must define its “pragmatic guiding star”, an infallible vision

• **Prime directive:** Live and let live. Today we know enough to destroy the biosphere and hence ourselves, and yet we are not knowledgeable enough to model and nurture the biosphere in every scientific detail to assure our co-dependent survival. And we are very far from becoming space-farer en-masse to migrate to another earth-like planet.

• **Nature is a creative system engineer:** Irrespective of our diverse spiritual believes, we have been successfully evolving for millennia in human form as reverse engineers by developing technologies (from discovering fire and rockets to medicine delivering nano particles in blood) by understanding & emulating the working processes and the underlying working rules behind diverse natural phenomena.

• **Science-technology-economy-politics (STEP) and sustainable evolution:** In every step of our evolution from primitive to modern days, STEP functions have always necessarily been and always will be inseparable from each other because the sustainable evolution is our prime directive and embedded in our genes.

• **STEP leads to enquiry based spiritualism, or becomes STEPS:** Healthy spirituality, or the enquiry about meaning, purpose and future vision of life, individualistic or biospheric, evolves through systematic observation of nature’s evolutionary processes. We find the organizational patterns and working rules in them and then use those rules intelligently for our personal evolution congruent with the collective evolution.

• **Like all social enterprises, i-sqaure-EPR will have a focused objective**: It is scientific - keep on mapping nature’s interaction processes with increasingly higher level of integrations of wide ranging natural phenomena. But our “guiding star” is the aspiration to understand the meaning & purpose of the cosmic evolution and our role in it by being a facilitator to sustainable evolution by promoting technology innovations as creative-reverse-engineers!

Proposed structure of i^2-EPR

- **A Virtual Global Institute:** A limited number of agreeable institutions from several countries will organize their own local institutes (i-EPR) at their own cost, congruent with their institutional mission and local governance. All these i-EPR will adhere to the core vision of the i-sqaure-EPR. The international virtual global center, composed of representatives from all the i-EPR's, will have the role of a facilitator. Because funding is local, all the research activities will reside in the local institutes. The international body will only facilitate the coordination of the short- and long-term research programs to be complementary to each other to maximize the collective speed and productivity of all.

- **Organizational principle:** We shall emulate to the best of our knowledge the organizational principles behind the best organically evolving system to our knowledge – the collective evolution of lives in the biosphere. They are driven by (i) symbiosis, (ii) synergy and (iii) food-chain (iv) eco-driven (v) competition. It is not pure "survival of the fittest". The organizational principles must be pro-actively congruent towards empowerment of the local centers and individual researchers and rules must be designed for guiding rather than controlling and stifling activities.

Why virtual and why global?

• **Dichotomy of academic freedom and strangulation:** All important human social enterprises are meant to be organized and managed to maximize the collective benefit to the entire society – empowerment of all by allowing development of knew knowledge and their dissemination. Unfortunately, self-interests of well organized groups have always taken precedence. New knowledge and information are used to maintain the privileged position and the associated benefits. The livelihood (economic survival) depends upon being able to “fit into” the main stream. “Acceptance” and “Group-think” are pragmatism! [See Smolin’s book]. New scientific concepts that can potentially challenge those currently in main stream, can challenge the structural power and access to limited Government funds from those who are in decision making positions including all those who rely on the benefits percolating down from these power positions. Thus, “nobody understands quantum mechanics” is not sufficient reason to challenge the interpretations of quantum mechanics. Teleportation and Quantum Computing are drawing enormous funds!

• **Why Global? Avoid strangulation:** Only properly funded institutions can attract brilliant minds. Academic institutions are still the biggest draw of minds. Thus, a university would be the best place to start such a research institute. Unfortunately, an out-of-box research center based in a single university could face strangulation at birth! A globally distributed organization will have a much higher probability of succeeding in its eventual mission.

• **Why Global? Magnitude and weight of the proposed research problem :** The proposed research problem is enormously important and burdensome. It requires global attention and global participation. Midwifery for the birth of the progeny of Quantum Mechanics (QM) will require intensive attention from many creative and unorthodox scientists just as were required for the birth of QM out of Classical Physics.

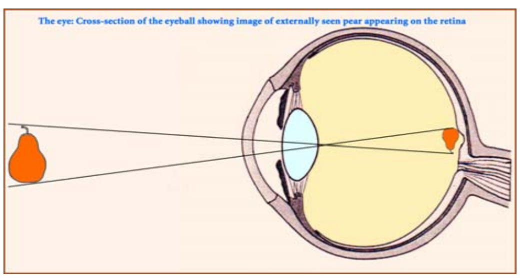
Building the case for CC-LC-ER epistemology for i-square-EPR activities

• **Physics is synonymous with seeking *Conceptual Continuity (CC)* among diverse observed phenomena by iteratively and creatively constructing *Logical Congruence (LC)* among them all to find a higher level of organization leading to coherent maps of nature.**

• **But to understand the structure of particles and the interaction processes behind the observed results to visualize elusive realities, we must integrate *Emergencism* and *Reductionism* to CC-LC-thinking to develop CC-LC-ER epistemology. This will help us understand the inner structures of the interactants and the resultant products) by enquiring and distinguishing for their new *Emergent* properties from those they possess when they are *Reduced* to more fundamental constituent elements. Emergencism and Reductionism are inseparable complementary modes of enquiries.**

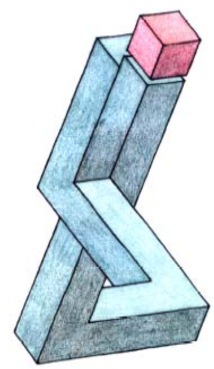
Understanding the subtleties behind observations before applying CC-LC-ER epistemology

Real world is really real if we spend time to find the conceptual continuity amongst our diverse observations by imposing logical congruency through all ! Our lack of fathoming the real processes undergoing in the micro universe may appear elusive, but it does not mean that the real universe is non-causal, non-local and mystical ! Emergence of complex properties can also be logically mapped.



Human neural-nets reconstruct the reality out of the inverted digital image formed on the rods and cones of our retina.

Elusive but real. Choose between young or old woman by differentiating chin vs. nose.



A real illusion. Looks real but impossible to construct in reality.

Personally, I really am not totally objective about the outside universe. I simply cannot be! I “see” what is really functionally important for my survival in the real world with my limited number of sensors. My thinking and interpretations are also colored by my genetic endowment, 100 trillion symbiotic microbes and bacteria, my family and social training and my personal knowledge and ego driven by my own successes and failures! Objectivity of our interpretations have to be refined by repeated application of CC-LC-ER epistemology. [Above pictures are taken from the web.]

Mathematical congruency and visual symmetry & elegance are insufficient guides to extract nature's objective reality

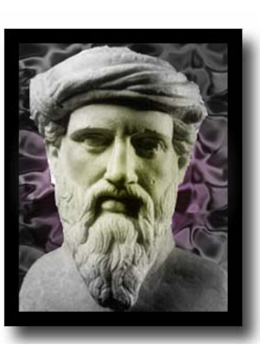
CC-LC-ER epistemology is a critical tool!

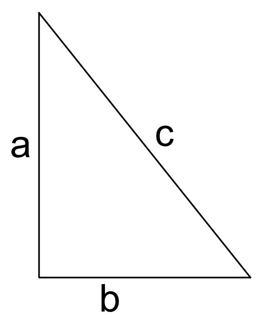
Consider two examples:

1. **Pythagoras' theorem and**
2. **Ptolemy's Geocentric planetary model**

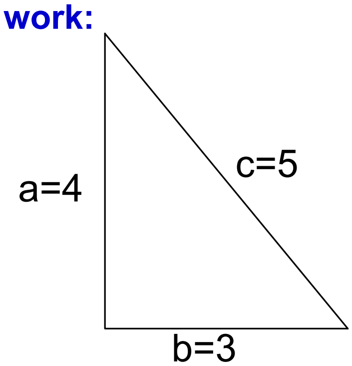
1. Pythagoras' single quadratic relation can be replaced by a pair of linear relations

Consider Pythagoras' theorem





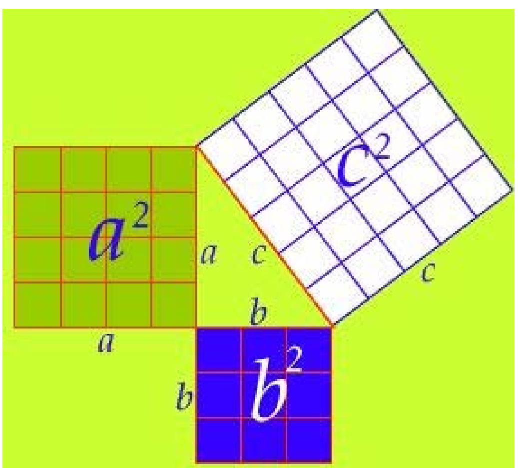
Compare with my modified theorem from the 7th grade home work:



$$c^2 = a^2 + b^2 \quad \textbf{vs.} \quad c = 2a - b \text{ where } \frac{a}{b} = \frac{4}{3}$$

Mathematically they are equivalent to each other !

But, Pythagoras' relation aids the visualization of the logic behind its success. My linear relations work but fail to aid the visualization.



$$c^2 = a^2 + b^2$$

The total number of unit squares on the hypotenuse is exactly equal to the some of those on the other two sides. [The picture is taken from the web.]

My relations do not directly give any insight into the physical reason of correctness.

It just works!

$$c = 2a - b \text{ with } \frac{a}{b} = \frac{4}{3}$$

$$c^2 = 4a^2 + b^2 - 4ab$$

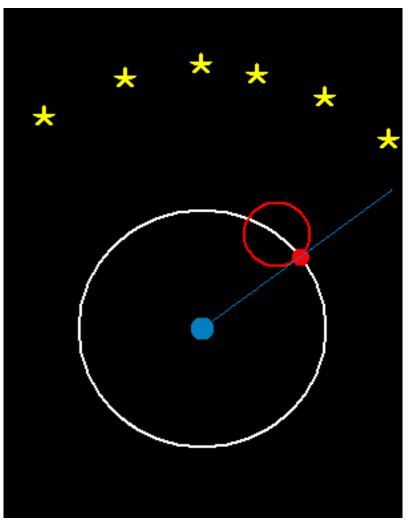
$$= 4a^2 + b^2 - 4a.\frac{3}{4}a$$

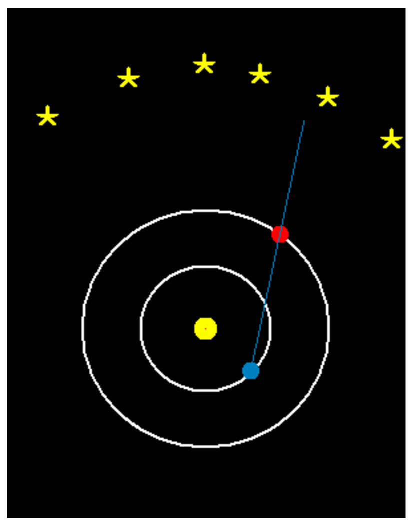
$$c^2 = a^2 + b^2$$

2. Revivability of Ptolemy's Geocentric planetary model !

Even visualization is not enough to guide us into discovering nature's reality

Many different human logic (mathematics) can solve the same problem different ways. Ptolemy's Geocentric planetary model can be successfully updated with nine different "epicycles" for each of the nine planets. This is far fewer "free parameters" than most of the recent "successful" string theories require!





Pictures are from the web.

Ptolemy vs. Copernicus

What is an observation?

It is the *Superposition Effect as Measured (SEM)* between some entities in our experiments.

• **1.** We do not know completely even a single entity, whether an elementary particle or a complex system, in every detail under different conditions of interactions.

• **2.** All sensors (interactants, or detector-detectee) have inherent restrictive rules of engagements with each other, which limit the observables that we can record. A detector is incapable of "reporting" to us everything that it experiences.

• **3.** Thus, we are for ever deprived of complete information regarding any observation even for a very well defined experiments.

• 4. So, science of modeling or mapping nature will always be a "work in progress". We are forced to organize a finite set of observations predictable by an equation that can be logically completed only by incorporating human logic supported hypotheses, some of which may or may not be congruent with the eventual cosmic logic we are seeking to discover.

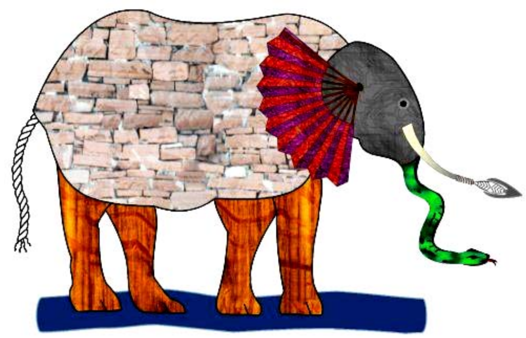
• 5. A logically complete equation is also logically closed to accommodating any radically different logic. If the "successful" equation, like that of Schrödinger's, can accommodate a wide variety of observations, we may suffer from the illusion that it represents a "complete" theory!

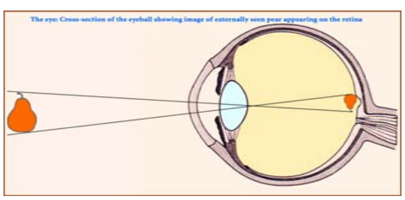
• 6. We are thus forced to accept a dialectical contradiction in mapping nature. We must build a map only for a "local terrain" and even that has to be based on incomplete knowledge of the terrain, while our vision is to create roads to map the entire cosmic forest. Thus, all of our theories are, by definition, provisional and incomplete. Most likely they contain mistaken concepts (hypotheses) and hence cannot be simply slapped together to create one integrated cosmic map (a theory of everything).

• 7. Only choice is to advance iteratively by frequently stepping backward to identify and reject some of the human logic (hypotheses) from individual "solved" maps, which are not convertible to cosmic logic.

• 8. **CC-LC-ER epistemology** is the proposed tool to facilitate this iterative distilling process to steadily convert human logic into the desired cosmic logic allowing the construction of self-congruent bigger maps in multiple steps.

We are still Buddha's blind men who were instructed more than 2500 years ago to diligently employ the CC-LC-ER epistemology to reconstruct the cosmic elephant!





Reminder:

- We don't "see". We are blind. We manipulate & interpret sensory chemical input.
- Barriers to our minds are self imposed, many a times collectively!
- We have found only useful "working rules", not inviolable LAWS!
- Above images are from web.

- Only by demanding conceptual continuity (CC) by imposing logical congruence (LC) among all the observations by all the blind men did they reconstruct the elephant with some semblance to reality, but outer reality only. Emergencism and reductionism (ER) are essential to appreciate the whole living elephant!
- To visualize the processes in the micro world of interactions, we must cultivate the humility to accept that we are literally blind!
- All of our information is what our sensors tell us. Like the blind men, the sensors themselves do not see & experience everything and they are not capable of reporting everything they experience.

Logically dissecting

the observation process

or

the superposition effect as measured (SEM)

SEM provides the foundational information to CC-LC-ER epistemology

Universality of superposition effects as measured (SEM) is at the core of doing physics

- 1. We can scientifically measure only re-producible quantitative ***transformations*** that are experienced by our interactants (or detector-detectee, or sensor-sensee).
- 2. Any transformations in measurable physical parameters requires ***energy exchange*** between the interactants.
- 3. The energy exchange must be guided by a ***force of interaction*** between the interactants and it must be strong enough to facilitate the exchange of energy, which are usually constrained by the characteristic limitations of each interactant.
- 4. All force rules being distance dependent, energy exchange between the Interactants requires that they must experience each other as **locally present or *physically superposed*** entities (experience each other within their sphere of influence).

Evidence of universal **"Superposition effect"** (or causation steps): Interactants must be physically ***superposed*** within the range of their ***interacting force*** that will allow some ***energy exchange*** followed by some ***transformations*** that is measurable for us. Superposition effect is an **active local process**, not a passive mathematical principle ! Mathematical formulation must recognize this **Reality Epistemology.**

Re-visiting superposition effects as measured (SEM) in view of the four force rules that we understand, so far!

1. **Gravitational force (GF):** All cosmic entities, from galaxies, stars, planets, atoms and elementary particles, the entire observable material universes is effectively superposed on each other as far as GF is concerned. GF is weak; its range is very long.

2. **Electromagnetic force (EMF):** Stability of atoms, molecules and their all possible transformations, including their interactions with electromagnetic waves (light, etc.) are all dictated by this force. A dominant part of the biospheric evolution is driven by this force. EMF is relatively stronger than GF, but the range is shorter. The superposition effects due to the EMF from the molecules of two different human bodies are essentially negligible (un-entangled) on a first order analysis.

3. **Weak Nuclear force (WNF):** Radioactivity and related isotopic nuclear transmutations are a byproduct of this force. The range of WNF is of the order of the size of the atomic nuclei. The superposition effects due to two radioactive atomic nuclei within the same bound molecule is negligible within the first order analysis.

4. **Strong nuclear force (SNF):** Our slow physical evolution relies on the stability of an array of nuclei held together by this SNF, built into stable atoms and molecules by the EMF and held on the surface of the Earth under the atmosphere by the GF. The superposition effects due to two atomic nuclei within the same bound molecule is negligible within the first order analysis.

While the emergent observable material and light based universe may generically appear as NON-LOCAL, a careful analysis of SEM tells us that all measured phenomena are necessarily LOCAL since all forces of interactions have a finite physical range ! Entanglement is operative within the operating range of the force.

An example of conceptual integrative power of CC-LC-ER epistemology

We are expecting major new developments based on this over-arching understanding:

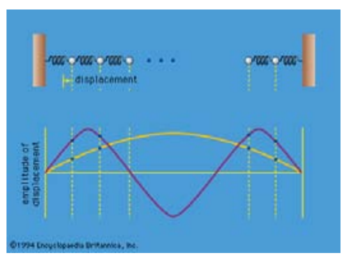
There is a preponderance and universality of harmonic undulations (internal and external),

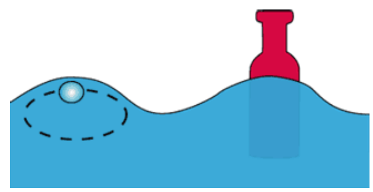
however,

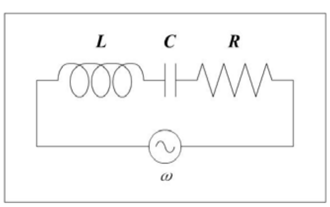
only a rare few constitute physically propagating waves !

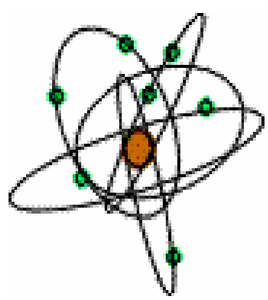
Our universe is dominated by various harmonic undulators, but very few of them obey strict wave equation!

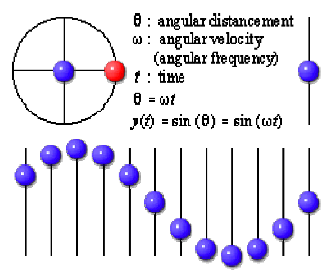
Everything observable in this universe are built out of a few stable elementary particles, which are all emergent in the cosmic medium with some intrinsic internal harmonic undulation or spin. Even the complex macro systems like the Solar system and the galaxies have their own characteristic internal harmonic undulations. Even human technology is replete with mechanical and electrical harmonic undulators. Only rare few harmonic undulations are waves in reality !











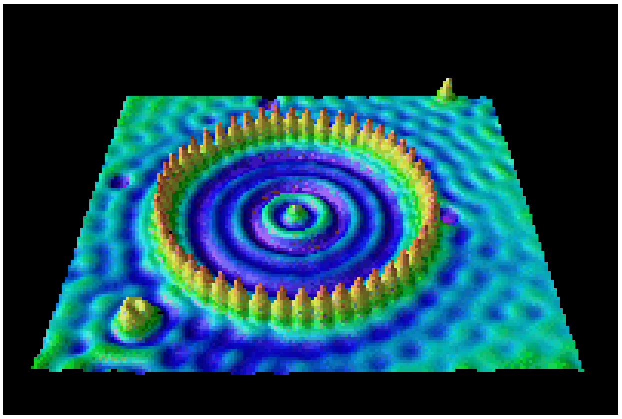
$\sin 2\pi\nu t$ or $\cos 2\pi\nu t$; frequency ν is inverse of the harmonic period τ

We are really no longer fundamentally limited by Heisenberg's Uncertainty Relation (HUR)

HUR is essentially a corollary of Fourier theorem

And the "Mother" theorem has never been elevated to the status of a principle of Physics !

And, now our visualization capability has reached the atomic domain that was un-imaginable during Heisenberg's time!



Scanning tunneling micrograph of 48 iron atoms arranged in a circle by picking and placing one atom at a time

1. By ignoring HUR, while the core achievements of QM do not suffer at all, the QM philosophy can get rid of all the unnecessarily assigned mysticisms like non-causality, non-locality, teleportation, etc. in measurements that defies our **SEM** process as we have defined.
2. Does the structure of Schrödinger's "wave equation" really represent a propagating wave? A propagating wave require second derivative of time equated to second derivative of space coordinate.
3. Are elementary particles and atoms really non-local and "dispersive" probability waves? Then how could we manipulate Angstrom size individual atoms using modern nano-tipped tools?
4. Etc., etc.

Another example of application of CC-LC-ER epistemology in compliance with SEM:

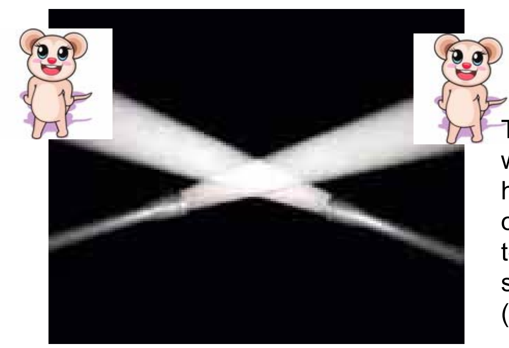
We discover that we have been missing something rather fundamentally simple for millennia!

- **Light beams by themselves cannot produce interference effects !**
- **Alternately speaking, the superposition effects as measured (SEM) due to light beams can become observable only when some interacting material dipoles are simultaneously stimulated by all the superposed beams on them.**

Interpretational and technological implications are enormous !

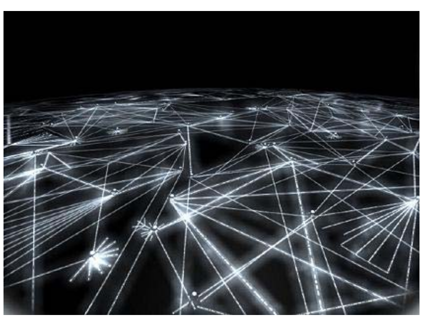
Examples of absence of superposition effects from light beams in the absence interacting material dipoles !

Trillions of unwanted beams can cross the path of our desired light beam before we can receive and analyze the un-modified properties carried by the beam.

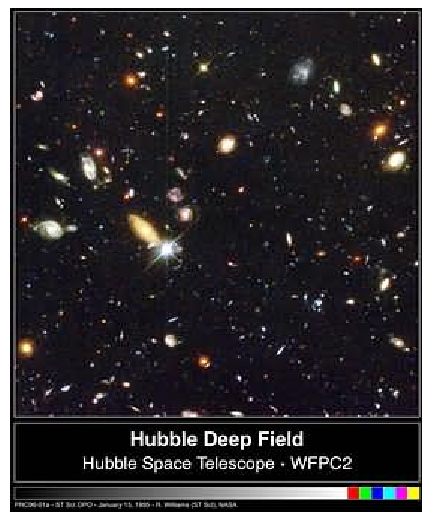


Otherwise

The visual world would have been full of spatial and temporal scintillations (speckles).



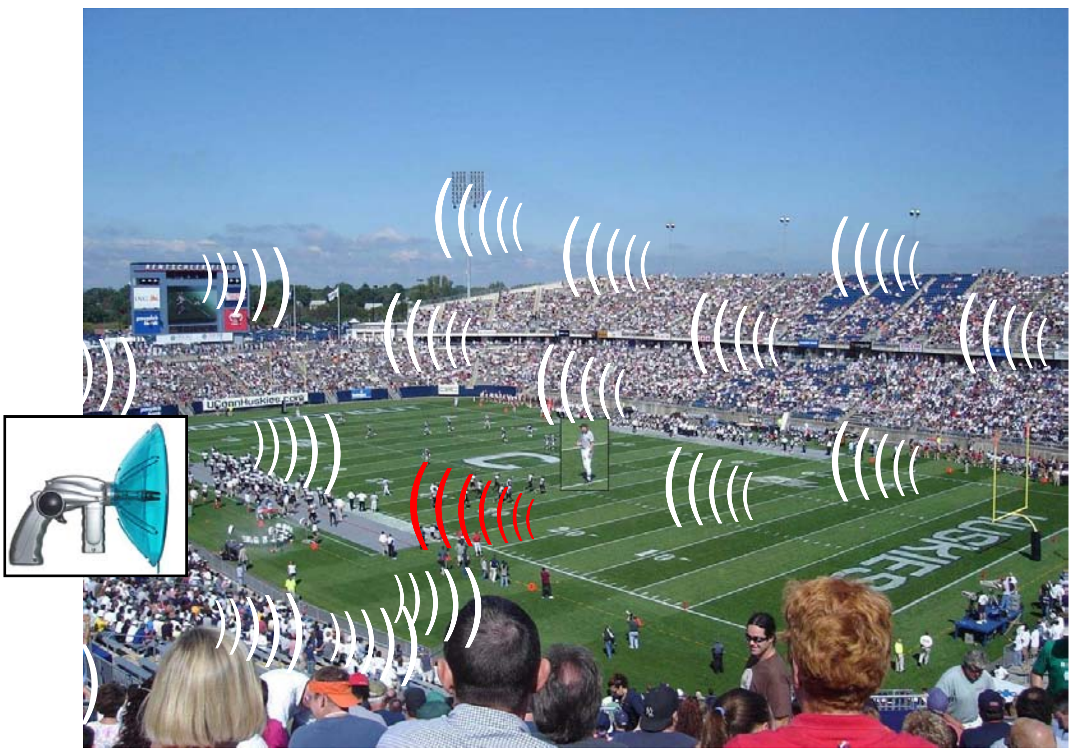
WDM internet data would have been destroyed by temporal interference (heterodyne effect).



Expanding universe, indicated by Doppler shift, would not have been measurable.

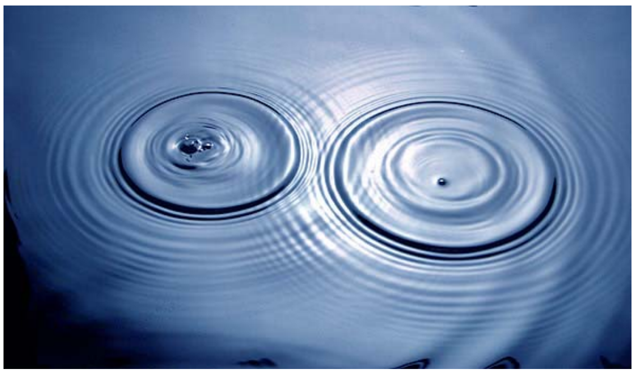
Well formed light beams cross each other without modifying each others spatial and/or temporal energy distribution.

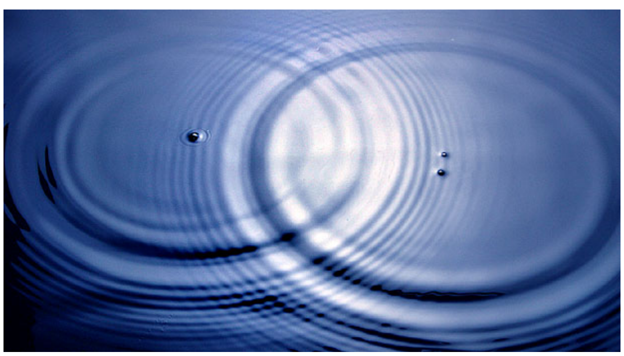
Light and sound beams pass through each other essentially undistorted from one corner to another in a crowded stadium, unperturbed by millions of other beams !



C. Roychoudhuri, SPIE Newsroom: http://newsroom.spie.org/x5251.xml

Even water waves pass through each other without perturbing each others collective behavior except at the locations of actual superposition !





• Harmonic undulations on a water surface and their propagation remains undistorted, even though the water in the LOCAL-regions of superposition show the modified resultant undulations.

• Wave forms by themselves do not interfere. If the supporting medium that is observable and shows local superposition effects.

• Unfortunately the cosmic medium in which light is emergent is not yet directly observable to us to display "local interference" of light beams.

Non-interference of wave forms is a generic property of nature !

An example of productivity of CC-LC-ER epistemology

Next two slides provide a list of recent publication by the author based on CC-LC-ER epistemology & non-interference of light

Notice:

- The titles themselves are indicative of the epistemology used.
- The productivity in terms of topic diversity within a period of four years (2003-2007)

List of recent publication by the author based on CC-LC-ER epistemology & non-interference of light

1. "Shall we climb on the shoulders of the giants to extend the REALITY horizon of Physics?" by C. Roychoudhuri, invited talk at the 4th International Conference on "Quantum Theory-Foundational Reconsiderations", at Vaxjo U., Sweden, Jun.11-16, 2007; to be published in 2007.
2. "Can classical optical superposition principle get us out of quantum mysticism of non-locality and bring back REALITY to modern physics?" by C. Roychoudhuri, invited talk at the ETOP conference at Toronto, Jun.3-5, 2007; to be published in 2007 by SPIE;
3. *The Nature of Light: What Is a Photon? by* C. Roychoudhuri, A. F. Kracklauer & Kathy Creath,; CRC Press (2007); in preparation.
4. "Can a deeper understanding of the measured behavior of light remove wave-particle duality?" by C. Roychoudhuri, SPIE Proc.**Vol.6664**, paper #2 (to be published, Aug. 2007).
5. "Can we get any better information about the nature of light by comparing radio and light wave detection processes?" by C. Roychoudhuri and P. Poulos, SPIE Proc.**Vol.6664**, paper #12 (to be published, Aug. 2007).
6. "Can the hypothesis 'photon interferes only with itself' be reconciled with superposition of light from multiple beams or sources?" by C. Roychoudhuri, N. Prasad and Q. Peng, SPIE Proc.**Vol.6664**, paper #24 (to be published, Aug. 2007).
7. "Bi-centenary of successes of Fourier theorem! Its power and limitations in optical system designs" by C. Roychoudhuri, invited paper, Proc. SPIE Vol. **6667**, paper #18 (Oct. 2007).
8. "If EM fields do not operate on each other, why do we need many modes and large gain bandwidth to generate short pulses?" by C. Roychoudhuri, N. Tirfessa, C. Kelley & R. Crudo,; SPIE Proceedings, Vol. **6468**, paper #53 (2007).
9. "Locality of superposition principle is dictated by detection processes" by C. Roychoudhuri, Phys. Essays **19** (3), September 2006.
10. "Spectral Super-Resolution by Understanding Superposition Principle & Detection Processes", by C. Roychoudhuri and M. Tayahi, Intern. J. of Microwave and Optics Tech**.,** July 2006; manuscript ID# IJMOT-2006-5-46: http://www.ijmot.com/papers/papermain.asp.
11. "Various ambiguities in re-constructing laser pulse parameters" by C. Roychoudhuri and N. Prasad, proceedings of the October, 2006 IEEE-LEOS Annual Conference, Montreal, Canada; invited.
12. "Do we count indivisible photons or discrete quantum events experienced by detectors?" by C. Roychoudhuri and N. Tirfessa, Proc. SPIE Vol.**6372**-29 (2006).

List of recent publication by the author based on CC-LC-ER epistemology & non-interference of light (list-p.2)

13. “If EM fields do not operate on each other, how do we generate and manipulate laser pulses?” by C. Roychoudhuri, D. Lee and P. Poulos, Proc. SPIE Vol.**6290**-02 (2006).
14. “Are dark fringe locations devoid of energy of superposed fields?” by C. Roychoudhuri and C. V. Seaver, Proc. SPIE Vol. **6285-**01 (2006), invited.
15. “A critical look at the source characteristics used for time varying fringe interferometry” by C. Roychoudhuri and N. Tirfessa, Proc. SPIE Vol.**6292**-01, (2006), invited.
16. “Role of the retinal detector array in perceiving the superposition effects of light” by C. Roychoudhuri and V. Lakshminarayanan, Proc. SPIE Vol.**6285**-08 (2006).
17. “Reality of superposition principle and autocorrelation function for short pulses” by C. Roychoudhuri, Proc. SPIE Vol. **6108**-50 (2006).
18. “If superposed light beams do not re-distribute each others energy in the absence of detectors (material dipoles), can an indivisible single photon interfere by/with itself?” by C. 18. Roychoudhuri, SPIE Conf. Proc. **5866**, pp.26-35 (2005).
19. “If superposed light beams do not re-distribute each others energy in the absence of detectors (material dipoles), can an indivisible single photon interfere by/with itself?” by C. Roychoudhuri, Proc. SPIE Vol.**5866**, pp.26-35 (2005).
20. *“The Nature of Light: What Is a Photon?* Eds. C. Roychoudhuri, Katherine Creath and A. F. Kracklauer, Proc. SPIE Vol.**5866** (2005); Year of Einstein Special Conference.
21. “Propagating Fourier frequencies vs. carrier frequency of a pulse through spectrometers and other media” by C. Roychoudhuri, Proc. SPIE Vol.**5531**, 450-461(2004).
22. *The Nature of Light: What is a Photon?*”, Guest Eds. C. Roychoudhuri & R. Roy, Optics & Photonics News Trends; special issue of OPN, October 2003. [http://www.osa-opn.org/abstract.cfm?URI=OPN-14-10-49].
23. “Measuring properties of superposed light beams carrying different frequencies” by D. Lee and C. Roychoudhuri, Optics Express **11**(8), 944-51, (2003), [http://www.opticsexpress.org/abstract.cfm?URI=OPEX-11-8-944].
24. “Limits of DWDM with gratings and Fabry-Perots and alternate solutions” by C. Roychoudhuri, D. Lee, Y. Jiang, S. Kittaka, M. Nara, V. Serikov and M. Oikawa, Proc. SPIE Vol.**5246**, 333-344, (2003), invited.

Summary of the results expressed in the published papers listed before that provide both improved understanding of classical and quantum optics and potential for a wide variety of technological innovations

• **1. Superposition effects are created by detectors: (**i) Accordingly changing the detectors or modifying their physical properties by secondary external fields will change the out come due to the same set of superposed optical fields. (ii) The definition and the theory of coherence need to be expressed in terms of correlation of multiple dipole undulations of the same detector induced simultaneously by multiple fields rather than as field-field correlations. Consequently new and more accurate theory and measurement techniques can be developed for characterizing very short pulses.

•**2. Optical signals and responding material dipoles are all space, time and energy finite:** (i) Generalized theory of spectrometry based on finite pulses conform to classical formulas for time integrated records, but time-frequency band width product (spectral resolution) is not a fundamental limit of nature but a function of our sensor arrangements. (ii) Pulse broadening through “dispersive” media is due to “time diffraction” just as space-finite aperture introduce fringe broadening.

• **3. Light beams by themselves do not produce mutual energy re-distribution (interference fringes) either in space or in time: (**i) Mode-lock laser theory needs to be modified in terms of properties of saturable absorbers (interacting dipoles) leading to more innovations in short pulse laser technology. (ii) The concept of ‘photons interfere only with themselves’ (Dirac) needs to be fundamentally revised, which will open up newer and better way of creating possible practical quantum computers, etc.

It is time to frame great new questions to generate great new break through knowledge about the ongoing *processes* in nature

• Great questions of any time are framed based on existing observations. If the answer is right, it will necessarily lead to new observations and hence new questions beyond the original question.

• Biologists, as humble reverse-engineers, diligently emulating the chemical processes behind all living activities, have found an over-arching and integrating working principle – the DNA helix – across all living things!

• Physicists have been happily playing with almost half a dozen separate "solved puzzles" and trying to force fit them together for over half a century even though they are not logically self-congruent for the desired merger.

We have proposed a great new CC-LC-ER epistemology that can accommodate great questions from great minds allowing iterative distillation of many untenable human logic from many of our separate theories to increasingly higher planes of mutual congruence & integratability towards cosmic logic and hence cosmic reality even though we can only start with incomplete and mutually incongruent theories!

Thank you for you patience !

Elizabeth Park, Harford, Connecticut. By CR.

I.

University of Toronto Institute for Optical Sciences Collaborative Program in Optics

Emanuel Istrate, Amr S. Helmy, John E. Sipe, M. Cynthia Goh and R. J. Dwayne Miller

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Abstract: We describe the activities of the Institute for Optical Sciences (IOS) at the University of Toronto towards the establishment of a Master's Program in Optics. The IOS was formed as a collaboration between faculty members interested in optics from the four departments of Physics, Chemistry, Electrical and Computer Engineering and Materials Science and Engineering. One of its goals is to serve as unifying entity for graduate and undergraduate programs in optical sciences. The details of the proposed graduate program will be discussed. It will be set up in the form of a collaborative university program, where students must satisfy the requirements of one of the four home departments, as well as a set of IOS-specific requirements of the program. IOS-specific activities include attending the Distinguished Visiting Scientist Series, participation in a best-research-practice mini-course, where essential research skills are discussed, as well as participation in an annual internal conference. The benefits of this interdisciplinary program, for students, faculty and relevant industries are discussed. The students will benefit from a wider exposure and a more coherent curriculum. The IOS will also serve as local community within the campus to which students could belong and network. Faculty, on the other hand, will benefit from a reduced teaching load, as redundancies among the departments will be removed.

1. Introduction

The understanding and practical use of optics and photonics is, by its very nature, a multi-disciplinary activity. Since there exists no single material that performs all necessary optical functions, as is the case in electronics, significant materials research is necessary, requiring expertise in chemistry and materials science. Understanding the various optical phenomena and the interaction of light and matter requires knowledge of optical physics, solid-state physics, electromagnetism and wave propagation. Finally, for the effective design of optical devices an engineering approach to the problem is best. Therefore, developments in optics benefit greatly from interdisciplinary collaborations. Faculty members with an interest in optics, and the corresponding research at the University of Toronto, were traditionally separated in several departments. The Institute for Optical Sciences at the University of Toronto was founded in order to provide a common home to professors with a shared interest in optics, and to encourage collaborations in this multidisciplinary field. The Institute is a network of 27 faculty members from two faculties and four departments, spanning the disciplines described above.

Along with the separation of optics research into several departments, student education in this field is also divided. As a result, students will try to receive an education in optics while registered in any of the four departments of Physics, Electrical and Computer Engineering, Chemistry or Materials Science and Engineering. Unfortunately, none of these departments offers a complete coverage of the field. Students with a strong interest in optics will try to find courses in other departments, in addition to those of their home department. This practice is not widely advertised, however.

The division of students into four departments, in addition to limiting their access to relevant courses, also limits their interaction with peers studying the same problems. Each department has a few yearly events meant to form a community among their graduate students. There are, however, no inter-departmental events fostering a community among students with similar academic interests. This lack is felt particularly strongly in multi-disciplinary fields such as optics, with students working on very similar topics who do not know about each other, due to the lack of communication between graduate students of different departments. Some students may learn about each other's work when taking courses together, but as mentioned above, this is not a common practice.

With a large number of expert faculty working in the general areas of optics and photonics, as well as many relevant courses, the University of Toronto has most of the resources needed to offer a graduate program in optics. For this purpose, it would only be necessary to combine these resources, which are presently scattered among the four departments. As a result, the most natural route is to set up a graduate program in optics as a collaborative program, combining courses already offered by the four departments.

2. Structure of a Collaborative Graduate Program at the University of Toronto

All graduate programs at the University of Toronto are administered by the School of Graduate Studies (SGS), which in turn is governed by the rules of the Ontario Council on Graduate Studies (OCGS). Fortunately, the SGS and the OCGS already have mechanisms in place for collaborative graduate programs combining courses and resources from multiple departments [1]. The main goal of a collaborative program is to offer an additional multidisciplinary experience for students, who are enrolled in one of the participating home programs. This added value is usually obtained from courses offered in the collaborating programs, or through a multi-disciplinary focus of the thesis.

Being a collaboration among several existing program or departments, such a program does not need significant new resources. In particular, students are admitted to, and registered in, one of the participating departments, and need to fulfill all requirements of that department. In addition to this, they are admitted to the collaborative program, which usually involves some additional requirements. In particular, a collaborative program must add value to what is normally available in a single department. It must also provide a common learning experience, which usually takes the form of a core course, or a seminar series. For programs with a thesis requirement, it is expected that participating students' thesis topics will be in the area of the collaboration. Since they fulfill all requirements of their home department and home program, students will receive a degree for that home program. The degree will carry, however, a mention that the student participated successfully in the collaborative program.

Each department or home program participating in the collaborative program must do so in a meaningful way. The departments should normally have faculty members whose research focus is in the area of the collaborative program, but participation can also be achieved if students of a department participate in the collaborative program, or if the program makes use of some shared facilities or courses from a given department. Finally, each participating department will have a number of *core faculty members* of the collaborative program. These are the members with an interest in the focus of the program.

A collaborative program is governed by a program committee, under the leadership of a director. The program must also be able to approve the granting of the degree designation to the graduate students. This is normally achieved by the presence of a collaborative program faculty member on the thesis examination committee, or by a collaborative program representative approving the recommendation for degree completion.

The structure of the collaborative program, as defined by SGS and OCGS make this a nature choice for the graduate program in optics, as most goals of the optics program align well with the requirements of a collaborative program.

3. The Collaborative Program in Optics

The Institute for Optical Sciences already fulfils many of the requirements for a collaborative program. It has faculty members of all four participating departments, which will naturally form the core faculty members of the collaborative degree program. Most graduate students of these supervisors have optics as their main thesis focus, satisfying again the requirements if they were to enroll in the collaborative program. A number of optics courses are already being offered by the four departments. Furthermore, the IOS already offers several common activities for students aiming to build a community of optics students at the University of Toronto. As a result, the Institute for Optical Sciences is in the process of setting up a collaborative graduate program in optics at the University of Toronto.

As a first step, the IOS will set up a Collaborative Master's Program in Optics, with a PhD program to be added in future years. Eligible students will be those admitted to one of the four departments of Chemistry, Electrical and Computer Engineering, Material Science and Engineering and Physics. While students of IOS faculty members will be encouraged to register in the program, it will be open to all students in these departments. They will have access to courses from all four departments, with the requirement that at least one course be taken from outside their home department.

3.1. Building an Optics Student Community within the University of Toronto

A very important OCGS requirement for collaborative programs is the common activity for all students. This is particularly important, since students are registered in different departments, and have little opportunity to interact. As they share a common interest in optics, however, they need to interact and draw value by exchanging different viewpoints – which necessarily come from the different departments – on the same subject.

To reinforce its international profile, the IOS runs a yearly *Distinguished Visiting Scientists* seminar series. In this series, four world-renowned scientists each spend two weeks at the IOS and give a series of four lectures aimed at optics graduate students. The extended stay is meant to foster individual contact between IOS students and the visiting scientists. In order to introduce students to each other more directly, the institute also runs a series of bi-weekly seminars, where students present their research topics to their peers. The presentations are complemented by formal introductions of students, and informal networking. The IOS also delivers a series of best practice sessions, teaching students essential skills for the optics laboratory and for research work in the field of optics. Finally, the institute organizes a series of professional skills activities, to supplement the very strong technical training of the students with essential business skills. When the collaborative program launches, the IOS will also set up an optics conference, where students will present their latest research results. All these activities are open to IOS students from all four departments, encouraging the formation of an optics student community at the University. Students registered in the collaborative program will be required to participate in these activities. In order to give credit for student participation, these activities will be collected into a new IOS course. No numerical mark will be received in the course, only a pass/fail status; the course will not involve an additional teaching load.

3.2. Organization of the Collaborative Program

The collaborative program will be overseen by a graduate program committee, with one member from each participating department and a chair. When selecting members for the committee, the aim is to find members of the IOS, who are also on their departmental admissions committee, and will therefore be able to make an informed decision about admissions to the collaborative program as well. In order to satisfy the requirement that the collaborative program be able to approve the granting of the degree, an IOS faculty member will be required to participate in the thesis examination committees for the students.

The chair of the committee will be the director of the IOS. While the individual courses of the program will be offered by the participating departments, the Institute for Optical Sciences will organize all other common activities of the program, including the sessions on the best practices in optics research. The institute will also be responsible for the detailed administration of the program through its academic program coordinator.

3.3. Related Activities of the Institute for Optical Sciences

Being committed to student education, the Institute for Optical Sciences is also in the planning stages of a course on experimental methods in research, which will become a central part of the collaborative program in optics. The course will teach incoming graduate students useful techniques to be used in a research lab, with an emphasis on optics. Topics to be covered include alignment of optics, signal to noise analysis, etc. Students participating in the collaborative program will be encouraged to take this course. For undergraduate students, the IOS will offer a course on holography, demonstrating many principles of optics, such as interference and diffraction, in a visual way.

4. Benefits of the Collaborative Program

The collaborative program brings benefits to both the students and the participating departments and faculties. Students will have access to a wider range of courses, which provide a more complete coverage of the field of optics. They will also benefit from the participation in the best practices sessions, the optics conference and an optics retreat to be organized by the institute. All these activities will result in the formation of a community among the optics students, which currently does not exist: at the present time the optics student body is segregated between the various departments, with few opportunities for communication between them. Finally, by receiving the special mention on their degree, students will receive credit for participating in an innovating multi-disciplinary program, and will be able to demonstrate their commitment to optics to future employers.

By working with the four departments, the IOS will also ensure that the curriculum will be more consistent. At the present time, optics courses at the University of Toronto are introduced by each department independently, with little regard to overlaps or gaps with the courses of the other departments. The IOS is working with faculty members in the four departments to identify such areas of overlap. The university and its faculty will benefit from a reduced teaching load, by removing any redundancies between the courses offered by the four departments. Since there are few such specialized programs in Canada, the program in optics will also demonstrate the university's commitment to pursuing an area of study of great importance in today's technology based economy.

5. Summary and Conclusions

The collaborative program in optics of the Institute for Optical Sciences will bring together students from the four departments of Chemistry, Electrical and Computer Engineering, Materials Science and Engineering, and Physics who share an interest in understanding and using light. This is a natural continuation of the way the IOS connects researchers from these four departments with a common interest in optics. Although students can already take advantage of courses from other departments, and of many of the activities already offered by the IOS, the collaborative program will organize these in a coherent fashion, and give credit to students for their participation.

At the present time, the preliminary proposal has been approved by the School of Graduate Studies and work is currently under way to define the exact program requirements. In addition to internal approval at the University of Toronto, the program also needs to be approved by the Ontario Council on Graduate Studies (OCGS). The collaborative Master's program is, however, only the first step in the introduction of optics programs at the University of Toronto. This will be followed by a collaborative PhD program and in the longer term by an undergraduate program in optics. Together, these programs will provide our students with a complete optics education, from an institution that is already world-renowned for its work on optics.

References:

1. Ontario Council on Graduate Education, "Report of the Working Group on Collaborative Programs," June 2001, available at http://ocgs.cou.on.ca/_bin/briefsReports.cfm

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Business Development Activities at Academic Institutions as Related to the Education, Training, and Career Development of the Next Generation of Scientists and Professionals.

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Abstract

Every year large sums of tax payers money are used to fund scientific research at various universities. The result is outstanding new discoveries which are published in scientific journals. However, more often than not, once the funding for these research programs end, the results of these new discoveries are buried deep within old issues of technical journals which are archived in university libraries and are consequently forgotten. Ideally, these scientific discoveries and technological advances generated at our academic institutions should lead to the creation of new jobs for our graduating students and emerging scientists and professionals. In this fashion the students who worked hard to produce these new discoveries and technological advances, can continue with their good work at companies that they helped launch and establish. This article explores some of the issues related to new business development activities at academic institutions. Included is a discussion of possible ways of helping graduating students create jobs for themselves, and for their fellow students, through creation of new companies which are based on the work that they did during their course of university studies.

Introduction

Every year thousands of students graduate from our academic institutions and start looking for jobs. Even though this is a good course of action for most graduating students, it is not the appropriate thing for a considerable portion of students. This group of students would benefit more if they do not look for jobs but rather create new jobs for themselves through establishing of new businesses based on work they did at the university and ideas they developed through their course of education.

Case Studies

The following are stories about students who were going through college and graduate school at one of the top universities in the United States during the 1990s. In these stories the names have been altered for privacy reasons. These are stories about students who had an entrepreneurial spirit and would had benefited from being encouraged and helped to create new jobs for themselves rather than looking for jobs upon graduation.

Kelly went through college and graduate school supporting herself through tutoring and part time teaching jobs. During her undergraduate years, she worked about fifteen hours per week as an academic tutor for the athletic department of her university. Her job was tutoring student athletes in such fields as mathematics, physics, and engineering courses. In addition she had a number of regular clients from the local high schools. During her graduate years she worked as an engineering teaching assistant. She was told by numerous people to be an excellent teacher. This included her students, their parents, many college professors, and high school teachers. She was a person who was truly dedicated to the important profession of educating young people and she very much enjoyed and took great pride in the work she did.

Upon graduation Kelly could have gone to create and launch a tutoring and teaching business. In this way she could have gone on to provide excellent service to the students of her community, do what she liked best, and could have provided a number of new tutoring and teaching jobs for many of her classmates. Throughout the years her business could have become a national franchise with new employment opportunities for thousands of people. But this did not happen.

Alberto was a graduate student in the 1990s at a research center at one of our most prominent universities. This research center was dedicated to research and development work in the area of advanced semiconductor technologies. During the course of his doctorate research work Alberto designed and built a machine for the specific purpose of packaging a new type of high power semiconductor lasers which at the time were at the cutting edge of optoelectronic technology. He also developed a novel technique of bonding and packaging of these semiconductor based optoelectronic devices. He integrated this new device packaging technology into the machine he had designed and built. As a result of this work numerous papers were published in various prestigious scientific journals. However, no new jobs were created for either Alberto or anyone else.

Various aspects of the technology which Alberto developed, including the design of his new high power laser diode packaging machine could have been patented. This was not done. With proper support and guidance Alberto could have gone on to productize and bring to market his optoelectronic packaging machine and the novel high power laser diode packaging technology which he had developed. This could have effectively been accomplished through the creation of a new applied optoelectronic technology firm. In this way a new company could have been established and new jobs could have been created for Alberto as well as for many of the next generation of students graduating from the same research center from which Alberto graduated. But none of this happened.

Working in a similar research field as Alberto was Maribel. Like Alberto, Maribel was also working on research projects funded by prominent government research agencies. Like the work of Alberto, the work of Maribel also had a highly applied nature. Her work was related to test, measurement, and characterization of a new type of semiconductor based optoelectronic devices.

As part of her work Maribel designed and developed a series of new test and measurement techniques. Her work included the development of a series of new highly industrialized application specific analysis software for automated test and characterization of new optoelectronic devices used in the field of Dense Wavelength Division Multiplexing (DWDM) technologies. DWDM is the technology which is the foundation of the modern fiber-optic based telecommunication industries. Maribel could have gone on to create and launch a new laboratory instrumentation and scientific analysis software company which could have had the potential of becoming a multi-million dollar business. But this did not happen.

Ivan, an engineering student at a large highly ranked university during the 1990s, supported himself throughout his university years by writing papers for professors at his university, creating conference presentations for them, and doing a variety of graphics design works for them such as preparing exceptionally interesting technical diagrams used in demonstrating the results of their research work. He occasionally offered his services to professors in the form of ghost writing book chapters for them. In addition to these, since he was an experienced photographer with artistic talents, he used to have photographs taken of the experimental setups used in the laboratories of engineering and physics professors. These photos were then used in various magazines, publications, and conference presentations by his clients. After graduating, Ivan could have gone on to create a new technical writing and graphics design business which working with various advertising and publishing firms could have resulted in the creation of a number of new jobs for the community. But this did not happen.

What to do

The students whose stories were narrated above ended up getting relatively good jobs following their graduation. However, they could have gone on to launch new businesses and could have created many new employment opportunities for themselves and for others. This did not happen. These are opportunities lost and we should ask ourselves why this did not happen and what could be done to prevent similar failures from happening in the future.

1) We need more professors and educators who are fully dedicated to the important task of educating and training of our next generation of professionals. Most professors working at our top research oriented universities are so busy with doing research that they do not have much time to focus primarily on the education of students. These professors are constantly under tremendous amount of pressure to generate new sources of funding for the university each year. Their measure of success is primarily the amount of financial funding they generate each year for the university and the number of technical papers they publish. They are not incentivised to worry about their students being able to start and establish new businesses.

When I was attending university as a graduate student one of my professors, who is now a world famous scientist, stood in front of a classroom full of students and said: "As a scientist, teaching is a burden for me." As a student attending that class I was very hurt and offended by this comment. We need to hire more professors who believe that teaching and the profession of education is an honour and a social privilege. It is important to have at least a portion of our academic faculty to be men and women who are primarily dedicated to the important task of educating our next generation of professionals and helping our graduating students create new companies and new jobs.

It is best to hire professors who have a diverse multi-faceted background and skill set covering both academic scientific knowledge as well as industrial and business world experiences. An educator who has a doctorate degree in his or her field of expertise and some years of academic scientific research experience can add some value to the education of our students. However, an educator who has this same qualifications but in addition has years of experience working in the industry and also has product management, marketing, and business development experiences can add much more value when it comes to educating our future professionals and helping them launch new businesses thus creating many new jobs.

2) A significant percentage of our university students have entrepreneurial spirit and ambitions with great potential to start their own companies soon after graduation or even while at college. This select group of students need to be encouraged to create jobs for themselves, and for their fellow classmates, instead of looking for jobs elsewhere.

A young person in his or her early twenties may not readily be aware that such options exist, or if they do then they may not have the confidence or access to the means to make such dreams come true. They need to be supported in achieving their entrepreneurial ambitions. The students whose stories were told earlier in this article are among such individuals but at the time they did not have access to proper business guidance and support in order to start their own companies.

3) We need to establish New Business Development units at our universities. The mission of these New Business Development departments should be to provide guidance and support to young undergraduate and graduate students who have the talent to be our future business leaders and who wish to start their own new companies while still in college or soon upon graduation.

Major universities typically have dedicated scientific research centers that are the focal point of scientific research activity within each area of technical specialty. Usually dozens of graduate and undergraduate students work at such research centers along with a number of engineers, scientists, technicians, and several professors. The head of the center is a scientific director who is a senior professor in charge of leading and managing the research activities of the whole center and is responsible for generating the necessary annual financial funding for the ongoing operations of the research center.

What typically is missing within such research centers is the position of Director of Business Development. Someone whose mission would be to productize and market the great technologies that are created at the research center. This person would be responsible for assisting those students of the center who are interested create new companies based on the research work they have performed at the center. If during the 1990s there existed a Director of Business Development at the particular research center where Alberto and Maribel worked, then it could have been possible that these two students would have been encouraged and enabled to create their own new successful companies.

Many universities currently have Technology Transfer departments which essentially market the research results of the professors to the industry primarily in the form of licensing the patent rights of the new technologies developed by the university faculty. However, in addition to these Technology Transfer departments there should exist New Business Development departments which would be fully dedicated to helping students launch new businesses, ideally based on the work done by them during their course of studies.

Why not help and support students, and provide guidance to them, so that they can begin establishing a new company with a viable business plan while still going through college. By the time such individuals graduate from university they potentially could be in a position to hire their fellow classmates. Also because they have created a mission and a professional goal for themselves, they will be able to tailor their university course of studies in a more optimum fashion.

They can choose and tailor their courses in such manner that by the end of four years they would be well equipped with the right tools in order to succeed in the business venture they have already embarked upon, as opposed to going through a standard four year college program and upon graduation wondering what to do with their education and what type of job to get. Instead of looking for job opportunities they will be able to offer job opportunities to others.

4) We need to provide to interested students incubator facilities and assistance in applying for both government as well as private sector funding in order to start their new businesses. This effort must be led and directed by the New Business Development department with heavy participation of the interested academic professors. Those university professors who choose to participate in this type of activity should be rewarded for their contributions and successes. The primary measure of success of the New Business Development department, and of the professors who are working with this department, should be how many new jobs were created by the students of the university soon upon their graduation.

Under this scenario it would not have been considered sufficient that the students whose stories were mentioned earlier in this article, all successfully graduated with advanced technical degrees and found jobs. Success could only have been claimed if all of these stories would have ended with successful new businesses and companies having been created. Ultimate success would have been if today the companies created by these students were thriving prosperous businesses employing thousands of individuals.

5) A significant portion of the scientific research done in our universities is funded by government research agencies such as the Defense Advanced Research Projects Agency (DARPA). The result is outstanding new discoveries which are published in scientific journals. However, more often than not, once the funding for these research programs end, the results of these new discoveries are buried deep within old issues of technical journals which are archived in university libraries and are consequently forgotten. Ideally, these scientific discoveries and technological advances generated at our academic institutions, and paid for by tax payers, should lead to the creation of new jobs for our graduating students and emerging scientists and professionals. In this fashion the students who worked hard to produce these new discoveries and technological advances, can continue with their good work at companies that they helped launch and establish.

In order to achieve the above mentioned objectives it is highly beneficial that government research agencies, in addition to the research programs they typically manage, also have a series of programs dedicated to productization of the research results produced through their currently funded research programs.

Such industrialization and business development programs should be managed by government agency program managers whose focus would be on closing the relatively wide gap between universities generating novel ideas and the introduction of these ideas to market in the form of well developed technologies and products. In doing so a mechanism will be created through which many new companies are created based on scientific research performed at the research centers of our academic institutions.

Program managers and directors working at our government research agencies are in a position to facilitate this and thus contribute in a significant way to not just providing the funding necessary for the training of our next generation of scientists and engineers but also contribute to, and positively influence, their professional advancement. This can result in the creation of a series of new industries and businesses leading to the generation of numerous new employment opportunities for our graduating students.

Summary

This article is about how to plant the seeds of future industries through encouraging and supporting new business development activities at our universities.

Many of the students studying at our academic institutions have entrepreneurial spirit and possess innovative applied technological ideas. These students should be encouraged and be provided with proper guidance and support. They should be enabled so that they are in a position to create new jobs for themselves and for their fellow students instead of looking for jobs after they graduate.

The way to do this is through hiring more professors, educators, and administrators, who are truly dedicated to the task of educating our young minds and are in a position to help and support students with their new business development ideas and efforts.

We should have at our academic institutions dedicated business development directors whose primary function is to provide guidance and support to students in regard to starting new companies. These business development directors should have the responsibility of facilitating the success of the students in creating new job opportunities.

About the Author

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III.

Advancing teaching opportunities through pre-commercial photonic devices

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Abstract: The Photonics Technology Access Program [PTAP] provides academic researchers with pre-commercial photonic devices. Since one of the goals of PTAP is to promote teaching, the program has developed several approaches to expand teaching opportunities with the processes used to provide the devices.

1. Introduction

In July 2002, the United States Government initiated a program whose mission is to provide pre-commercial, state-of-the-art photonic devices to universities for teaching and research. The National Science Foundation [NSF] and the Defense Advanced Research Projects Agency [DARPA] sponsor the Photonics Technology Access Program [PTAP]. The Optoelectronics Industry Development Association [OIDA] administers PTAP and acts as the broker between industry and the universities.

The rationale behind PTAP is that in a rapidly changing technical field, if researchers have to acquire devices on the commercial market, by the time their research is completed and published, the next generation of devices is already on the market. Providing researchers access to devices <u>before</u> they are available on the market, improves the quality and timeliness of their research product. Furthermore, students gain experience with leading-edge technology, enhancing the quality of teaching. Lastly, the program creates and strengthens relationships between faculty and industry. This is particularly important for young faculty who may not have yet developed strong industry connections, and faculty at schools with lesser-known photonic programs.

A second element of PTAP is to act as an "angel investor" and provide seed funding for new ideas. Often a professor or student has an innovative idea but no funds to acquire the devices to test it. Clearly, they can submit proposals to one of the funding agencies, but without some hard data, the proposal may not receive funding. PTAP can supply a device that will enable the researcher to perform some preliminary experiments and obtain data that improve the quality of proposals. This provides a benefit to both the funding agencies, which get higher quality proposals, and researchers, whose odds of success improve. Since PTAP specifically does not provide funding for the research itself, professors must pursue some other source of funding for the actual work.

2. Evolution of teaching opportunities

Initially PTAP accomplished its teaching objectives simply by providing novel devices. The process as originally envisaged is relatively straightforward. PTAP would solicit and competitively evaluate brief proposals that request devices. Once the reviewers identify the proposals selected for funding, PTAP notified the researcher and then worked with him or her to identify an appropriate source of device. PTAP would order the device and the vendor would deliver it directly to the researcher and bill PTAP.

2.1 The first innovation – graduate students as proposal authors

After the first few competitions, we realized that the true stakeholders in the outcome of the solicitation were the graduate students. They are the ones whose lab work and theses depend on their ability to obtain the necessary materials. Furthermore, given the funding situation today, faculty has to focus on obtaining grants that provide more resources than just an interesting device. To deal with these realities PTAP changed its guidelines to encourage proposals written by students, under faculty supervision.

The attractiveness of having students write the proposals was two-fold. First, for many students this would be the first opportunity to write a proposal that could affect the outcome of their research. We viewed the exercise a teaching experience, and by requiring the faculty member to sign off on the proposal, the students would get guidance from the outset. Secondly, we anticipated that the Program would receive more proposals from a wider cross-section of schools and departments because of “viral” advertising among graduate students. Our experience was in line with our expectations.

At the same time, we saw challenges in addition to benefits from this approach. The first challenge was how to ensure fairness in the evaluation process. Most likely, a proposal written by seasoned faculty would be better quality and more compelling than one written by a student. To address this potential for disparity, we asked the proposals to identify clearly all the authors and their academic rank. We factored this information into the evaluation process, with student-written proposals getting more leeway.

Secondly, we were concerned that inexperienced students lacked the structure to put together a cohesive proposal that addressed all the necessary elements. To address this concern, we developed a numbered template for proposals and required that all proposals address the points in numbered sections of the proposal that related back to the solicitation. Not only did this ensure that all the necessary information was present in every proposal, it made evaluation a lot easier because of the inherent consistency of proposals.

2.2 A lesson in following directions

Since the solicitation specifically asked that proposals be three pages or less, and follow the given numbered format, we were rather surprised to see that a number of students (and faculty) chose not to follow directions. After tolerating this for the first few solicitations, we embarked on another teaching opportunity – emphasizing that when a solicitation specifies a format, requests specific information, or provides other directions, it is incumbent on the person preparing the proposal to follow those directions to the letter. The harsh reality of the real world is that reviewers do not have the time or motivation to go through the proposal and seek out the necessary information buried within. Rather, they are likely to mark that evaluation criterion with a low grade or as not responsive. This in turn, may significantly lower the proposal’s probability of success. Given the low success percentage of many of today’s solicitations, the reviewers’ job often is to eliminate as many proposals as it is to pick successful ones.

We implemented this teaching opportunity in a manner that would not harm the authors. Rather than eliminating the proposal for failure to comply with the solicitation requirements of length and format, we acknowledged the receipt of the proposal and indicated that we had logged it in as received. We asked the author, however, to resubmit the proposal and this time to follow the directions. After we received the amended proposal, we sent another email explaining why we had subjected them to this extra effort, and what we hoped they had learned from the experience.

2.3 Components for lab courses

In the course of identifying interesting pre-commercial components, we came across one company that was discontinuing its line of tunable lasers. We were able to purchase a significant quantity of these lasers at deeply discounted prices. From previous solicitations, we were aware that researchers liked agile devices and that there would be high interest in these devices. The problem, however, was that these devices were truly pre-commercial, and as such, the company had not yet developed user manuals or data sheets and could provide only limited user information.

We turned this problem into a teaching opportunity. We provided Professor Ryszard Pryputniewicz at Worcester Polytechnic Institute about a dozen devices and all the information that we had – a couple of pages showing pin configuration and max/min parameters. Luckily, we also had a point of contact from the company who was willing to provide some additional information if so asked. Prof. Pryputniewicz took the tunable lasers and structured a design course around them. The students received a “black box” and their assignment was to characterize the device. After they had a thorough understanding of the device, the students designed an RS-232 interface/driver card for the laser. Lastly, they prepared a data package. They kindly made this package available to other groups who obtained the lasers through PTAP.

2.4 Devices for follow-on research

Specialty fibers provided another interesting opportunity for using device availability to drive teaching opportunities. The cost of fabricating the glass preform and then drawing the fiber, set the fiber’s cost. The cost is virtually the same whether a researcher needs 10 meters or 10,000 meters of fiber. Most researchers do not need the full output of a fiber draw, and therefore, the cost of a custom fiber draw is often prohibitive. PTAP has paid for specialty fiber draws and has delivered the requested length to researchers. PTAP then took the excess fiber, and after a negotiated lead-time, published the fiber specs on its web site and made it available to the research community at large. The benefits are two-fold: researchers get access to unusual fibers fabricated to their specifications, which are not available elsewhere. More importantly, once the original requestor publishes the experimental results, other researchers can obtain the same fiber to replicate the results and to perform follow-on work. In a way, PTAP acts as a consolidator without having to bring all the parties to the table at the outset.

3. Conclusion

The activities of PTAP demonstrate that program managers can create enhanced teaching opportunities through program is execution. Such activities enhance the value of the effort to the sponsors and participants. They also deliver content that ordinary classroom instruction cannot.

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I.

Photonics Xplorers and Leaders: Challenging Diverse Students in a Flat World for Emerging Careers

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Abstract
The Photonics programs address the question of how to integrate scientific content, student encouragement, and parental support to engage minority high school students to experience success in areas of a national need. Historical data indicates African Americans do not take advanced mathematics and science courses, especially physics, in high school. Therefore, we propose using a variety of strategies for providing instruction in leadership, experimentation, research writing, communications and scientific presentation to work with students, families and teachers in promoting selection of and academic achievement in challenging science courses. Seventy-five African American students are participating in year-round Photonics programs at The Science House on NC State University's Centennial Campus. Students from sixteen counties in North Carolina learn about fiber optics, communications and the properties of light.

Introduction
The Piedmont Region of North Carolina is one of the fastest growing science and information technology centers of the world. Each day over 37,000 workers stream into Research Triangle Park where IBM, Nortel, Cisco and other science and technology companies operate major facilities. These technology, manufacturing and research facilities draw scientists and engineers from around the world, however there is a need for a larger and more diverse workforce, which should include more North Carolina natives. North Carolina must do more to attract and prepare students from diverse backgrounds to join the science and technology powerhouse this state has built.

The sixteen rural and urban counties served by Photonics Xplorers and Leaders include a population representative of the entire state, with about 31% African American and 5% Hispanic students. To underscore the need for the program, consider that for these counties the 9th to 12th grade student graduation rate of 42% to 65% brackets the statewide average. Of those that do graduate from high school about 48% go on to four-year colleges, and 34% to community colleges or technical schools.[i1] This college-going rate lags behind the national average.

A key step in the education of students for the science and technology workforce is the high school physics course, normally taken in the senior year in NC. While the national physics enrollment rate in the last decade has increased to about 28%[2], in North Carolina in 2003-2004 only 10,555[3] out of 356,000[4] grade 9-12 students took the high school physics end of course exam. This number has decreased slightly in the past decade. Although there is no statewide data on the relative participation of minorities in the high school physics course, nationally only about 22% of African Americans and Hispanics take physics.[5] Obviously North Carolina needs to do more to promote and support minority students into science and technological careers.

While the percentages of African Americans and Hispanics in the national science and engineering workforce are steadily increasing, they are still below their relative representation in the college-degreed workforce.[6] The national technology industry is lacking the contributions and strengths that come from a socially and ethnically diverse workforce.

Origin of the Imhotep Academy, Photonics Xplorers and Photonics Leaders Program

Imhotep Academy is a pre-college program designed to increase student awareness and enthusiasm for learning science, technology and mathematics. Imhotep Academy is an integral part of The Science House, which is operated by the College of Physical and Mathematical Sciences at North Carolina State University. This robust program started over fifteen years ago for middle and high school students strives to improve students' grasp of science technology, engineering and mathematics (STEM). According to the Bureau of Labor Statistics, 20 of the 25 occupations listed as having the highest median annual earnings - including Anesthesiology, Computer and Information System Manager, Flight Engineers and Physicists - are dominated by the science fields. We want Imhotep children to fill these emerging positions. The main points of the Imhotep Academy business plan are:

- The mission of Imhotep Academy is to serve as a catalyst for change by teaching exciting hands-on inquiry-based lessons to enhance academic skills for underrepresented students in the disciplines of Mathematics, Marine, Earth and Atmospheric Sciences, Physics, Chemistry and Statistics, which are the departments in the College of Physical and Mathematical Sciences.
- The objective of Imhotep Academy is to nurture students' interest in pursuing science, math and technology careers.
- Imhotep Academy encourages underrepresented students to acquire and practice the skills required for success in the science, mathematics and technology workforce as identified by Thomas Friedman in *The World is Flat*.
- Imhotep Academy has expanded programming offerings to include the grant-funded high school component; Photonics Xplorers and Photonics Leaders.
- Imhotep Academy's success hinges upon serving a diverse population of motivated students, creative teachers and the supportive parents of students who return each session.
- Curriculum offerings include relevant theme-based instruction encouraging and stimulating academic interest and excitement for students and teachers.
- Evaluation data documents the continuous need for this student program in preparing females and underrepresented students for our high tech world.
- Imhotep Academy receives significant financial support from the College of Physical and Mathematical Sciences to tap into the talents of traditionally under-represented students.
- Future plans are to implement strategies for leveraging resources for growth and sustainability.

Imhotep Academy program meets a continuous need for nurturing and unleashing the potential of under-represented students to excel in mathematics, science and technology. Imhotep Academy's programs and other pre-college programs like it are more important than ever because public schools do not have the opportunity to expose and encourage children to fill the STEM type jobs that are available or emerging in our globally competitive world. Over the past decade, technological advancements have changed our lives and the job market. As a result, the National Science Foundation has predicted science and engineering careers in the United States will grow by 26 percent and that over half of the scientists and engineers are forty years or older. It is also predicted that by 2012, we will have 1.25 million more positions in these fields. While the jobs grow, the people to fill them decrease and we must work to remedy the shortfall.

According to the National Science Foundation, African Americans represent only 6.9% of those employed in science and technology occupations in 2000. This is up from 20 years ago when it was 2.6%, however, this rate is still below the proportion of African Americans in the population. Thus, these findings justify the need for this program's expansion and more resources for the educational pipeline to help turn this situation around. Imhotep Academy has expanded program offerings to include an algebra program and grant-funded high school component to further help students experience success in preparing for scientific classes and emerging careers.

The high school Photonics programs are preparing our next generation of technology leaders to be the catalyst of change by exposing students to new photonics related career options. Photonics Xplorers and Photonics Leaders are year round science, mathematics and technology programs for high school students from across North Carolina. Students attend these programs at The Science House on Centennial Campus at NC State University. For our success in the global economy, America depends upon a robust and reliable pipeline of scientists, technicians, technologists, engineers, and mathematicians. A recent ITEST newsletter stated that over 80% of the fastest growing occupations and two-thirds of the occupations with the largest job growth are dependent upon a knowledge base in mathematics and science.[7] Fifty percent of the current engineering and science workforce are approaching retirement[8] and U.S. universities will graduate qualified candidates to fill only 50% of the computer and information related jobs expected by 2012.[9] Women and minorities still remain under-represented in the STEM workforce. A diverse American pipeline will increase our ability to create, innovate and adapt in the global market place.

From reading *The World is Flat* by Thomas Friedman, students in both programs (Photonics Xplorers and Photonics Leaders) explored emerging careers in the global market place and the implications as it impacted their lives and career preparation. From this reading the students and their families discovered the importance of a STEM education and the impact of photonics in every area of their life. *The World is Flat* provided a platform for students to grasp the importance of the field experience within the following companies: Progress Energy, Analytical Instrumentation Facility, NCSU; College of Veterinarian Medicine, NCSU; IBM, Friday Institute, NCSU; Merck Pharmaceutical, NCSU College of Engineering, NCSU; North Carolina Division of Water Quality, North Carolina Department of Natural Resources, Shoder Education Foundation, Cisco Systems, Inc. Instrotek, Inc, Jones Cnossen and Dolle Engineering; BD Technology, Plexus Technology, EMBARQ and the Physics Laboratory, NCSU. At the end of the summer experience, students were able to synthesize and integrate the importance of their experience into an oral presentation as well as written reports.

In 2007, the Photonics Xplorers program will complete three years of programming and Photonics Leaders will complete two years of engaging nearly 120 high school students in the wonders of photonics (the science of light energy), mathematics, scientific research and presentation skills, organizational, leadership, career preparation skills (resume, interview, communication). Our goal is to improve students' competence in science and nurture their interest in science, research and careers.

Xplorers and all its features

Photonics Xplorers is a multidisciplinary program for culturally diverse students that are historically underrepresented in the sciences and engineering. Photonics Xplorers is funded by the Burroughs Wellcome Fund (BWF) Student Science Enrichment Program Awards to support creative science enrichment activities for students in the sixth through twelfth grades who have shown exceptional skills and an interest in science, as well as those who may not have an opportunity to demonstrate conventional "giftedness" in science but are perceived to have high potential.

Photonics Xplorers, a year-round program for high school freshmen and sophomores funded by the Burroughs Wellcome Fund. The Xplorers have made the leap to high school and are learning strategies to succeed. They are building their mathematics skills and learning about light and communications using the nationally recognized Active Physics[10] curriculum.

The Xplorers project is an outgrowth of Imhotep Academy, an academic year and summer enrichment program for middle school students from groups underrepresented in science and mathematics. In the past fifteen years the Academy has averaged 50 6-8th grade participants per semester totaling into the thousands students served. Many former Academy students are now college graduates and have testified to the importance of the Academy in guiding their career aspirations.

Photonics Xplorers introduces twenty ninth and tenth graders annually, mostly from groups underrepresented in science and engineering, to the technology of optical science and photonics. Two groups of twenty students recruited from nearby schools and from science enrichment programs for underserved students such as the Imhotep Academy participate in a two-year continuous learning and mentoring experience. In each session of the two-year program students investigate optics, electronics, build devices, learn about photonics careers, meet scientists, and present their findings to others, especially their peers and corporate partners.

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The students meet one week each summer and five Saturdays each academic semester. The students construct optical and electronic devices and perform experiments that teach physics science content, experimental skills and provide products for students to share with their teachers and fellow students. These activities build on the extensive expertise in optics and photoelectronics at NC State and in Research Triangle Park, as well as the excellent teaching laboratory facilities at The Science House. Drawing from the nearly fifteen-years experience of the Imhotep Academy in mentoring middle school students and their parents, we counsel the ninth and tenth graders, and their parents about course selection in mathematics, science, college preparation and career choices in high school. Upon successful completion of Photonics Xplorers, students are recruited to become Photonics Leaders.

The fundamental goal of the Photonics Xplorers project is to encourage students to take advanced mathematics and science courses all four years of their high school experience. To achieve this goal we

- provide hands-on experiences that build confidence and a sense of personal achievement in science,
- reinforce fundamental mathematics and science concepts that are central to high school science and mathematics courses,
- counsel and encourage students with mentors and role models in the science and engineering field
- channel the rising eleventh and twelfth grades students toward other science and mathematics enrichment programs such as Photonics Leaders.

The students are recruited from middle and high schools near the NC State campus and from programs that focus on middle school students from groups underrepresented in science and mathematics. These include the Imhotep Academy and SPACE program, Upward Bound and MSEN Precollege programs at NC State, UNC-CH, NC Central University and North Carolina.

We intend that each student will complete two full years with the program and will be prepared to participate in science enrichment activities targeted towards eleventh and twelfth graders. Building on their experiences from grade six through ten science enrichment programs at NC State, upon completion of the Photonics Leaders programs students will be prepared to step into existing collegiate research internships at NC State and elsewhere.

Photonics Xplorers consisted of 58 participants, 22 males (38 %) and 36 (62%) females during the last 3 years with students from 15 different counties in North Carolina. Students were selected to produce a diverse cohort of students with the following ethnic backgrounds: 72% African-American, 6% Asian, 4% Bi-racial, 14% Caucasian and 4% Hispanic. All the students accepted in the program had above a 3.00 grade point average.

Leaders and all its features

Photonics Leaders is funded by the National Science Foundation (NSF) Information Technology Experiences for Students and Teachers (ITEST) program established in direct response to the concern about shortages of IT workers in the United States. ITEST program funds projects that provide opportunities for both school-age children and teachers to build skills and knowledge needed to advance their study and to enable them to function and contribute in a technologically rich society.

In July 2005, the Photonics Leaders project was established at North Carolina State University with a grant from the National Science Foundation (NSF). In accordance with the goals of the ITEST program we seek "to provide opportunities for school-age children … to build the skills and knowledge needed to advance their study, and to function and contribute in a technologically rich society."[11] Based at The Science House, Photonics Leaders program seeks to enhance access to science classes and careers for all students, especially minority students, by giving them opportunities to participate in real scientific investigations making use of a variety of technological tools. The theme of the program, Photonics, is the nexus of optics, electronics, networking, communication and scientific instrumentation. Photonics is the basis of optical communication from the optical fiber of the DVD to the plasma screen. The photonics industry requires hardware and software scientists and engineers who will design, build and maintain the nation's communications infrastructure. Electronic and photonic instrumentation appear in every manufacturing plant and research establishment in the country.

We have chosen photonics because it allows students to investigate the technology they see and use on a daily basis. They will investigate how the physics of light and the technology of solid-state electronics meet in devices such as TV remote controls, or fiber optics computer connections, or CD players. The Photonics Leaders wire simple devices such as an optoelectronic interface, simulate projects with scientific software, and learn to use a variety of technology tools that make real-world scientific investigation possible. We enhance students' ability to communicate orally and in writing, hone their mathematics skills, and provide them strategies to help them succeed in high school and higher education for STEM careers.

The high school juniors and seniors that participate in the year-round (Fall, Spring and Summer) program for two years

- take part in hands-on science and technology activities to increase their awareness of photonics careers and prepare them for further education and the workplace,
- enhance their mathematics and communications skills and develop career awareness, and
- plan, conduct and report research projects, and serve as interns in research or technology laboratories at NC State or in Research Triangle Park.

Students are recruited from public, private, charter and home schools from across North Carolina but especially in Wake, Johnston, Harnett, Chatham, Orange, Durham and neighboring counties. Most will come from middle school Imhotep Academy and Photonics Xplorers programs at The Science House. The program will also tap into other pre-college programs at NC State (SPACE program) and UNC-Chapel Hill (MSEN pre-college program). This recruiting area includes urban and rural schools. In the past Imhotep Academy students have traveled from as far away as the village of Ahoskie, 3 hours from Raleigh, to participate.

The Photonics Leaders will step into new roles as future scientists and engineers. They are encouraged to develop a mission statement, set goals, develop and prioritize strategies, and accomplish their objectives. Students work in teams on learning assignments and research activities. Speakers from the technology community and field trips to laboratories reinforce these activities. Students develop PowerPoint presentations and web pages to report their research, and use spreadsheets and data analysis software to analyze their results. The juniors and seniors undertake a cooperative research project and explore the world of work through a summer internship. Teachers coming from the research community and The Science House guide high school students in their work.

The Photonics Leaders meet minority scientists from the university and industry who serve as role models for the Xplorers and Imhotep students. We are building a community of minority students and families that encourage academic achievement and success. It has been pointed out that peer culture has a negative effect on the representation of African American students in science.[12] The Photonics Leaders produces a reinforcing peer culture among the participants and the sister programs of Imhotep Academy and Photonics Xplorers.

Students participate in a three-week summer experience (120 hours) which also includes a field interaction, five Saturdays (4 hours each) in the Fall and five Saturdays (4 hours each) in the Spring, totaling 150 hours per year. The students will receive a scholarship of $1200 per year to remove the temptation to take a part-time job else where. To encourage students to remain in the program and to allow them to use technology daily, participants are issued a jumpdrive, an example of a photonic device. Three cohorts of 20 students participate for two years. Because the third cohort students will only complete one year we will seek alternate learning opportunities for their senior year.

Photonics Leaders use teaching strategies and materials from several other high school science programs at The Science House. Much of the format for collaborative research, experimentation and reporting comes from the successful Student Science Colloquies, which introduced students to areas of innovation in science.[13] Many Colloquies graduates have gone on to university work in science and engineering. Photonics students investigate technology they encounter routinely. Students built telescopes, laser diode circuits, electronic robots, fiber optic light guides and carry out scientific research using lasers and other photonics devices in biweekly and monthly sessions.

Photonics Leaders served 41 students, 19 males (46%) and 22(59%) females in two years from Alamance, Durham, Harnett, Nash, Northampton, Pitt, Onslow, and Wake counties. Students were selected to produce a diverse cohort of students with the following ethnic backgrounds: 77% African-American, 4% Asian, 2% Bi-racial, 14% Caucasian and 2% Hispanic. Five students were placed on the waiting list and joined the program before the first session due to attrition. Their unweighted grade point average was a 3.02.

Evaluation Strategies
Through pre- and post-student attitude assessment of the students, we measured the impact of the program on the students' perceptions of science and their perception of themselves as scientists or engineers. We regularly survey their parents to learn their perceptions of the program and their understanding of the education choices they and their children must make. We track student's courses and grades through their senior year.

Internal surveys are used to plan the mentoring sessions for parents and students. Sessions on high school preparation, college planning, and strategies for parents to encourage their children to persevere in advanced mathematics and sciences courses in high school were incorporated in the parental component.

After each semester we analyze the curricula and student products to refine plans for the next semester. The learning activities we develop will be reused in other Science House programs and student products will be displayed on The Science House website. Program outcomes and successes are reported through papers and presentations at professional education meetings.

Evaluation Outcome Selections from Photonics Leaders Project 2006-2007 Year Two report EDSTAR, Inc[13]
Goal 1: The first goal of the program is to guide and prepare high school students recruited from minority-serving programs at NC State and elsewhere through and for a transition to STEM programs in two- and four-year colleges.

This goal was evaluated using the following measurable outcomes:

- **Evaluation Objective 1.1** Students complete a pre-test at the beginning of the 3-week summer program and a post-test at the end. The post-test is administered again after the five Saturday sessions held in the fall.

- **Evaluation Objective 1.2** Students' grades and performance on the state's End-of-Course exams will be collected each fall and spring, and evaluated for all major core curricula (e.g., English, Science, Mathematics, History).

- **Evaluation Objective 1.3** Each student's participation in Photonics Leaders will be continuously monitored over two years, as will their selection of courses including the sciences and advanced placement classes. Additionally, 90% of students will express satisfaction ("satisfied" to "very satisfied") with the program, and will be able to articulate an understanding of possible STEM career paths they could pursue for post-secondary education.

Goal 2: The second goal is to impart to participants a deeper and richer understanding of STEM careers as human endeavors that require hands-on skills, resourcefulness, and communication skills not often addressed in the high school science and mathematics classroom. This goal was evaluated using the following measurable outcomes:

- **Evaluation Objective 2.1** Students will maintain a journal where they will record their experiences and observations, and respond to writing prompts periodically (e.g., "Define 'hypothesis' and how one is evaluated." "Describe some of the major steps in conducting a research investigation." "Identify five fields of scientific investigation."). EDSTAR will score the writing prompts using a 4-point rubric (1-showing little to no understanding; 4-showing very good understanding).

- **Evaluation Objective 2.2** Each year, students will complete the Test of Science-Related Attitudes, designed to measure secondary students science-related attitudes along seven dimensions: social implications of science, normality of scientists, attitude toward scientific inquiry, adoption of scientific attitudes, enjoyment of science lessons, leisure interest in science, and career interest in science.

Evaluation outcomes in science knowledge, writing and science content prompts, student presentation, interest and aspiration are discussed further in this section.

Science knowledge --Content subjects covered included:

- Wave velocity, wavelength and frequency
- Coherence and incoherence
- Differences between an incandescent lamp, an LED, and a laser
- How a lens can be used to magnify an object or expand a light beam
- Differences between sound and light waves
- How the color and wavelength of light are related
- The components of a simple electronic circuit
- How electrical currents are used to produce sound or light waves

Content Tests

Each student in the Photonics Leaders Program takes a Science Knowledge Content Test designed to help the program staff understand what the students know as they begin the program. The 10-item test consists of 6 open-ended questions, (1 of which also has a multiple choice portion), 3 multiple-choice questions, and 1 diagram. One of the multiple-choice questions asks how the student learned about the Photonics Leaders program. The other questions focus on different aspects of photonics such as light, waves, and electrical circuits.

The final question asks students to draw a picture of what they believe a photonics scientist or engineer looks like at work, including details to show what the scientist's laboratory, activities and lifestyle are like. Each question is scored using a rubric ranging in scores from 1-5 with 5 being the highest. Students are graded on their level of understanding of the concepts mentioned in the content test. With regards to the question in which students are asked to sketch the scientist, the characteristics of the drawing are used to assess students.

In September 2005, 21 participants from Cohort I were given these tests, which the instructors then scored. The average pre-test score was 12.1 of a possible total score of 43. In December 2005, 17 Cohort I students took the same test and their average score was 16.5, for an improvement of 4.4 points. Twelve of students' test scores increased and five of the twelve increased by at least 5 points.

In April 2006, 9 students from Cohort I retook the test, scoring an average of 24.4. Between December 2005 and April 2006, the students average test scores increased by 7.9 points. Seven students' test scores increased, and five of the seven increased by at least 5 points. The average score increase over the three testing periods was 12.3 points.

Cohort II students were added to the program in the spring of 2006. They were given the science content test on June 26, 2006 as a pre-test and July 20, 2006 as a post-test. Thirteen students took the pre-test; 12 of these students also took the post-test. The average pre-test score was 12.6 and the average post-test score was 23.8 (of 43). All twelve students increased their test scores—one by as much as 14.4 points.

During Summer 2006, Cohort I took another science content test that would measure prerequisite knowledge of the photonics content they would learn during the summer. This science content test contained 4 multiple-choice questions. The following topics are covered on the test: laser beams and the characteristics of their paths, waves, and electronic circuits. Students received one point for each correct answer for a total possible 4 points.

Cohort I took the second science content assessment as a pre-test on June 26, 2006 and as a post-test on July 20, 2006. Twelve students took the pre-test with an average test score of 2.8 of 4. Eight of the twelve students took the post-test with an average score of 2.9 of 4.

The strongest predictors of student content post-test scores were their weighted high school GPAs upon entering the program. The correlation coefficient was .53.

Writing and Science content prompts

In addition to the Science Content Assessment, the students are periodically given science-related prompts—small scenarios in which they are required to write how they would react in such a situation. Some are specifically related to the Photonics Leaders curriculum; others are more generally scientific. Students are graded not only for the content of their response, but also for their writing skills. Students receive scores of 0-4 in each of these categories. Students are given 6 prompts a year, three in the fall and three in the spring. After each prompt is scored, a short feedback summary is provided to the director of the Photonics program so that feedback can be provided to the students for continued improvement. Following are examples of prompts given in the fall and spring.

Prompt 1: Cell Phone Prompt
Prompt 2: Telescope Prompt
Prompt 3: Fiber Optic Prompt
Prompt 4: Laser Range Finder Prompt

The writing and content prompt results follow:

Cell phone prompt

There is a fear that using a cell phone can be damaging to health. Sociologists, economists, scientists and politicians all have opinions on how to respond. If you were a scientist, how would you investigate this issue?
Both Cohorts I and II completed the first prompt, and Cohort I have completed it twice—once during their first year and again during their second year. Among Cohort I students, their writing improved tremendously from the first year to the next. In the first year, nine students from Cohort I answered this prompt. Of the seven students who retook the cell phone prompt in Year 2, six improved their scores. None of these students received a 4 in the first year, and only one student received a 3. When they retook the test, four received a 4 and two received a 3. Their average writing scores went from 1.8 to 3.1.

Cohort I science content grades also improved and students took different scientific views of the problem. Some treated the problem as if cell phones were damaging to use while driving because they might cause accidents. Others would examine potentially harmful emissions from the phone itself. Both were legitimate ways to address the prompt. Their science scores improved from an average of 1.1 to 2.0.

Cohort II responded to this prompt during their first year. Although no comparisons can yet be made regarding their own improvement, their writing scores were higher than the first writing scores of Cohort I for the same prompt. Their average writing scores were 3.1; their average science scores were 2.2.

Telescope prompt

You work for NASA and are in charge of tours for middle school students. One asks you what a telescope is and how it works. How would you respond?
Cohort I responded to this same prompt during Year 1 and during Year 2. Nine students answered this prompt during Year 1, and seven of these nine answered it again in Year 2. Again, writing scores improved dramatically, with only one student receiving a 4 and one student receiving a 3 initially, and four of the seven students receiving scores of 4 during their Year 2 attempt. Average writing scores improved from 2.2 to 3.4.

Five of nine students from Cohort I received scores of 1 for their science content the first time they responded to the prompt. Of the seven who responded again during Year 2, four received scores of 3, and nearly all improved. Average science content scores went from 1.6 to 2.6.

Fifteen students from Cohort II responded to this prompt, and 8 of the 15 received scores of 4 for their writing. The writing score average for all 15 was 3.0. Their average science content score (1.9) was slightly higher than the first Cohort's average.

Fiber Optic Prompt

You are a fiber optics expert. Describe several real world applications of fiber optics and its importance to a seventh grade student, friend or parent.

Both Cohorts I and II took this prompt in November 2006 for the first time. Four students from Cohort I and nine students from Cohort II completed this prompt. The three Cohort I students averaged 3.0 for their writing scores and 3.0 for their science content scores. The nine Cohort II students scored higher with averages of 3.8 for both their writing and science content scores.

Laser-Range Finder Prompt

What is a laser range finder used to measure and describe how you would use this device to carry out an experiment related to applications of photonics in engineering, chemistry or biology?

This prompt was given to Cohorts I and II for the first time in March 2007. Nine Cohort I students and 19 Cohort II students completed this prompt. The Cohort I students averaged 3.3 on their writing scores and 3.1 on their science content scores. Again, the Cohort II students scored higher, averaging 3.6 on their writing and 3.4 and their science content.

Student Presentations

Students are given a number of opportunities to horn their oral communications skills. They are coached in presentation skills and the development of a professional image, including appropriate attire. The presentations are also an opportunity to demonstrate what they have learned about various topics in photonics.

Students gave brief presentations demonstrating their knowledge and understanding of Photonics for their classmates and instructors. The first presentations were on various topics related to sound. The second presentations were on various topics related to lenses. At the end of the spring semester, and again at the end of the summer program, students gave presentations before an audience of their classmates, instructors, parents, industry and university supporters as well as The Science House staff. The presentations were very well received. Students dressed professionally, and the presentations showed evidence of careful preparation and scientific knowledge.

In the spring, students were asked to choose a photonics-related topic to present. Topics were wide-ranging and reflected the students' interests and comprehension of physics concepts as they related to photonics. For the first time, students were required to accompany their talks with a visual aid. The students were also required to prepare a poster for a session following the oral presentations. In many cases, the posters produced did double duty as a visual aid for the presentation, although some students chose to produce PowerPoint presentations. Most students demonstrated excellent speaking skills–appropriate posture, eye contact, volume, etc. Some students found that their visual aids were too small for the audience to see well. Some students also found themselves facing the visual aid instead of the audience.

During the summer, each student built a device that worked based on photonic/optoelectronic principles. One element that stood out was the students' ability to discuss how their finished projects were suppose to work. Students whose projects didn't work were able to articulate hypotheses as to why the devices didn't work. Most were not discouraged, and their problems were often not the result of carelessness, but rather too many things having to go right for the end result to work. Students readily admitted their mistakes, which often included soldering improperly (a skill which takes practice), ambiguous directions (two young men told how the directions instructed them to use a "grown" resistor, and they weren't sure if it meant "green" or "brown"), etc. Many of the "failures" were actually successes, in that the students knew what probably went wrong and how they would do it differently. They were also able to articulate many scientific properties of their devices. One young man who successfully produced a random number generator told why it was actually more random than throwing dice, and explained the variables involved in the latter. One student who produced a laser mouse with a microphone told how she now understood how her remote control for her television worked. The students who did not produce successful devices seemed to learn as much as those who did.

Seven Cohort I students gave presentations in both the spring 2006 and the summer 2006. Students were graded on a 4.0 scale. Students improved in nearly every area of presentation and delivery, with the most dramatic improvement in the use of visual aids.

"What I learned mostly from the lab is that even if something does not work perfectly, you can still gain something from it…. This has opened me up to do more technology-based things other than just a business type career. I want to do things that are more hands-on now."—a Photonics Leader student presenting her random number generator in which only one die of two

The presentations were overall a successful element of the program. One could see growth in the students throughout the year. As their presentations became more polished and their scientific knowledge increased, their enthusiasm also became more apparent. The students seemed to be enjoying the program and appreciating the opportunity to learn sophisticated science.

Interests and Aspirations in STEM

During the 2005-2006 program year, 22 students from Cohort I reported on their career interests. The majority of them (73%) reported interests in STEM careers both at the beginning and end of the year. Students' career aspirations did not change during the year.

In fall 2006, both Cohorts I & II students responded to questions about career interests and intended college majors. Of the 32 students, 20 (63%) listed STEM-related careers such as computer and aerospace engineering and the science of medicine and pharmacology.

Data Summary

Evaluation outcomes in science content knowledge indicated the average scores of the participants have constantly increased from three to twelve points during each testing. In writing and content prompts Cohort II students are scoring consistently higher in their writing as compared to the scores of Cohort I who's skills have steadily improved over time. Student presentation skills have demonstrated significant improvement over time due to the increase photonics knowledge with ability to organize content, delivery and producing appropriate visual aids and scientific models. Tremendous student growth was noted in this area—from students being unable to speak for 90 seconds to running out of time in a three to five minute presentation. Interest and aspirations reflect the least amount of change due to the majority of the students participating in these programs come highly motivated and dreams of pursuing a degree and or career in the STEM discipline.

At the closing of the Photonics Leaders spring session, twelve of the eighteen parents in attendance shared their perceived impacts of the program:

- 67% of parents believe that the Photonics Leaders program has helped their child decide on a specific career or college, considering they entered the program with an interest in science, technology, engineering and mathematics
- 50% of parents believe their child has benefited from the program
- 25% of students have included NC State in their list of potential colleges.
- 17% say that their child is more organized.

The Burroughs Wellcome Student Science Enrichment Program Survey (SSEP) shows that 81% of students who participate in the Photonics programs have a better understanding of a scientist's role, have learned information useful in their science class and are eager to share the Photonics Leaders program with family and friends.

The programs have done a stellar job of targeting minority students. Seventy-five percent of participants are African American, nine percent are Asian/Pacific Islander, 14 percent are Caucasian and two percent are Hispanic. Forty-six percent are male and 54 percent female. Ninety-one percent of the students experienced a successful encounter and have a better understanding of photonics according to *BWF SSEP Student Feedback Survey*.

Conclusion

Our complex society of today requires students that can analyze and respond to issues based on an ever-changing knowledge base, which will require students to go beyond memorizing facts by taking initiative and responsibility for their learning. An inquiry–based learning environment provides opportunities for children to do science and learn the problem-solving processes used in communication and thinking skills required for the 21st century.

If North Carolina and the United States wish to remain globally and economically competitive, we must better prepare students and teachers by garnering significant corporate and community support emphasizing the value of science and mathematics. Intervention must occur early to help all children realize that science and technology are a good "fit" for them before something else "hooks" their attention.

At Imhotep Academy we are committed to empowering a new generation of productive young people and to challenge them to pursue academic excellence and become technologically savvy so they can improve their career choices. Instead of cutting programming we should be expanding our program offerings by

- Leveraging resources from parents, partners, and community leaders to ensure program growth and sustainability.
- Ongoing recruitment of outstanding teachers and students with a passion for science, mathematics and technology.
- Keeping students engaged and motivated through inquiry instruction in all classes from elementary through college.
- Providing opportunities for high school students to mentor other Imhotep students.
- Building parents' awareness of preparing students for a 'flat' world.
- Encouraging high school graduates especially Photonics Leaders to affiliate with the Undergraduate Research Symposium pipeline.
- Incorporating teacher training and developing an evaluation plan for longitudinal documentation of program.
- Publishing the impact of parent, community, university and corporate networks on informal science learning programs at The Science House.
- Incorporating program components to support participants in the program from middle school, high school, college and career and measure the longitudinal impact.
- Developing a seamless curriculum to sustain students through the educational process of becoming future scientists, mentors and technology experts.
- Finding additional grant funding to increase program offerings.

Besides being a multitalented genius, students are reminded that Imhotep means, "to come in peace" and being a part of the global community we must all work together to save our future generation by the choices we make today. This challenges us to scale up the program offerings and makes the program an international model of success for introducing underrepresented students to emerging careers and opportunities in the scientific community and the global workplace.

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II.

Report on an Optics Outreach Program in Montréal

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Abstract: In accordance with its mission, the Student Chapter of the Optical Society of America (OSA) in École Polytechnique de Montréal organises numerous outreach activities to trigger the interest of students 6-17 years of age in optics. In the last two years, these workshops have attracted over 450 students.

OCIS codes: (000.2060) Education, (000.1200) Announcements, awards, news, and organizational activities

1. Chapter Outreach Activities Background

One part of Optical Society of America's (OSA) mission is to disseminate information about optics and photonics worldwide. As a way to reach this goal, it creates and finances regional student chapters who would do educational outreach. The OSA Student Chapter of École Polytechnique de Montréal has been founded in 2003 with optics education in mind as one of its main goals. In the last years, we decided to focus our activities on outreaching young people in order to encourage them to pursue their studies in the field of optics. We strongly believe in the importance of this mission because it attracts young students to the fascinating field of optics and hence we participate in forming the next generation of engineers and scientists in our domain, and because, at the same time, it increases the awareness of decision makers of tomorrow about the importance of scientific work. We started our mission by demonstrating exciting optics phenomena to students in university's open houses and in events we organised at the university. Our activities were very much appreciated by young people and demands for demonstrations increased. Meanwhile, we realised that hands-on activities would be even more captivating than demonstrations and decided to duplicate the setups to enable student direct participation in the activities. Hence, our outreach programs have developed into hands-on activities designed for teams of two and are very successful. These activities effectively captivate younger kids and teach wave properties of light, properties of waveguides, electronic circuits and optical signal modulation with their applications in telecommunication to middle and high school students. In this paper we describe six of our most successful activities.

2. Description of the Activities

In order to effectively reach a significant number of students, the activities organised are often integrated into other events such as university open houses, annual science fairs and "Girls and Science" programs [1]. It allows us to benefit from the organisation, publicity and infrastructure of the event such that we can concentrate on the preparation of the activity itself. To reach even more students, the Chapter also gives hands-on courses to groups of teachers so they can spread the knowledge in their schools. The Chapter has also published an optics teaching manual that is distributed to some high-schools [2] and is available free of charge to all teachers in Québec's province (Canada). Table 1 summarises the activities we have organised thus far and gives some information about the time and money required to organise these activities. Details about each activity follow.

Table 1: Summary of activities and heritage on preparation time and cost of the activities

Activity	**Gelatine waveguide workshop**	**Telecommunication hands-on activity**	***Extreme Microwave* presentation**	**Liquid crystals activity**	**Special hands-on activity for teachers**	**Optics outreach activity guide**
Targeted audience	Middle and high school students	Middle and high school students	Students and parents	High school teachers	High school teachers	High school teachers
Number of participants in each activity session	10 to 40	10 to 40	80 to 250	40	40	–
Event	Open house, "Girls and Science"	Open house	Open house, autonomous activity	"Girls and Science"	"Girls and Science"	–
Preparation time to build the kit	3 hours	40 hours	10 hours	3 hours	10 hours	80 hours
Preparation time for each session	1 hour	1 hour	1 hour	–	2 hours	–
Minimum activity length	30 min	30 min	60 min	30 min	1 hour	–
Cost ($US) to build the kits	50	485	50	–	–	–
Cost of each session for 10 teams ($US)	5	10	10	10	25	–
Note	Gelatine and telecommunication activities are often joined into a single activity		Setup cost does not include the microwave oven	Our initial setup is kindly provided by Dr. Jacobs [3]	We used material from our other activities	Financed and edited by a non-profit organisation

a) Gelatine Waveguide Workshop

The gelatine workshop is a hands-on activity where transparent gelatine is used to create waveguides and a laser pointer is used as a source to teach the principles of total internal reflection, light propagation in bent waveguides and optical couplers to middle and high school students.

We normally arrange the seats in the room to facilitate having 10 teams of two or three students. Usually three Chapter members lead this activity. One member first introduces the activity with a short presentation on the general concepts behind waveguides, including total internal reflection and its role in transferring light into media such as optical fibres. Each team receives a piece of gelatine, a ruler, a knife, a plastic tablemat and napkins, plus a regular red laser pointer. They are led to observe the total internal reflection of red laser light in straight and bent gelatine slabs, and to create different optical devices such as waveguides, power splitters and couplers while the presenter explains how light travels in a bent fibre and optical couplers. During this time, the two other members answer questions and assist the teams by making sure they follow the required steps

To prepare the gelatine (Table 2) before the activity, 6 pounds of unflavoured cooking Knox™ gelatine [4] is mixed with 1 litre of warm water. Then, the mixture is poured into a plate to form a 2-cm thick gelatine slab and chilled until set before being cut into 6 cm x 20 cm pieces to be used to create the waveguides.

Table 2: Gelatine waveguide workshop material required for ten teams of two or three students

Quantity	**Material**	**Approximate Total Cost [$US]**
12 pouches	Knox gelatine	3
10	Laser pointers	10
10	Rulers	10
10	Cutters	10
10	Tablemats	10
2	Container to prepare the gelatine	Borrowed from Chapter members
1	Pack of wet napkins	3

The use of gelatine and red laser light provides a vivid visual reference to students for some of the most important and fundamental applications of waveguides, which are the basis of telecommunication systems. The pedagogic impact of the image of red laser light internally reflecting off the walls of gelatine waveguide as well as the beam of light being divided into two paths and propagating in different branches in a gelatine coupler on the students' long-term learning cannot be overstated.

Figure 1: Total internal reflection occurring in gelatine waveguides

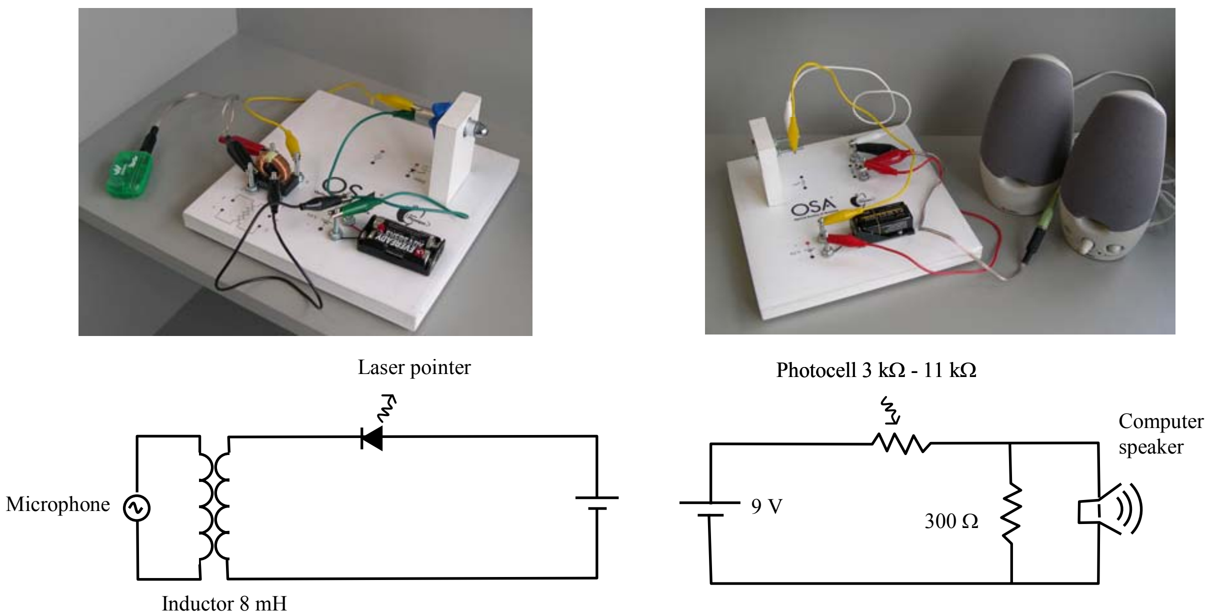
b) Telecommunication Hands-on Activity

The telecommunication hands-on activity works as the complement of the gelatine waveguide activity and gives a broad view of telecommunication systems to students. Hence the students are in 10 teams of two or three and 3 chapter members lead the activity. Before starting the practical part, we carry on a short brainstorming session on the meaning of telecommunication, and we give a theoretical presentation on the extent of the global telecommunication system and its usage in daily life such as telephone conversations.

Figure 2: Teaching transmission of data by optical pulses

Each group receives a telecom kit (Figure 3 and Table 3) designed and built by our Student Chapter to demonstrate the implementation of a circuit transmitting sound through an optical signal. These kits are designed with an emphasis on ease of use for participants, both in terms of understanding the electric circuits involved and practical method of connecting the components.

The kit consists of two boards, one for the emitter circuit and one for the receiver circuit. On the emitter side, the sound signal to be emitted is converted to an optical signal through a laser pointer. The optical signal is then transmitted either through free space or through a gelatine waveguide to the receiver side. The receiver side uses a photo-cell to convert the optical signal back to an electric signal to feed the speaker load. All components of the circuits are fixed on the kit boards with long screws used as connectors. Participants can easily connect the appropriate screws using wires with alligator clips to close the circuits. For each setup, an AM/FM radio or an amplified microphone bought in a dollar store is used as the input sound source. Alternatively, the participants may use their own MP3 player. The output is a pair of standard computer speakers.



(a

(b)

Figure 3: Emitter (a) and receiver (b) circuits mounted on individual boards.

Table 3: Telecom kit material required for ten teams

Quantity	Part Number (Digi-Key Corporation)	Material	Approximate Total Cost [$US]
20	–	8"x 8" wooden boards	150
10	–	Amplified microphones	10
10	–	AM/FM radios	10
10	–	Computer speakers	100
1 pack	–	Screws	5
1 pack	–	Nuts	5
1 pack	–	Washers	5
10	PDV-P8001-ND	Photocells 3kΩ–11kΩ ohm, 5.10 mm	22
10	OD301J-ND	Resistors, 300 Ω, 0.25 W	4
10	BH9V-W-ND	9 V battery holders	8
10	2463K-ND	2 AA battery holders, 6" lead	
10	237-1232-ND	Inductors, 8 mH	40
10	GC396-ND	Wire test leads, 27 awg, 15"	58
20	CP-2410-ND	Alligator clips, 44 mm, black	9
25	CP-2411-ND	Alligator clips, 44 mm, red	11
1	W200-100-ND	Speaker wire, 22 awg, 100'	7
10	CP-3506-ND	3.5 mm connectors, female, mono	11
20	CP-3501-ND	3.5 mm connectors, male power plug	13
10	–	Laser pointers	10

The telecommunication hands-on activity proves to the students that learning optics and technology is not beyond their reach and capability. During this activity, in addition to learning the principles of telecommunication and the concept of signal conversion from sound to electric to optical and vice versa, students obtain hands-on experience in mounting complete electric circuits, aligning laser light so that it reaches its destination. Other than the excitement and satisfaction of learning about one of the most important contemporary technologies, finishing the task provides them with a sense of achievement and increases their confidence in their ability to learn and do science.

c) Extreme Microwave Presentation

The *Extreme Microwave* presentation showcases amazing optical phenomena triggered by the common kitchen microwave oven (Table 4). During the microwave shows, the basic principles of microwave ovens are first explained to participants. Then, we describe the optical phenomena that underlie the creation of electric-arcs in the oven using a piece of carrot, the generation of sparks using steel wool, the creation of a plasma with a common wax candle, and the creation of luminous worms moving in a fractal pattern for example on a compact disk (CD). To accommodate a large audience with a single oven, a webcam is used to project the live image of the oven interior on a giant screen. Over the years, we found that best results are achieved with ovens that do not use a wave stirrer fan and hence create intense localised hotspots due to constructive interference. These are usually the ones that are equipped with a turntable inside. In order to reach the optimum result, the turning plate should be removed and the experimental object should be placed in the oven where constructive interference arises.

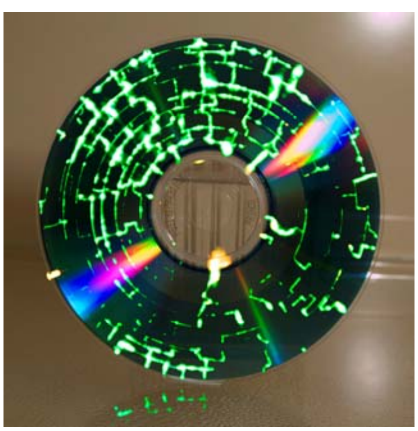
(a)  (b) 

Figure 4: Optical phenomenon observed with a CD (a) and a carrot (b) in a common kitchen microwave oven

Table 4: Examples of objects experimented during *Extreme Microwave* presentations

Object	Effect	Note
CD and DVD	Creation of fine green luminous worms moving on the disk surface	CD-RW, CD-R and CDs that are volume printed like the ones we get when we buy software give different results.
Carrot and grape	Creation of plasma at the junction between the two halves.	Carrots must be cut with a tapered center (see figure 4-b). The grapes must be almost completely cut in halves, keeping the skin to connect the two halves.
Incandescent light bulb	Light bulb's filament will light and stable plasma can be created in the bulb.	Clear light bulbs are preferable. Letting the plasma run in the bulb might melt the bulb and create a nice shape after the glass blows up.
Fluorescent tube	Tube will light.	
Steal wool	Steel wool will catch fire.	A small quantity of steel wool should be used since it creates a lot of smoke and might be difficult to extinguish.
Lit candle	Creation of a plasma ball floating in the microwave.	It is possible to stabilise the plasma ball if the candle is put under a large glass bowl.

The microwave demonstrations are very effective in attracting the interest of a very large public during events such as university open houses. The activity is such a resounding success every time that a 250-seat university amphitheatre is filled easily. Kids, teenagers and adults of every age are eager to see the spectacular demonstrations which are heavily publicised. Most adults and people with a scientific background are fond of hearing about plasmas, energy conversion from microwave energy to visible light, and electric discharges on CDs. For their part, kids are principally interested in the spectacular results themselves.

d) Liquid Crystals Activity

During the fifth annual OSA Student Chapter leadership meeting held on October 2006, Dr. Stephen D. Jacobs and his group from University of Rochester [3] introduced a very intriguing educational kit on liquid crystals. Using this kit, the optical properties of liquid crystals and their dependence on temperature is taught to students through the making of mood patches that change their color according to body temperature. One can then point out the many applications of liquid crystals to today's technology.

Thus far, we have trained a group of teachers to use this liquid crystal kit. Two members were needed for this activity. One member helped each team with the practical section, while the other explained the theoretical presentation. In the workshop, we explained the necessary scientific background then helped them go through the kit once and make mood patches themselves. To provide better support for teachers to give the activity in their classrooms, we supplied them with detailed instructions and information provided by Dr. Jacobs.

e) Special Hands-on Activity for Teachers

We have optimised our strategy to reach more students using the means available to us by targeting teachers. In fact, we decided to train high school teachers to use our setups so they can directly use our outreach activities in their own classes. Recently, we gave our first demonstration to a group of 40 teachers in the framework of a "Girls and Science" event [1] in Montreal. Teachers received training to prepare the material to perform the gelatine and telecommunication activities as well as the liquid crystal experiment.

In order to help teachers reproduce the activities in their classes, the Chapter has offered to provide them with detailed instructions on how to build the telecommunication kits and has offered to go once to their classroom and help them with the activity. The Chapter also lends all the material and setups to teachers who request it, free of charge.

The teachers who attended the workshop obtained a high level of comfort with the scientific content and felt quite confident about performing the activities in their classrooms. They showed a lot of interest in our kits. Although our Chapter has offered to lend the kits to teachers, no teacher has made a request yet, but they have rather requested detailed instructions to build their own setups. We hope the full support and all the information we have provided for teachers completely enables them to carry on the activities in their classrooms.

f) Optics Outreach Activity Guide

Another way we found to reach high school teachers was to publish a manual on optics outreach activities. We wrote a guide [2] that provides detailed guidelines about how to give interesting and engaging hands-on activities with light. It addresses science teachers who already have knowledge of refraction but are not comfortable with explaining guided optics concepts. The manual first explains the fundamentals of fibre optics and gives the scope of the activity. Then, it describes three activity modules: refraction of light, total internal reflection and waveguides. The activities use fish tanks, gelatine and laser pointers to demonstrate the concepts. For each activity, the guide gives the list of material, detailed instructions to give the activity and the explanations to be given to students. At the end of the guide, wrap-up questions and discussion topics are suggested. Our guide will be distributed in Quebec province (Canada) high-schools by our editor who has kindly waived all fees for this publication. The editor, CHAPOP, is a non-profit organisation whose mission is to support young people through the development of individual and social skills. Their goals achieved in publishing our guide are to heighten teenagers' awareness in choosing a career in sciences and technologies and reinforce teenagers' motivation and determination to study.

3. Results and conclusion

The participants in our activities give us excellent feedback. We distributed a survey to measure their satisfaction in some open houses. The attendants were mainly composed of high school students and their parents. 97 % of them have rated our outreach activities 'very' or 'extremely' interesting, while finding the workshops to be captivating, complete and instructive. Some even declared that they now seriously consider pursuing studies in optics.

Up to now, we have given our demonstrations and hands-on activities to approximately 450 students from grade school to university level. The described activities have fulfilled the Chapter's objectives by providing an opportunity for young students to interact with scientists and presenting optics concepts which may not be part of their regular school curriculum. Participants' testimonials lead us to believe that we have left participants with an attractive image of the field of optics.

4. Acknowledgement

The authors thank all the members of École Polytechnique OSA Student Chapter for their hard work. They also sincerely appreciate the teaching material and the liquid crystals kits that were courteously provided to the Chapter by Dr. Stephen D. Jacobs. Student chapter's activities are financially supported by OSA Student Chapter activity grants and by the Engineering Physics Department of École Polytechnique de Montréal.

5. References

[1] See http://www.lesfillesetlessciences.ca/

[2] M. Aubé and F. Busque, "La fibre optique : l'autoroute de la lumière", Chantier d'apprentissage optimal – CHAPOP, Montreal, 2007, 22 p. The manual can be obtained by writing to the editor at info@chapop.ca.

[3] The instructions to find material are distributed free of charge by Dr. Stephen D. Jacobs (sjac@lle.rochester.edu).

[4] Michael E. Knotts, "Optic Fun With Gelatin", Optics and Photonics News, (50), April, 1997

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III.

A simple and effective 'first' optical image processing experiment

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Abstract: Optical image processing experiments can contribute to an understanding of optical diffraction and lens image formation. We are trying to discover a highly effective way of introducing lens imaging and related topics, light scattering, point sources, spatially coherent light, and image processing, in a laboratory-based holography-centered introductory optics course serving a mixture of physics, chemistry, and science education sophomores and juniors. As an early experiment in this course, a microscope slide bearing opaque stick-on letters forming a word such as PAL is back-lighted by a point source of laser light. The surround for the letter A is transparent, while the surround for the letters P and L is made translucent with Scotch MAGIC^{TM} tape. A 20-cm focal length converging lens forms a bright image of PAL on a screen, and also an image of the laser point source in a (transform) plane between the lens and the screen. Students are startled when they see that they can choose to pass only the image of the letter "A" or only the images of "P" and "L," by very simple manipulations in the transform plane. The interpretation of these experiments is challenging for some students, and the experiments can lead to a significant amount of discussion. Useful explanatory ray diagrams will be presented. Many demonstrations of optical image processing require long focal length lenses and precise manipulation of somewhat complex passing/blocking filters. In contrast these experiments are easy to set up and easy to perform. Students can fabricate the required objects in a matter of minutes. The use of zero-order laser light helps students discover the essential simplicity of the ideas underlying image processing. The simultaneous presence of both scattered (spatially incoherent) and not scattered (spatially coherent) laser light is thought provoking. Current explorations to further develop these and other closely-related experiments will also be described.

1. Introduction (Purposes, Related literature, related methods; outline of paper)

Our objective is to introduce students to lens imaging in the context of optical image processing. In addition students are introduced to light scattering (clean glass versus translucent tape), point sources. Better students discover basic ideas about depth of focus as influenced by aperture diameter. The experiments described were created for use in a laboratory-based holography-centered introductory optics course serving a mixture of physics, chemistry, and science education sophomores and juniors. The experimental apparatus and experimental procedures described introducing lens imaging in the context of optical image processing. The author believes the apparatus and procedures described are simpler than any described elsewhere. Because of this simplicity, they can be used with almost no previous experience with lens imagine. Despite this simplicity, they seem very effective as an introduction to optical image processing.

Optical image processing is introduced in most sophomore-junior level optics texts[1]. A second source of information on optical image processing and optical diffraction is a set of lab experiments authored by Arthur Eisenkraft, and distributed for many years by the Metrologic Corporation. These materials are still available through the company Industrial Fiber Optics[2]. A very attractive apparatus for teaching optical image processing is the house diffraction plate, an apparatus created by Ronald Bergsten, at the University of Wisconsin, Whitewater. The Bergsten diffraction plate is based on a diffractive method of color imaging first described by J. D. Armitage and A. W. Lohmann[3]. Our method is simpler to implement than any of the previously described methods. Also, since it uses zero-order laser light, and no diffraction grating, it is easier for the beginning optics student to grasp. In previous experiments, the distinction is between low-spatial frequency and high-spatial frequency diffraction gratings. In our method, the distinction emphasized is between scattered laser light (spatially incoherent laser light) and non-scattered spatially coherent laser light. The objects utilized are microscope slides with attached opaque letters, and Scotch Magic^{TM} tape. A razor blade or thumbtack serves well filter. The manipulations are not 'critical' or stressful.

The experimental arrangements, and the basic phenomena, are described in some detail in Section 2. In Section 3 diagrams that are useful for interpreting the results are discussed. In Section 4 comments are made on how this apparatus relates to previous experiments, and how the objects described in this report might be further elaborated.

2. Experimental procedures and results

2.1. Objects used

In Figures 1 and 2 examples of objects used are shown. Figure 1 shows the word ALE affixed to a 25 mm by 75 mm microscope slide. The three letters are formed by opaque stick-on (or dry-transfer) figures. Words containing a ‘pointing’ letter, like the letter A, work well to highlight when an image has, or has not, been inverted. In our experiments two of the letters had a translucent surround, and one had a transparent surround[4]. The translucent surround was fabricated by covering the letters L and E, and the surrounding region, with Scotch MAGIC™ tape. See the L and the E in Fig. 1 and the W and the G in Fig. 2, as examples. However, the letter ‘A’ had a transparent surround. The transparent surround was arranged simply by placing no tape over the letter or its surrounding region, and by keeping the glass clean, to minimize light scattering. See the letter ‘A’, in ALE in Fig. 1 and the letter ‘A’ in WAG, in Fig 2, as examples.

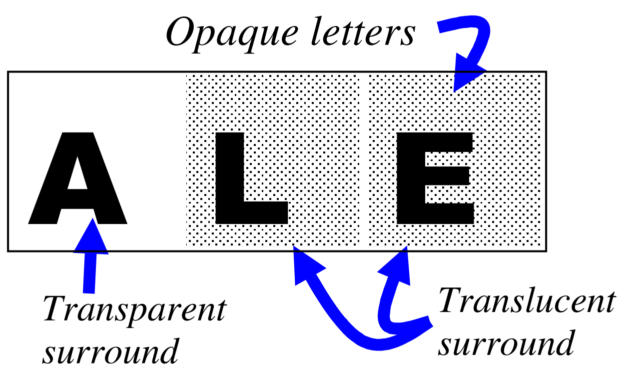

Figure 1 An example of a translucent-transparent object.

The strong scattering characteristic of the Scotch MAGIC™ tape, and the lack of scattering by the clean microscope slide, are demonstrated in Fig. 2. A photograph is shown of a back-lighted transparent-translucent microscope slide, bearing the three figures W, A and G, formed by placing a camera at a slightly off-axis location. The letters with a translucent surround are highly visible, while, in a darkened room, the letter “A,” which has a transparent surround, has low visibility.

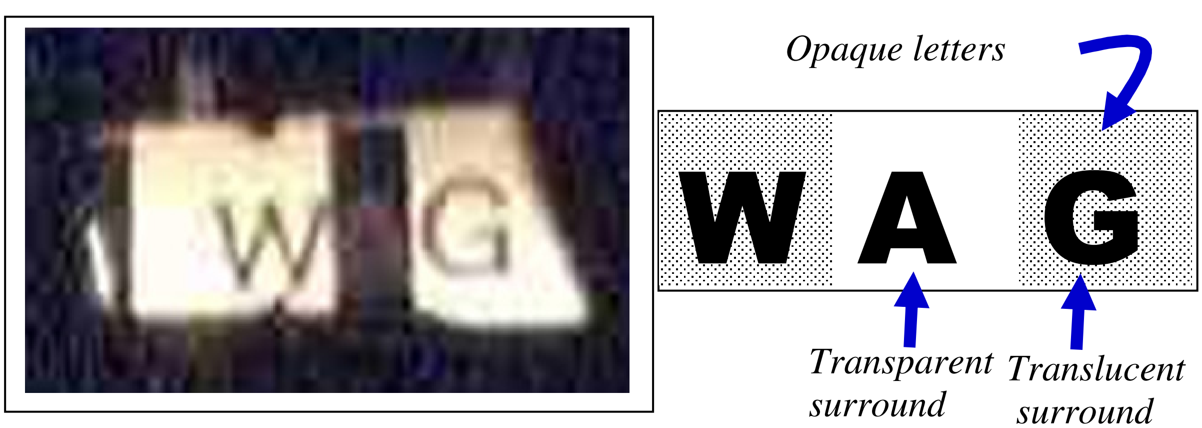

Fig 2. Photograph of the back-lighted translucent-transparent object shown on right.

2.2. Experimental arrangement

Figure 3, below, shows the basic experimental arrangement. For clarity, the system is shown twice in Fig. 3. In 3a), the light rays that have been scattered by the translucent tape on the microscope slide are emphasized. In 3b the light rays that pass through the transparent regions of the slide are emphasized.

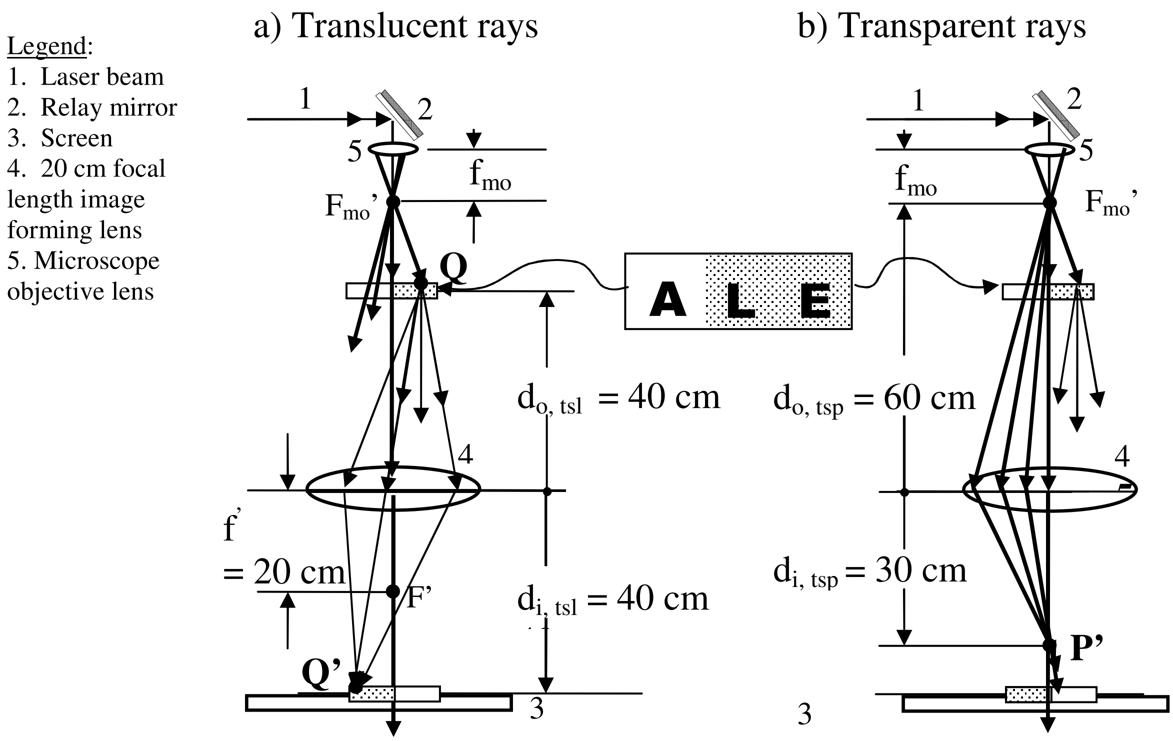

Figure 3. Translucent light rays (3a) and transparent light rays (3b) are shown. Both types of rays transit the system simultaneously. For the purpose of clarity, two drawings are introduced.

We will refer to light that has been scattered by the translucent tape as "translucent light." We will refer to light that has not been scattered by its passage through the microscope slide as "transparent light," because it has passed through one of the transparent regions of the microscope slides.

Two different object distances are involved in this optical system. The point source of the transparent light is at a different distance from the lens than the point sources of the translucent light. In Fig. 3, the point source of the transparent light is the focal point (F_{mo}') of the beam spreading microscope objective lens. F_{mo}' might be $d_{o,\, tsp} = 60$ cm from the image forming lens (or usually even more). In contrast, the point sources of the translucent light are distributed over the surface of the tape that covers portions of the microscope slide. The tape is two focal lengths ($d_{o,\, tsl} = 40$ cm) from the 20 cm focal length image forming lens. We might think of the translucent tape as consisting of a large number of tiny "point-sized" randomly oriented and randomly sized prisms, Each of these tiny prisms directs its portion of the incident light in a different direction. Thus each part of the tape sends light out in all directions (like a tiny pinhole), but accomplishes this without absorbing or blocking much of the light.

Because there are two different object planes, one at 60 cm and one at 40 cm from the imaging lens, there are also two different conjugate planes.

- For the translucent light:

- The object plane is the surface of the translucent scattering tape, at $d_{o,\,tsl} = 40$ cm[5].
- The conjugate image plane is at $d_{i,\,tsl} = 40$ cm. This assumes a converging imaging lens with a focal length of 20 cm.

- For the transparent light:
  - The object plane is at the focal point of the beam spreading microscope objective lens, $d_{o,\,tsp} = 60$ cm from the imaging lens in our example. This is the point F_{mo}' in Fig. 3b.
  - The conjugate image plane is at $d_{i,\,tsl} = +15$ cm, in our example. This is Point P' in fig. 3b.

Students perform this experiment twice, first back-lighting the object with parallel rays from a laser collimator, and second for a situation like that shown in Fig. 3, with the point source of the spatially coherent laser light at a non-infinite distance from the imaging lens ($d_{o,\,tsp} = +60$ cm in our example). When the laser point source is at infinity (collimated laser beam), the conjugate image plane for the transparent light is at the imaging lens focal length, i.e. at 20 cm in our example. On the other hand, if the point source of the laser beam is moved closer to the imaging lens (to $d_{o,\,tsp} = 60$ cm in our example), then the conjugate image plane moves further from the imaging lens, to a distance greater than 20 cm (to $d_{i,\,tsp} = 30$ cm in our example).

2.3. Phenomena observed

This relatively simple experimental arrangement provides a rich environment for exploration. Two main types of phenomena observed are shown in Figure 4 and in Figure 5.

Figure 4 (below) shows optical image processing in action.

- Case 1. Images of all three letters A, L and E are seen on a screen 40 cm past the imaging lens. In Fig. 4a, the razor blade is not utilized, and none of the light passing through the imaging lens is blocked. A clearly resolved image of the letters L and E results. These are focused images formed by translucent light, on a screen at 40 cm from the imaging lens. Also, an image of the letter A appears.
- Case 2. The image of the letter A is blocked/filtered. Images of L and E are seen. In Fig. 4b, the razor blade metal acts as a blocking filter for transparent light. At the same time, most of the translucent light passes around the razor blade. The clearly resolved images of the letters L and E, formed by translucent light, are seen on a screen 40 cm from the imaging lens. However, the transparent light is blocked if any small opaque object is placed at P' in Fig. 3b. The letter A does not appear. The region on the viewing screen surrounding the 'black letter A' turns dark, making the image of the 'black letter A' not visible.
- Case 3. The image of the letter A is passed; the images of L and E are blocked. In Fig. 4c, the small hole in the razor blade is placed at Point P' in Fig. 3b, and this hole passes most of the transparent light. The solid part of the razor blade is extended by black construction paper, causing most of the translucent light leaving the imaging lens to be blocked. Only the image of the letter A appears on the screen.

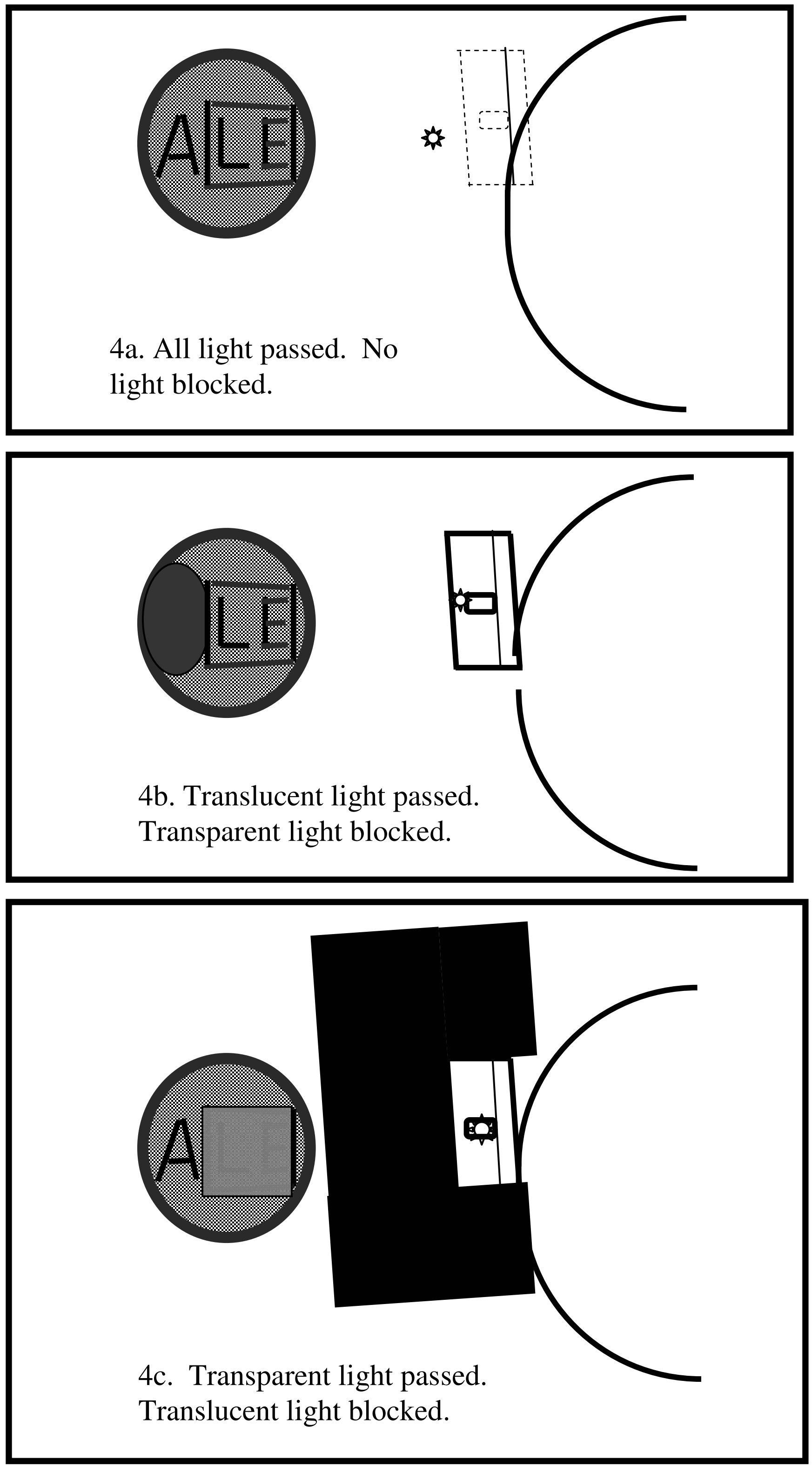

Figure 4. Optical image processing in action.

Figure 5 shows another dramatic phenomena, which quickly catches student's attention. Students see that the image of the letter A appears everywhere past the imaging screen.

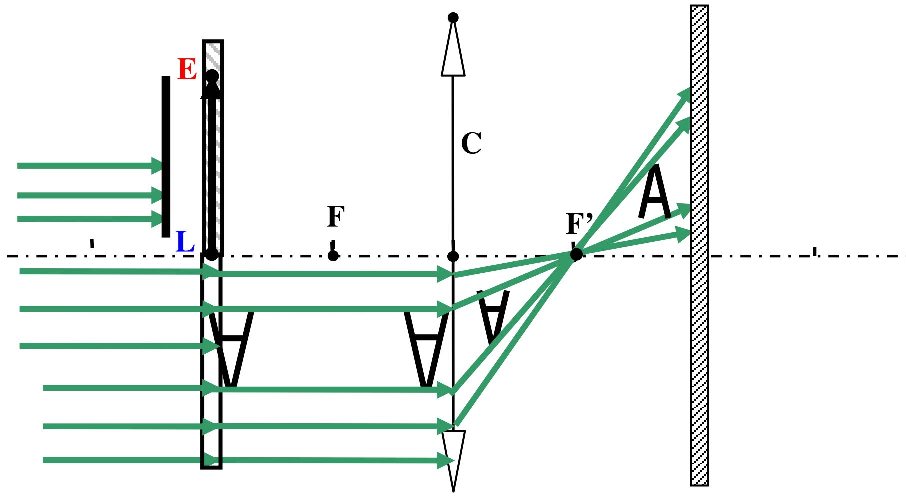

Figure 5. Transparent (unscattered) light is shown for the case of a collimated laser beam backlighting the object. The shadow of the opaque figure A is visible on a sheet of white paper placed anywhere between the microscope slide and the lens, and also anywhere between the lens and the viewing screen.

3. Ray models and discussion questions

Figure 5 serves both to describe an important observation, but also helps to explain this phenomena (the letter A is visible at many view screen locations). A main question then arises: Why is the letter A visible at essentially all locations of a screen, while the L and the E form clear images only for a very narrow range of screen locations. To move the discussion forward, a diagram like that shown in Fig. 6 can be introduced.

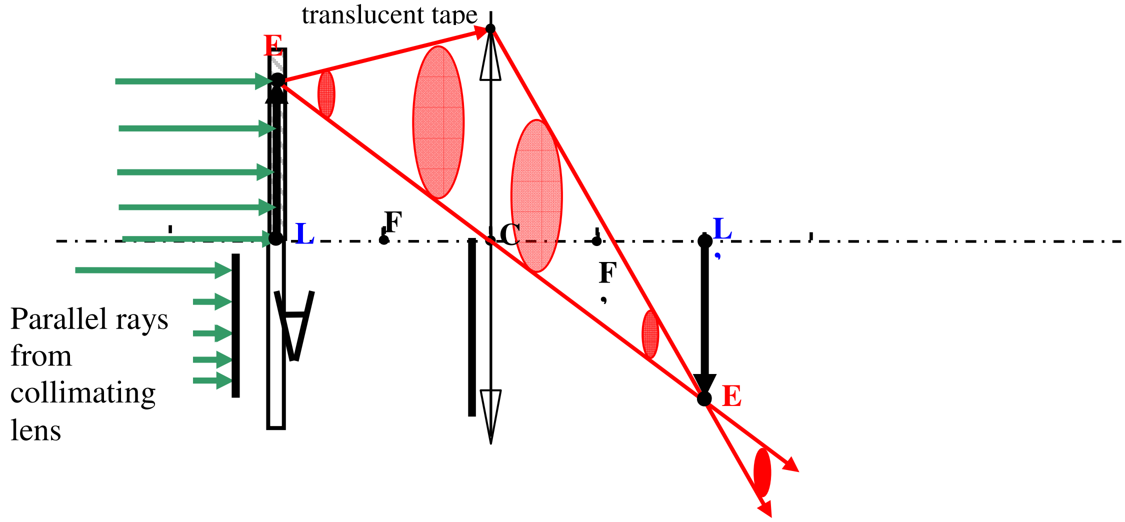

Fig. 6. Translucent light, i.e. light scattered from translucent "Magic" Scotch tape is emphasized. Transparent light is omitted from this diagram.

For a person experienced in optics, the theory underlying the formation of the focused image, as depicted in Fig. 6, should be familiar, and will not be discussed in detail here. We simply note that the quantitative part of the image location involves only the lens image position equation (1/do + 1/di = 1/f). The image size is treated by the lateral magnification equation m = hi/ho = (-1)(di/do). The theory of 'depth of focus' can also be introduced, because it comes natural to try to explain why the screen position has some tolerance for error, which forming the positions of the L and the E. However, the 'image' formed by the light passing through the transparent surround of the letter A, in ALE, for example, is not a conventional focused image. Explaining the behavior of the image of the letter A, and putting it in a proper perspective can challenge even the experienced student of optics.

In this author's opinion, one should avoid stating that the image of A is always 'in focus.' The image of the letter A is not a focused image. Focused images, both real and virtual have, as a main characteristic, that they have a definite location. The letter A, in the example being discussed, does not have a restricted image location. It is not a focused image of the type usually encountered in beginning imaging experiments.

Rather, what appears to be an image of the letter A is, in fact a 'shadow' analogous to the shadowing action of a pinhole in a pinhole camera. The opaque letter A, affixed to the microscope slide, and back-lighted with laser light is like a large aperture 'pinstop' camera. The shadow formed by the opaque letter A is carried wherever the transparent rays go, and so, quite dramatically, appears on a white sheet of paper moved to various locations on either side of the imaging lens. A dramatic indication of the presence of diffraction around the edges of the opaque letter A shows up on the screen in an experiment like that depicted in Figure 4b, if the transparent light is blocked by a push pin, rather than by a razor blade. Then the edge diffracted light is not focused into the same small region as the undiffracted light, and this edge diffracted light is not blocked by the push pin. Then, the shape of the letter A is outlined by a thin red line. In traditional optical image processing, this is regarded as a demonstration of 'optical differentiation.'

Several specific discussion questions have been formulated and presented to students to stimulate them to develop their thinking about the observed phenomena. Several are listed next, with brief answers.

Q1. Is the image of the letter 'A' a focused image? (Answer; No, because it has not definite location, unlike the letters of the L and the E.)

Q2. What is the image plane conjugate to the object plane occupied by the letters L and E? (Answer: The plane for which the letters L and E have the sharpest appearance. The point here is to introduce/review the concept of conjugate planes.)

Q3. What is the image plane conjugate to the laser point source? (Answer: It is the transform plane, the plane where the blocking/passing filters must be located to perform image processing[6]. This is a more sophisticated use of the concept of conjugate planes.)

Q4. What can we do to increase the range of variation of the viewing screen that is permitted when obtaining a clear viewing of the images of L and E? (Answer: Decrease the diameter of the imaging lens. An additional diagram that is an extension of Fig. 6 is useful here, to explain 'depth of focus.' Light scattered from two different points on the tape must be displayed, and discussed. The circle of confusion can be introduced.)

Q5. Identify a plane in which the images of L and E would be <u>least</u> well resolved. (Answer: The plane just after the image forming lens.)

Q6. Specify the location and form of a blocking filer for the letter A, given the lens focal length and the distance of the laser point source from the imaging lens. For the letters L and E. Similar for passing filters. (Answer: For the form, see Fig. 4. For the location, use the lens image position equation.[7])

Q7. What will happen to the image of the L and the E if one-half of the lens is blocked, say the upper half? (Answer: The images will become dimmer, but no single point on the L or the E will be completely blocked.)

Q8. What will happen to the image of the letter A if one-half of the upper half of the lens is blocked? (Answer: if the 'A' is well centered vertically, then one-half of the letter 'A' image will be blocked, while the other half will appear on a viewing screen anywhere past the lens.)

4. Conclusions

These experiments are a fun way to get started with imaging, and optical image processing. However, they are challenging for some beginning students. The next time I teach this experiment, I will try breaking the experiment down into three separate parts. 1. Give students a microscope slide having three opaque letters, and no translucent tape. 2. Give students a slide with three opaque letters, with all surrounding regions covered by tape. (No transparent light.) 3. Give students the translucent-transparent object, like those shown in Figures 1 and 2.

To further elaborate the object, it is very attractive to then proceed to the introduction of weak holographically formed diffraction gratings, for example with vertically spaced lines, to serve as a surround for the opaque letters. This would move these experiments in the direction of more traditional optical image processing experiments. Additional interesting filtering operations would become available, and this object could be used to introduce the basic properties of non-focusing diffraction gratings.

Another interesting variation would be to replace the opaque 'A' with transparent surround. Instead make the surround opaque, and the letter A, itself, transparent. The figure A would then more obviously resemble the hole in a pinhole camera.

Because my optics course emphasizes holography, I require students to form records on holographic film of their processed images. Thus familiarizes students with film handling, and film chemical processing. Also students are sometimes surprised to see characteristics of the light pattern recorded in the film that they had not noticed while looking directly at the light beams. I would appreciate receiving feedback from anyone who tries this type of experiment.

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[1] A classic treatment is available in the text by Eugene Hecht, Alfred Zajac (1987) Optics, 2nd edition, Addison-Wesley, Reading, Massachusetts. Most other sophomore-junior level optics texts will also introduce the subject of optical image processing.

[2] The Metrologic Corporation has been purchased by Industrial fiber optics: http://www.i-fiberoptics.com/
This website makes readily available Arthur Eisenkraft's laboratory manual *Physical Optics Using A HeNe Laser*

[3] J. D. Armitage and A. W. Lohmann, "Theta modulation in optics," Appl. Opt. **4**, 399- (1965)
[4] The author has demonstrated the value of such translucent back-lighted objects for transmission holography. See Dale W. Olson, "Real and virtual images using a classroom hologram," *Phys. Teach.* **30**, 202-208 (1992); D.W. Olson, "The Abramson ray-tracing method for holograms," *Am. J. Phys.* **57**, 5 (1989), pp. 439-444; also "The elementary plane-wave model for hologram ray tracing," pp. 445-455.
[5] We use the Physics Sign Convention: Real objects and real images have positive distances from the lens.
[6] This point is less easily established in traditional image processing experiments.
[7] This question makes a good quiz question.

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IV.

Optics Education in the International Year of Astronomy

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Abstract:
The International Year of Astronomy (IYA) will be celebrated in 2009 to commemorate the 400th anniversary of Galileo's first use of the telescope for astronomical observation. The National Optical Astronomy Observatory (NOAO) in Tucson, Arizona, USA, is participating in a variety of international education activities to build awareness of the role of astronomy and optics in our modern technological society. We will outline our education plans specifically related to optics for the International Year of Astronomy. These plans include outreach activities that appeal to professional museum and classroom educators as well as the general public.

1. Introduction

The International Year of Astronomy (IYA2009) will be a global celebration of astronomy and its contributions to society and culture, highlighted by the 400th anniversary of the first use of an astronomical telescope by Galileo Galilei. The aim of the Year is to stimulate worldwide interest, especially among young people, in astronomy and science under the central theme "The Universe, Yours to Discover". IYA2009 events and activities taking place locally, regionally, and nationally will promote a greater appreciation of the inspirational aspects of astronomy that embody an invaluable shared resource for all nations. Many organization and individuals will play a key role in these education programs. Percy (1998) highlights the key roles that amateur astronomers play in astronomy education. The program builds on partnerships such as Project ASTRO (Bennett 1998) and the European educational campaigns and programs (West 1998).

One of the primary goals of IYA2009 is to promote widespread access to the universal knowledge of fundamental science through the excitement of astronomy and sky-observing experiences. To achieve this goal, one objective will be to enable as many people as possible, especially children, to look at the sky through a telescope and gain a basic understanding of the Universe at least one time during the year. All types of events are being planned in countries across the world, which include street astronomy events, star parties, professional observatory webcasts and more. Toward that end, there are already 8 countries signed up to host 21 events. A list of planned events to date is in Table 1 at the end of this article.

2. The US IYA Program

In February 2007, National Optical Astronomy Observatory Associate Director for Public Affairs and Education Outreach, Douglas Isbell, was asked by the American Astronomical Society (AAS) to assume the co-chairmanship of the US International Year of Astronomy (IYA) 2009 Program Committee, along with co-chair AAS Director of Education, Susana Deustua. Shortly thereafter, a new US program outline was prepared. The goal for the US program for IYA 2009 is simple but ambitious: "To offer an engaging astronomy experience to every person in the country, and build new partnerships to sustain public interest." To fulfill the goal, six themes were created. Of the six US themes, four will be aligned around topics related to optics education.

a) *Looking Through a Telescope*
Star parties, sidewalk astronomy, mobile telescope vans, binocular experiences, remote telescopes, observing with a spacecraft, etc. are activities that will be encouraged in a variety of venues (observatories, science museums, nature centers, etc), so that everyone has a chance to view the wonders of the sky at least once during 2009.

b) *Telescope Building and Optics Challenges*
The theme will focus on affordable telescope kits, "Hands-On Optics" activities on telescopes, related contests and internships.

c) *Research Experiences for Teachers, Students and Citizen-Scientists*
The research experiences encompass observing at telescopes, remote observing and image processing, data mining, work with members of NASA/ESA science teams, coordinated ground-based, space-based and amateur observing.

d) *Dark Skies Are a Universal Resource*
Recently, two global, citizen-scientist programs have started to heighten the awareness about the impact of artificial lighting on local environments, and the ongoing loss of a dark night sky as a natural resource for much of the world's population. Students, families and teachers all over the world participated by observing and recording the magnitude of visible stars toward the constellation, Orion, as a means of measuring light pollution in a given location. In addition, quantitative measurements of urban dark skies were taken toward zenith using digital sky-brightness meters. Using these as models for activities for IYA2009, dark sky preservation pervades areas related to optics education such as matters of stray light, light sources, shielding, vision, public health and economic issues.

In particular the science education group at the National Optical Astronomy Observatory (NOAO) in Tucson, Arizona, USA is charged with coordinating two of the working groups: *Telescope Building and Optics Challenges* and *Dark Skies Are a Universal Resource*.

2. Telescope Building

NOAO will be stressing educational workshops comparing Galileo's small refracting telescope to large, modern optical reflecting telescopes such as the Gemini 8-meter diameter telescope, located on Mauna Kea and in northern Chile.

The NOAO group has also developed a Hands-On Optics (HOO) kit called "Terrific Telescopes" designed for use at small science and nature centers in their outreach efforts. The kit introduces the concepts of refraction, image formation by lenses, how to build a small refracting telescope, and how to measure its performance. We will be using this kit in outreach efforts coordinated with the IYA and the Association of Science and Technology Centers (ASTC), a worldwide organization that serves hands-on science centers. This kit represents a cost-effective teaching tool that covers the basics of image formation using lenses and mirrors, and also gives the participants "make and take" telescopes.

Key design issues for an affordable telescope that both the US-based and international-based working groups are pondering at the moment are:

- Should the telescope resemble the one Galileo used to look toward the heavens?
- Should there be an affordable kit for reflecting telescopes in addition to one for refractors?
- Should the image formed by the telescope be right-side up for use by students in classrooms or upside-down as with telescopes used in astronomical settings?
- Should there be a mount for each telescope? (To some, stability is a concern.)
- Should the telescopes be pre-produced, assembled and distributed or be in affordable, easy and ready-to-build kits?
- What power is needed to resolve things? Is 10x to little? Is 40x too much? Is 30x the right amount?

At present, one of the most affordable, unassembled telescope kit on the market is the Project STAR refracting telescope kit. This simple kit enables students to build a 16-power refracting similar to Galileo's. Students can use the telescope to see how it is similar to a pinhole camera, to view inverted astronomical images, to estimate the magnification power, to find the focal length of a lens and to see how the moon looked to Galileo. The Kit includes (10 of each unless noted): inner and outer tubes; plastic lenses (43mm diameter, objective, 400mm focal length); plastic lenses (17.5mm diameter, 25mm focal length); foam holders, cardboard spacers and washers for the eyepiece lenses; red plastic caps; 1 set of instructions and activities. A set of 10 telescopes costs $50.00.

How do you teach about telescopes?
In teaching about the optics of telescopes, NOAO's Hands-on Optics "Terrific Telescopes" module starts students off with an activity that investigates how light bends. Students explore ideas through hands-on experiences, formulate and test hypotheses, solve problems, and create explanations for what they observe. Through multiple activities they build a refracting telescope and measure its resolution. There are formative assessment opportunities throughout the module to gauge student comprehension. This module follows a "Learning Cycle" framework (exploration, concept introduction, concept application); however, it can be adjusted to follow the learning style framework that best fits the target audience.

Here the key activities in the "Terrific Telescopes" kit are discussed in the order in which the students experience them:

Light Through an Acrylic Block: A Demonstration: 10-15 minutes
Starting with a laser shining at normal incidence to an acrylic block, the teacher will slowly increase the incident angle. The students will observe that the path of the light changes as the incident angle increases.

Light Passing Through a Convex Lens : A Demonstration : 15-20 minutes
When parallel light beams encounter an object such as a lens, its shape can cause different light rays to bend by different amounts. Students predict the path of the rays through an acrylic block and through a lens, then determine if they are correct by using a mister or chalk dust to expose the laser beams.

Finding the Focal Length Using a Distant Object: 30-40 minutes
When looking at a brightly colored lamp on one side of the room, students will measure the focal length of a lens by forming an image of the light on a screen and measuring the distance between the lens and the screen.

Simple Magnifiers: 30-40 minutes
In this activity, students will explore the magnifying properties of the lenses and notice the connection between how much the lens is curved and its ability to magnify. The students can also see how a juice bottle filled with water can be used as a magnifier as well.

Build a Refracting Telescope I: 30-40 minutes
This is the first of several activities relating to refracting telescopes. Students will first determine how to arrange two lenses so that when they look though them they will see a magnified image of a distant object.

Build a Refracting Telescope II: 30-40 minutes
Using the configuration of lenses that they found previously, students will create a magnified image of a distant object. By placing the velum screen in varying locations, students will determine the function of each lens in a basic refracting telescope.

Build a Refracting Telescope III: 20-30 minutes
The students in groups of two or three will build the refracting telescope from the kit. They will then look through the telescope at distant objects, making notes about their observations.

A Measure of Resolution: 30-40 minutes
Using the telescopes from the previous activity, students will make and graph measurements to compare the telescope's resolution with that of their eye. Additional options include the comparison of the telescope's measured resolution to its theoretical resolution.

Build a Three-Lens Refracting Telescope: An Activity for Student Assessment: 50-60 minutes
What happens to a telescope's image when a third lens is added to the system? Students will find that a third lens creates an upright image and will draw the optical layout of such a system.

Once a student has gone through the "Terrific Telescopes" kit, she will learn:

- In a uniform medium, light will travel in a straight path.
- When light hits a boundary between two different substances, such as air and water, the path it follows can change.
- A convex lens can cause parallel rays of light to converge.
- The point at which parallel light rays meet after passing through a lens is called the focal point.
- The distance from the lens to the point where the light rays meet is called the focal length.
- Converging lenses can be used to project an inverted image onto a screen.
- Converging lenses can be used to magnify an object.
- The amount of magnification is related to the focal length of the lens.
- The point at which an image "flips" is the focal point.
- Focusing is done by adjusting the distance between the two lenses.
- To achieve the greatest magnification, the most curved lens (shortest focal length) is the 1 closest to the eye.
- The two-lens system will invert the image.
- The first lens creates an inverted, real image on the screen.
- The second lens acts as a simple magnifier, making the image larger.
- How to assemble a simple refracting telescope.
- How to estimate the magnification of a refracting telescope.
- Resolution is a measure of how much detail can be observed.
- How to determine the resolution of objects.

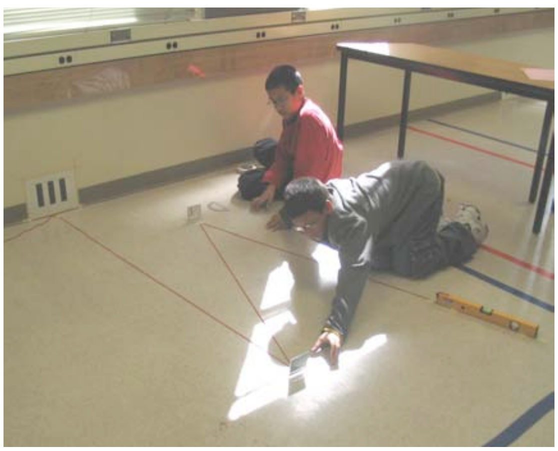
3. Optics Challenges

Optics challenges for IYA2009 could come in many forms; there are optics challenges that could be designed for museums, schools, Boys and Girls Clubs, other community centers, astronomy clubs, career days, camps, science festivals, optical societies, teacher professional development workshops at local and national levels (e.g., National Science Teacher Association meetings) and events like MESA Day competitions. (MESA stands for "Math Engineering Science Achievement" program and serves underrepresented students.) NOAO has hosted optics challenges in all of these venues. These events are an important part of our outreach to the community, and may serve as some of the ideas for IYA. As the basis for these challenges, NOAO has used many of the assessment activities in its six modules, in particular, the "Hit the Target" optics challenge from Module 1. In other cases, challenges have developed as a result of modules, such as the telescope competition from Module 3. Success of their application to events for IYA will rely on the adaptability of these challenges to satisfy a broader age range.

Here are a few examples of optics challenges hosted by NOAO:

"MESA Day" Telescope Competition
From 2004-2006, we partnered with the MESA Program in Arizona to host a "Build a Reflecting Telescope" competition in conjunction with the statewide MESA Day competitions. Students at each school were given a primary mirror, secondary mirror, and an eyepiece. Students had to design and test the telescope using these optical components. The telescope was judged on its design as well as its resolution. In 2006, 14 middle school and 9 high school teams entered telescopes in the competition. A survey of the teams revealed they spent an average of 16 hours per student on the telescope. Teams consisted of 3-4 students.

"MESA Day" Hit the Target Competition
Arizona MESA wanted to try a different competition for 2007. We decided to use a slightly modified version of "Hit the Target" from Module 1. Each team was given a kit containing a laser, several mirrors, a target, rulers, string and a protractor to practice before the competition. The middle school competition consisted of two rounds. Students had to bounce the laser off of two mirrors in the first round and three mirrors in the second round. The High school competition added a third round. In the third round, they chose how many mirrors to use. They could use from 3-6 mirrors and would score more points for using more mirrors. In 2007, a total of 37 teams entered the state competition. The competition was judged by trained NOAO student workers and staff.




St. Michael's School Optics Competition
St. Michael's School in Tucson has hosted a Tucson city-wide optics festival the last two years in conjunction with their science fair. The Optics Festival is held in mid-February after school. We set up several booths around the gym where students engaged in optics activities including exploring optical illusions, building kaleidoscopes, learning about luminescence, and learning about polarization of light. The festival also has a "Hit the Target" competition for fifth and sixth grade students. 40 teams of 2 students each participated in the competition in 2007. Prizes are donated by the school and NOAO including the grand prize, a pair of video iPods for the winning team. The St. Michael's Optics Festival attracted about 150 people in 2007 including students and parents.

4. Dark Skies Are a Universal Resource

There is a lot more optics education in a recent global campaign on preservation of dark skies than initially meets the eye. For a second year in a row the GLOBE at Night campaign (sponsored by NOAO and GLOBE) was held for two weeks in March. Students, families and teachers all over the world participated by observing and recording the magnitude of visible stars toward the constellation, Orion, as a means of measuring light pollution in a given location. The number of unaided eye observations increased from almost 4600 in March 2006 to almost 8600 in March 2007. This year's campaign took on a new twist to obtain precise measurements of urban dark skies toward zenith using digital sky-brightness meters. NOAO received funding to buy and distribute 135 Unihedron Sky Quality Meters to educators, students, amateur astronomers, professional astronomers, science museum staff, and IDA members in 21 U.S. states, the Washington, DC area, major observatories and five other countries. Kits for teaching about light pollution, designed and built by NOAO, were also distributed along with the brightness meters to the same sites. Both flavors of the program were designed to heighten the awareness about the impact of artificial lighting on local environments, and the ongoing loss of a dark night sky as a natural resource for much of the world's population.

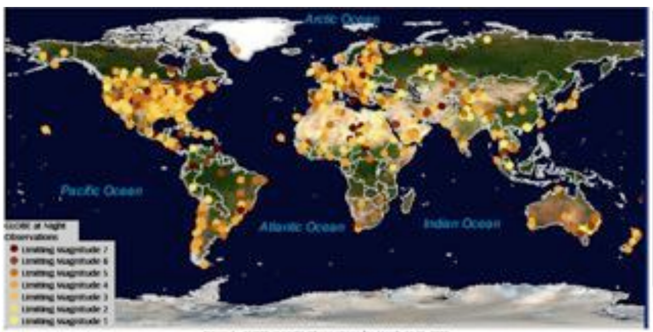


Figure 1. GLOBE at Night Observations for March 22-31, 2006

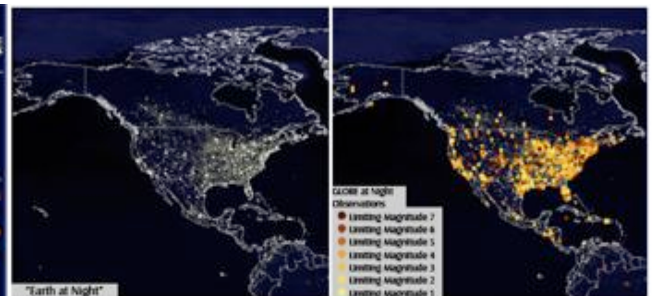


Figure 4. Comparison of "Earth at Night" in North America with GLOBE at Night
(C. Mayhew & R. Simmon (NASA/GSFC), NOAA/ NGDC, DMSP Digital Archive)

Light pollution is the illumination of the night sky caused by artificial light sources on the ground (streetlights, billboards, etc.). Both the light and the loss of contrast make it difficult to find fainter stars and nebulae. The amount of outdoor lighting increases as a result of increasing population. As cities and suburban areas grow, the number of lights at night also increases. Lights, contrast, and glare all impact the number of stars that are visible in a given location. Outdoor lighting is used for many reasons including security, sporting events, and advertising. Some outdoor lighting is more efficient in its design and/or placement and limits the amount of light shining up or away from the intended purpose. Using lights at night can be helpful, but there are trade-offs in the form of unanticipated effects. Lights at night can impact both the biology and ecology of species in the wild, such as the disorientation of sea turtle hatchlings by beachfront lighting. Light pollution can cause adverse effects to humans as well as the ecosystem, or to anywhere in the nighttime environment. These effects include glare, compromised visibility and vision, interruptions in the human circadian rhythm, visual clutter and confusion, energy waste, light trespass, and sky glow.

Two elements of light pollution affect astronomers most: skyglow and light trespass. Skyglow is a result of fixtures, which emit a portion of their light directly upward into the sky where the light scatters, creating an orange-yellow glow above a city or town. This light can then interfere with sensitive astronomical instruments trying to capture light from distant galaxies. Light trespass occurs when poorly shielded or poorly aimed fixtures cast light into unwanted areas, such as observatory and buildings. This light also interferes with astronomical instruments.
What can be done: use fully shielded light fixtures, those which put light only where it is wanted and needed, not up into the sky where it is useless, or onto neighboring properties where it will affect others. Also, certain light sources are more 'astronomically friendly' than others. Low Pressure Sodium (LPS) lights are preferable near observatories, whereas Metal Halides are less preferable.

Optics education pervades many areas of life. The GLOBE at Night campaign and other potential "Dark Skies are a Universal Resource" activities are among those areas. The success of GLOBE at Night 2007 is a major step toward the International Year of Astronomy in 2009, when one goal is to make the digital data collection into a worldwide activity.

Future Plans for GLOBE at Night and the SQMs

With more than 135 hand-held devices called "Sky Quality Meters" (SQMs) distributed to dozens of sites, mainly in the US but also in a few other countries, hundreds of SQM measurements at GPS-referenced points across towns and out into the countryside were made this March. This included taking multiple readings in different places (e.g. along a diameter across a town) and perhaps at different times (e.g. before and after lighting curfews). If this work is to have a lasting value and continue into the years to come, filter and sensor calibration are still issues to be resolved. For astronomy, such measurements in and around and on observatory mountain tops can potentially help in the refinement of feedback for astronomers and government authorities on the effects of relevant environmental (light-pollution) legislation and lighting codes in controlling the outward creep of light pollution, especially in areas around observatories. But it is also the dark sites in urban areas that we should identify and preserve.

The SQM program worked very well in 2007 at recruiting the interest and heightening the awareness of citizen-scientists and forming an initial database of sky brightness measurements. We are forming plans to expand that part of the program in 2008, perhaps adding more sophisticated (more stable?) web-linked meters being developed by Dan McKenna at the University of Arizona - and then decide more specifically how to play our part in the IYA in 2009.

Table 1. National and Global Activities for IYA related to optics education

Activity Name	Activity Description	National or Global	Contact Person	Email Address
Moons of Jupiter and small telescopes	Try to produce and distribute Galilean refractors for the observation of the Moons of Jupiter	Brazil	Dr. Augusto Damineli	daminieli@astro.iag.usp.br
Galileo Did It	To make 1 million Canadians to look through a telescope	Canada	Dr. Hesser	Hesser@nrc-cnrc.gc.ca
Astronomy at the Telescope 1609-2009	Conference that will stress the discoveries made via telescopic observations (starting with Galileo) 1-4 Jan, 2009	Hawaii, USA	Dr. Russell M. Genet	russmgenet@aol.com
Astronomy in the Italian Shopping Centers	To use the shopping malls in Italy to promote astronomy	Italy	Dr. Leopoldo Benacchio	benacchio@inaf.it
Faulkes Telescope Irish Competition	For schools, graduate students, postdocs, staff	Ireland	Dr. Michael Redfern	redfern@nuigalway.ie
Astro-Fest	Stargazing, lectures, concerts, 400th telescope fest, exhibition tour of telescopes, school for teachers, distribution of materials	South Korea	Dr. Young-Soo Kim	ykim@kasi.re.kr
Summer Astronomy in Portugal	People are invited to observe the Sun and Night Sky. Involves hundreds of sessions, using small telescopes and observatories.	Portugal	Dr. António Pedrosa	apedrosa@multimeios.pt
Moon Week 2009, Thomas Harriot's celebrations	Observe the Moon and Saturn, coincide with the 400th anniversary of Thomas Harriott observations of the Moon in July 1609, events at Syon House. (Thomas Harriot's observations of August 1609 and subsequently may have been the first uses of telescopes for astronomy) July'09	UK	Prof. Ian Robson	eir@roe.ac.uk

A telescope in every secondary school	Ambitious and complex	UK	Prof. Ian Robson	eir@roe.ac.uk
Card Telescopes for museums/ planetaria/ VCs		UK	Prof. Ian Robson	eir@roe.ac.uk
Looking through a telescope	Star parties, sidewalk astronomy, mobile telescope vans, binocular experiences, remote telescopes, observing with a spacecraft	USA	Doug Isbell	disbell@noao.edu
Research experiences for students, teachers, and citizen-scientists	Observing at telescopes, remote observing and image processing, data mining, work with members of NASA/ESA science teams, coordinated ground-space-amateur observing	USA	Doug Isbell	disbell@noao.edu
Telescope building and Optics Challenges	"Telescope amnesty", new telescope kits, Hands-On Optics, Contests and Science Festivals, Internships with big telescope projects	USA	Doug Isbell	disbell@noao.edu
The Quest to See Infinity: 400th Anniversary of the Telescope	TV program, documentary	USA	Richard Hudson	rhudson@tpt.org
400 Years of the Telescope	TV program entitled "400 Years of the Telescope: A Journey of Science, Technology, and Thought"	USA	Kris Koenig	kris@interstellarstudios.com
Globe at Night	To draw attention to the light pollution without having to get into politically charged issues of safety and security.	Global	Doug Isbell	disbell@noao.edu
Light Pollution	Awareness on the problems created by light pollution	Global	Bob Crelin	bob@bobcrelin.com
Sidewalk Astronomy	Give as many people as possible the chance to look through a telescope	Global	Dr. Rick Fienberg	rfienberg@skyandtelescope.com
Activities for small telescopes	To prepare activities to use the small telescopes	Global	Dr. Rick Fienberg	rfienberg@skyandtelescope.com
Track Galileo's Observations	On January 10 1610 Galileo pointed his telescope at the sky and made interesting discoveries.	Global		
Does Venus go around the Sun?	By using small telescopes, always under the same magnification of around 60X, follow the phases and apparent sizes of Venus from January to July, 2009. Each time, estimate the angular separation between Venus and the Sun. Then make a sketch showing the positions of Venus with respect to the Sun and the Earth every two weeks. Compare your results with Galileo's. Was Copernicus right? From Jan to Jul 2009	Global	Francisco Diego	fd@star.ucl.ac.uk

Calculate the speed of light by observing the moons of Jupiter	To reproduce the observations by Olaus Roemer who, using a small telescope, could calculate the speed of light by timing the motions of the moons of Jupiter discovered by Galileo nearly 70 years earlier. From mid Mar 2009 to mid Jan 2010	Global	Francisco Diego	fd@star.ucl.ac.uk

5. Conclusion

The International Year of Astronomy provides a powerful organizing force for optics education. Given the importance of telescopes to astronomy education and to teaching optics, IYA activities in this area will be of particular value to both fields. The wealth of activities coupled with the worldwide scope of the program will make for an exciting anniversary for the telescope.

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V.

Innovative Methods to Teach Optics in the Grade 5 Classroom

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Abstract: With the recent realignment of the Connecticut State Department of Education Core Science Curriculum Framework, light and vision were added to the science curriculum for 5th grade students and they will be tested on these concepts on the Connecticut Mastery Test (CMT) starting in 2008. In order to ready students for the test, our collaboration began with the development of a standards-based workshop to introduce optics concepts to fifth grade students in eastern Connecticut. After a successful initial workshop for students, it was apparent that more students would benefit from our lessons if their teachers were able to conduct the lessons in their own classrooms using authentic curriculum. We also found that the teachers were desperate for curriculum, knowledge and supplies to be able to teach the concepts. The result is a collection of lessons satisfying the needs of younger students and a professional development workshop for teachers in which hands-on lessons, scientific inquiry, and scientific literacy are combined to deepen the understanding and interest in the study of optics.

Introduction

The Connecticut Core Science Curriculum Framework

As shown in the excerpt (Table 1) from the *Connecticut Core Science Curriculum Framework Content Standards and Expected Performances – Core Science for grades 3-5* document, the state of Connecticut has included the study of light and vision for all 5th graders. It is important to note that this is the only appearance in the K-8 Science curriculum for the study of light and vision that is required by the state of Connecticut.

The Connecticut Core Science Curriculum Framework document is organized so that the *left* column is the *Content Standards*. These items are "narrative statements of science concepts that guide the development of a rich and rigorous curriculum." [1] Each *Content Standard* includes:

- A conceptual theme, followed by an overarching guiding question
- The content standard, a broad conceptual statement identified with a numerical code that serves as a general learning goal for the unit of study
- One or two supportive concepts, identified with bullets, that provide more specific information about the focus of the learning unit. [2]

In the *right* column are the *Expected Performances*. This is "the specific knowledge and abilities from the broader curriculum that will be assessed on the statewide tests given at Grade 5, 8, and 10." [3] The 2008 CMT is the first time that students in Grade 5 and 8 will be tested for their knowledge of science content.

In addition to *Content Standards* and *Expected Performances*, students are expected to understand and use scientific inquiry, literacy and numeracy in their study of the content subject. Scientific inquiry, literacy and numeracy are considered an integral part of the content standards for each grade level. More specifically, these topics are defined in the *Content Standards* as follows:

- Scientific Inquiry – a thoughtful and coordinated attempt to search out, describe, explain and predict natural phenomena.
- Scientific Literacy – speaking, listening, presenting, interpreting, reading and writing about science.
- Scientific Numeracy – mathematics provides useful tools for the description, analysis and presentation of scientific data and ideas. [4]

Table 1. Excerpt from Connecticut Core Science Curriculum Framework Content Standards and Expected performances – Core Science for grades 3-5. [5]

Grade 5 Core Themes, Content Standards and Expected Performances	
Content Standards	Expected Performances
Energy Transfer and Transformations – What is the role of energy in our world? **5.1 – Sound and Light are forms of energy.** ♦ Light is a form of energy that travels in a straight line and can be reflected by a mirror, refracted by a lens, or absorbed by objects.	**B 19.** Describe how light is absorbed and/or reflected by different surfaces.
Structure and Function – How are organisms structured to ensure efficiency and survival? **5.2 – Perceiving and responding to information about the environment is critical to the survival of organisms.** ♦ The sense organs perceive stimuli from the environment and send signals to the brain through the nervous system.	**B 20.** Describe how light absorption and reflection allow one to see the shapes and colors of objects.

Student Workshop – Introducing Optics

Because the study of light and vision is brand new curriculum, we wanted to introduce the concepts to as many students as possible. Our goal was to cover as many of the *Expected Performances* as possible in the short time available with maximum engagement and hands-on activities by the students. After careful evaluation, we selected lessons in which the students would study refraction, absorption, and the visible light spectrum. The lessons were presented in May 2006 at a student workshop entitled "A Little Light Magic" and included three content lessons with one of the lessons integrating scientific writing.

For the initial workshop, the students were participants in a program entitled *"Systems Explorers,"* an EASTCONN Interdistrict diversity program funded through the state of Connecticut. Serving the eastern Connecticut region, EASTCONN is one of six regional educational service centers (RESCs) providing educational services and training to students and teachers. The "*Systems Explorers"* program encourages teams of students from diverse backgrounds in grades 5-8 to build positive relationships, critical thinking and problem solving skills by working together in cross-district partnerships. This group of 350 students from rural and at-risk urban schools in eastern Connecticut provided us with an ample number of students to thoroughly evaluate the optics lessons we selected for content and scientific method.

All of our workshop lessons were adapted from the PHOTON Explorations, developed under the National Science Foundation (NSF/ATE) supported PHOTON and PHOTON2 projects. PHOTON and PHOTON2 were faculty professional development, laboratory improvement and curriculum development projects of the New England Board of Higher Education, funded by the Advanced Technology Education program of the National Science Foundation.

PHOTON used a traditional summer workshop model for teachers from the New England states, while PHOTON2 delivered a hands-on collaborative course to teachers across the United States by online distance learning.

We developed our lessons from favorite demonstrations of the participants in the PHOTON and PHOTON2 project, which have been edited and compiled into the PHOTON Explorations. The chosen Explorations best represented the concepts that the students are required to understand, while also providing highly engaging activities. They clearly demonstrated the procedures, activities, observations, and important findings and required the students to use scientific inquiry in their activities while also providing the necessary background information that the teachers needed to present follow-up lessons in their classroom. Though designed for the middle school and high school level, they were easy to adapt to the introductory 5th grade level.

The following PHOTON Explorations were selected:

- Exploring Light Spectra
- Exploring Refraction (Jell-O® Optics)
- The Magic Box

Using these engaging lessons, students created mailing tube spectroscopes for viewing a variety of light sources (the visible light spectrum), studied refraction, absorption, and transmission using Jell-O® Optics and practiced scientific writing in a lesson which used the “Magic Box” (a demonstration of polarization that creates the illusion of a solid wall in an otherwise empty box for a study in observation.)

Summary of Explorations:

Exploring Light Spectra

In this Exploration, each student built a spectroscope using a short mailing tube, diffraction grating slide, and cardboard disk with a narrow laser-cut slit.

This lesson provided the basic ideas of light essential to the understandings of all of the *Expected Performances*. Students were introduced to the fundamental colors of light, the visible spectrum and wavelengths and were especially thrilled to learn about ROY G. BIV. They examined the colors radiated by several unique light sources including fluorescent bulbs, gas tubes, filtered incandescent sources, lasers and LEDs (refer to photo 1). As part of their written work, students were required to complete a data table identifying the unique spectrum of each light source (refer to photo 2). By doing this, they were able to compare the light sources and speculate how the light was produced.

Photo 1. *Exploring Light Spectra* Exploration – student using spectroscope.

The highlight of this lesson was that the students were able to take their spectroscopes home. This is an important part of this lesson as the students were thrilled to be able to share the spectroscopes with their families. They not only were able to tell their families about the workshops but demonstrate and explain what they had learned using light sources within their homes. Of course, each spectroscope bore a safety label, affixed by the students themselves so they would be sure to notice, warning against looking at the sun or into a laser source. The safety label made a strong impression on the students. “Tim” wrote, “The spectroscopes we took home I used numerous times. Don’t worry, I haven’t looked into the sun.” Another student wrote, “Thank you for letting us make our own spectroscopes and take them home. I look at all kinds of lights to see what color the spectrum will be. I always make sure not to look into the sun.”

Photo 2. *Exploring Light Spectra* Exploration – student completing data table.

In a follow-up writing activity, students were asked to describe their favorite activity. “Kelsey” wrote “It is very hard to pick a favorite activity of the three. All of them were very fun and informative. I think the Spectroscopes was my favorite though. What I liked about Spectroscopes was how we got to build our own scopes and try different lights to see what colors make them. Plus, we got to take them home so we could use them ourselves. It was interesting how what colors you see in a light may not be what color(s) made it. Then we used a graph to record our data and see which light was the purest. The purest light has the least colors of roygbiv (red, orange, yellow, green, blue, indigo, and violet) in it when viewed through the Spectroscope. The purest light we viewed was the exit sign, which had only the color red. The least pure was the fluorescent light which had all of the roygbiv colors. My very favorite part about the Spectroscope was that I learned a lot of things I didn’t know before. At first, I didn’t even know there was anything called roygbiv or that colors unseen make the light you see. I didn’t know there was such a thing as a Spectroscope either. I also liked how the Spectroscope activity let us take part of what we learned home. I use my spectroscope all over my house now. The light over my stove in my kitchen is more pure than the one over my dinner table.”

Kelsey continues to describe the activity in more detail, “To build the Spectroscope was actually very simple. We used a cardboard tube and glued a circle of black construction paper with a slit in the middle to one side. We looked through the other side so that we could concentrate on one light at a time. Then, on the side we looked through, we looked through the grating and the tube to see lights and focus on only one of the lights. If we didn’t have the tube and slit, we’d be seeing all different lights and confusing colors through the grating. On either side of the slit, you could see the roygbiv colors that made the light you were viewing. The grating made this appear. It was very fun and interesting!"

Exploring Refraction (Jell-O® Optics)

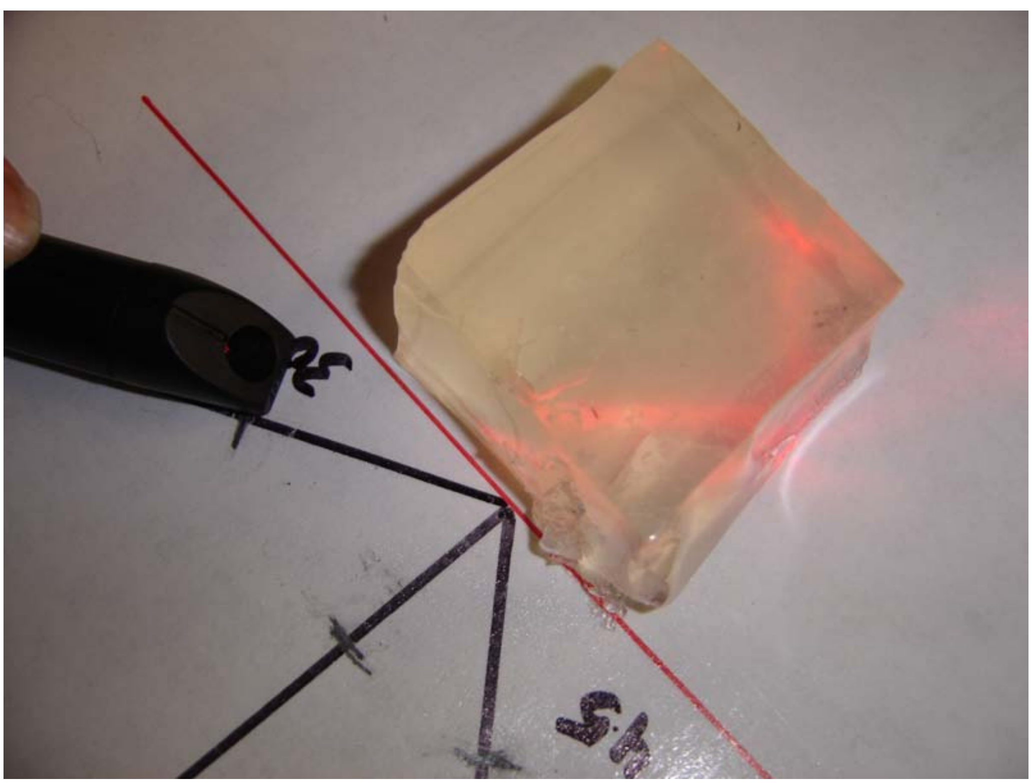
For this Exploration, students studied refraction, absorption, and how light travels through concave and convex lenses using laser pointers and plain gelatin blocks (Knox® brand) and various colors of Jell-O® Jigglers®.

This activity is also a demonstration of how an ordinary kitchen item can be used in a scientific lab. The blocks, concave and convex lenses were cut from trays of gelatin Jigglers® made using the recipe on the box of either the Knox® or Jell-O® brand gelatin. At this point, it was also the appropriate time to introduce and stress laser safety and safe practices in lab science. In order to participate in the activity, the students were introduced to the safety instructions. Refer to Table 2 for a list of the safety rules used for this workshop. Again, background knowledge was introduced on the behavior of light rays when transmitted through lenses and different media. Students used a block of gelatin (refer to photo 3) to demonstrate how a beam of light bends when it travels from air into a medium where it travels more slowly (gelatin). In further investigation, they used concave and convex lenses cut from gelatin to show how light behaves when traveling through a lens.

Table 2. Laser Safety Rules from "A Little Light Magic" student workshop.

Laser Safety Rules
1. Laser beams stay below the waist (laser pointers stay on the table.) 2. Never aim the laser beam directly into your eyes or the eyes of others. 3. Please respect the equipment so it can be used by others. 4. If you cannot follow the rules, you will be asked to sit out of this activity.

Photo 3. *Exploring Refraction* Exploration – gelatin block.



Students were highly engaged in this investigation because of the nature of the supplies (refer to photo 4). Vinny wrote "My favorite activity was using the lasers to see it refract in different directions off the jello." Another student, Andrew described the activity this way, "I liked to see the light bounce right off of the jello. I also liked to learn that different shapes and angles made a difference to how the light came out."

Photo 4. *Exploring Refraction* Exploration – student using laser pointer to demonstrate refraction.

Exploring Polarization – The Magic Box and Science Journal Writing

For this lesson in scientific writing, the Exploring Polarization – The Magic Box Exploration was used. A portion of the CMT will require the students to write in a "scientific" manner which differs from the expected style of writing on other portions of the test. Short responses with "just the facts" will be more appropriate for this portion of the test. For the lesson, the students first reviewed "descriptive" writing and were required to write about an everyday object in a descriptive manner. Then writing for science was introduced with an example of describing an object with "just the facts." Table 3 demonstrates the descriptive and scientific writing examples that were shown to the students. For this portion of the activity, the students broke into small groups and one student would write a description of an object. The other members of the small group would attempt to draw a picture of the object using the written description. Students often find writing boring, however, Brian found this lesson very engaging. He wrote "My favorite activity was the writing project because you got to write directions and someone else would try the best they could to do what you wanted. The favorite stations at the writing project was the one that you would draw a simple picture and write how to draw the picture. Then you would compare your pictures and see if they followed the directions correctly."

At this point the "Magic Box" was shown to the students and they were asked to describe what they saw (refer to photo 5). The students were not required to understand how polarization works as the box was the vehicle to inspire students to write scientifically. Many of the students were uncertain about what they were seeing. They were quite surprised when the instructor for this lesson passed a chopstick through the "solid wall."

Table 3. Descriptive and scientific writing examples.

Descriptive Writing	Scientific Writing
The yellow wooden pencil lies quietly on the desk waiting for someone to pick it up.	The pencil is made of wood, painted yellow and measures 6 inches long. It is laid horizontally along the table edge.

Photo 5. *Exploring Polarization* Exploration – student using "The Magic Box".

Conclusions from the student workshop and establishing the need for teacher professional development:

By using a workshop format, we were able to introduce optics to a large number of students in a very short amount of time. Each session lasted 50 minutes with about 60 students in each session. To staff the workshops, we each instructed one of the three sessions and used a literacy consultant to instruct the third session (the workshop in scientific writing). This enabled the classroom teachers to work with individual students who needed additional help. One of the most important results was the positive feed back from students and that they were very appreciative of the use of "real" supplies. Many students commented on how exciting it was to make a "real" spectroscope and use lasers. Several students wrote, "My favorite activity was the laser jigglers. I like it the most because you got to use a real laser." Another important result was how quickly the students learned the new vocabulary and how they were able to understand the principles of refraction, spectroscopy and the visible spectrum and were also able to write about these concepts. Obviously, the students were engaged and interested in the topics.

However, our workshop was only an introduction and it was obvious that in order to serve the entire northeast region of Connecticut and for the students to truly understand the lessons, teachers also needed a workshop dedicated to the study of light. By teaching the lessons themselves, teachers could also reinforce the concepts from our introduction to optics, explore more topics and answer student questions with more details than our time allowed.

The needs of the teachers were somewhat different than the students. They required not only more in-depth background knowledge of what they were teaching but also sample lesson plans aligned with the standards and lists of where to purchase low cost supplies and what to buy. Because most of the teachers attending the workshop were classroom teachers, they had little or no specific optics knowledge. The lessons needed to be presented in a clear, concise step-by-step manner with supplies that could be easily obtained and organized.

We developed a full-day professional development workshop, attended by 23 teachers, mostly from grade 5 but teachers from other grade levels were welcome to attend. In addition to the previous lessons, the teachers participated in other hands-on investigations introducing color perception and mirror reflection. Complete instructions and explanations for each activity, print and web resources for teaching optics, and a packet of additional learning resources for teacher and student were given to teachers. Again, PHOTON2 Explorations were adapted.

Additional lessons for professional development workshop:

What Color is a …? Reflection of Colors

This Exploration introduces the concepts of how the eye recognizes colors, and the absorption, scattering and reflection of light. This investigation involves trying to fool the eyes with different colors of light sources. By viewing objects first illuminated by color LEDs and then in white light, participants were visually able to understand how the eyes see color. Teachers suggested additional classroom experiments based on the same principles: for example, asking students to identify brightly colored candies by viewing them under different color illumination. Although the best results were from higher priced key-tag LEDs, inexpensive LED key-tags performed acceptably.

Hit the Target: the Geometry of Reflection

This laser target "game" was adapted from similar experiments from instructional materials developed by the NSF ISE grant Hands-On Optics: Making an Impact with Light [6] and University of New Mexico Science Inquiry Through Optics [7]. To introduce this activity, participants reviewed how to use measuring devices (protractors) to quantify what they notice about reflections. For teachers, they will learn that the angle of incidence equals the angle of reflection. For some students, they may not understand the terminology but they will be able to visualize the concept. We used inexpensive plastic mirrors and protractors.

After demonstrating an understanding of this theory, the "Hit the target" game is introduced. Students will use a laser pointer and mirrors to hit a target using progressively more mirrors to add to the challenge which demonstrates their knowledge of reflection and angles. The target has a range of point values so that the students can tally their scores.

This is an important activity for students because it not only is about reflection but also is an opportunity for them to use their early understandings of angles to demonstrate how light reflects. It is also a demonstration of how to incorporate scientific numeracy into a science lesson.

Results of the professional development workshop:

Results from the teachers have been very positive. They appreciated the background knowledge and lesson plans. Some of the teachers have been reluctant to introduce the lessons in their classroom because of their own lack of science knowledge and background. We have addressed this issue by providing on-going support to teachers who attend the workshops.

For other teachers, the lack of available school funds to purchase supplies is an issue. It is easier for them to purchase a large "kit" from a known educational distributor than to piece part supplies from smaller suppliers. This leads to sometimes not having the correct supplies or spending excess money on supplies that are not needed for a particular lesson. For our lessons, the cost of supplies was minimal and in some cases, students could bring the supplies from home. For instance, toilet paper rolls could easily be substituted for the mailing tubes in the spectroscope activity and an old CD could be stripped of its label to provide the diffraction grating. Again with the spectroscope activity, the student supplies are inexpensive but the teachers did not have a variety of light sources readily available. With out the light sources, this activity is not as effective. Another example is the Knox® gelatin for Jell-O® Optics is very inexpensive but to purchase laser pointers for an entire class (assuming 1 pointer for every 2 students in a class of 24) would require purchasing a minimum of 12 pointers. However, the laser pointers are used for more than one activity (the Hit the Target activity and Jell-O® Optics activity). For Hit the Target, the cost of glass mirrors is not a factor but plastic mirrors are easier to work with and safer in a classroom environment. Refer to Table 3 for a list of supplies we used for our activities.

Table 3. Supply comparison.

Exploration	High Cost Supply	Low Cost Supply
Exploring Light Spectra	Diffraction grating slides Mailing Tubes Light sources	CDs Toilet paper tubes
Jell-O® Optics	Acrylic lenses	Jell-O® or Knox®
Magic Box	Polarizing Film	
What Color is a…	Photon microlights	LED lights
Hit the Target	Glass mirrors	Plastic mirrors

To address this critical issue, we are developing the plans for a "lending library" of supplies. These supplies would be available to only those teachers who attend a professional development workshop. This will ensure that teachers are properly trained in the use of the supplies and knowledgeable in content. The professional development workshops for teachers will be offered yearly and as teachers become trained in the material, a greater variety of interesting lessons can be presented. We have been working with Connecticut's NSF/ATE supported Regional Center for Next Generation Manufacturing for both material support for the lending library of optics kits and marketing and support for the teacher workshops. While EASTCONN will market the workshops to the northeast region of Connecticut, with the Center's support, we will be able to reach teachers statewide.

Conclusion:

The immediate result of offering optics workshops for both students and teachers will be students who are highly prepared for the light and vision portion of the Connecticut Mastery Test. Further down the road, however, by using high quality, authentic and interesting investigations, students will be interested in studying optics and there by ensure the work force for the next generation.

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Project PHOTON: A Curriculum Development, Teacher Enhancement and Laboratory Development Project

Funded in part by the Advanced Technological Education program of the National Science Foundation (ATE #ATE 0053284). A project of the New England Board of Higher Education.

Project PHOTON2: Web-based Collaborative learning for Teachers

Funded in part by the Advanced Technological Education program of the National Science Foundation (ATE #ATE 0302528). A project of the New England Board of Higher Education.

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El día de la luz (the day of light)-two hours optics demonstration for secondary school students

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Abstract : In many countries the potential of optics as an exciting part of science is not fully exploited in high-school education. In addition, optics is often not taught in relation with daily experiences. With the motivation to expose the potential of doing otherwise to motivate students, we developed and implemented a two hour-long hands-on introduction to optics for high school students. We termed the program: The Day of Light. By attending the program, students learn basic concepts such as polarization, wavelength, color, stereoscopic vision, reflection and refraction in connection to everyday experiences based on applications of optics. The demonstration was fully organized and carried out by the ICFO Ph.D students who were members of the ICFO Optical Society of America (OSA) Student Chapter.

1. Introduction

Optics is often not taught in relation with daily experiences at high school level although optics is very visual and therefore can attract students. Moreover, many students do not appreciate the importance of optics even though they use it extensively in daily life. This is probably due to the intense curriculum and little time to prepare some attractive demonstration of optics. Moreover, high school physics instructors may have little background in optics because their background varies from physics to biology and they may have to teach a science field other than their background in high school.

With motivation to expose secondary school students to the fascinating field of optics using daily applications, we developed and implemented a two hour-long hands-on introduction to optics for high school students. Previously, there have been introductory workshops for elementary school students by other groups [1]. We named the program: El Día de La Luz (The Day of Light) [2]. In this workshop, we cover basic concepts of light, namely, polarization, refraction, reflection, and stereoscopic vision. In the selection of topics for demonstration, we particularly pay attention to applications and examples that students use and see everyday, such as liquid crystals used for the display of their mobile, CDs, perception of images in three-dimensions. We either visited the local high school or invited students and their teacher to our institute for our program. Those workshops were organized and conduced by the Ph.D students in the ICFO Optical Society of America (OSA) Student Chapter.

2. ICFO-OSA student chapter

Our OSA student chapter at ICFO based on Barcelona, Spain was founded in 2004 [3]. ICFO-OSA student chapter currently embraces 30 post-graduate students from over 15 countries. Since its initiation, we organized bi-weekly seminar by students in ICFO which became weekly colloquium from 2007, and invited some distinguished speakers in the fields of optics, such as Dr. Emil Wolf, Dr. Joseph Eberly, and Dr. Chris Dainty as our internal activities within our institute. Very recently, we organized and hosted the first exchange program among OSA student chapter in Europe where three other chapters from Southampton (UK), Munich (Germany), and Naples (Italy) participated. This initiative is to exchange research interests, get acquainted with other research institute, and establish a network. One of the most important out-reach activities in our OSA student chapter is to introduce optics to secondary school students. Through these activities, we earned the prize, the Excellence Award, from the OSA in year 2006.

3. El día de La Luz (The Day of Light) - Two hours optics demonstration

In this section, we present the typical format of our two-hour workshops on light. Usually, 40 students aged from 15 to 18 together with several high school instructors are included in one session. Prior to the presentation, we give students leaflets that summarize our demonstrations as shown in Figure 1 so that they could preview the main points of the workshop and high school teachers could learn the demonstration as well. As shown in Figure 2, we start with 10 minutes talk by using slides and posing students some fundamental questions such as 'where does light come from?' and 'what do we use it for?' in order to let students think about light sources such as the sun, light bulb, fire, etc. Then, we introduce basic concepts of light such as:

(1) Light can be described as a form of wave.
(2) Thus, it has the length of one cycle of this wave, called 'wavelength.'
(3) This wavelength corresponds to a color in the visible.
(4) Also as light is a form of wave, it has certain plane where the wave oscillates, called 'polarization.'

Then, we ask the students three everyday life questions about light to prompt students to think about optics before the hands-on experiments.

(1) How does the display of your mobile phone work?
(2) How do we guide light?
(3) Why is it handy to have two eyes?

So as to answer these questions, students go through three sessions of our experiments where each session is 20 minutes of hands-on experiments. Each session is conducted by two volunteers, and we switch the groups.

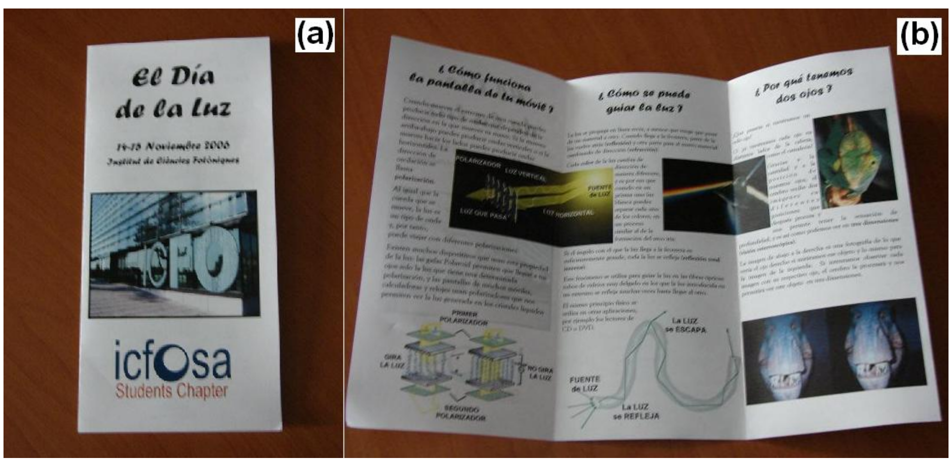

Figure 1: (a) and (b) A brochure of our program given to students.

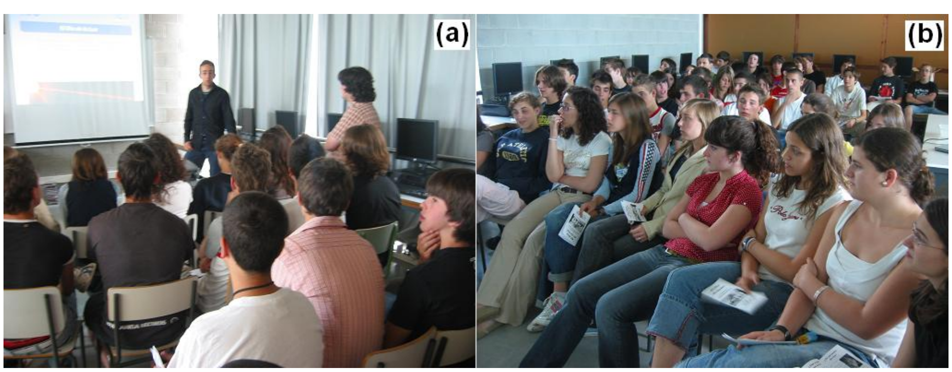

Figure 2: (a) and (b) Presentation prior to experiments.

Table 1: Materials for the experiment of polarization and liquid crystal.

Materials	number
Plastic polarizer	2
A box with white light source and a polarizer	1
Liquid crystal cell	1
liquid crystal kit from OSA Rochester section	50 [5]

3.1 Polarization and liquid crystal

First of all, the polarization of light is explained using a few slides. Then, we also show a plastic polarizer to students and explain why the polarizer looks dark. In general, light from the sun or light bulb is not polarized and has a variety of polarizations. The plastic polarizer lets one polarization of light pass, and reflects light with other polarizations. With two polarizer perpendicular to each other, we demonstrate that light is completely reflected, and therefore it looks dark. We pass the polarizers around so that students can play with them as shown in Figure 3.

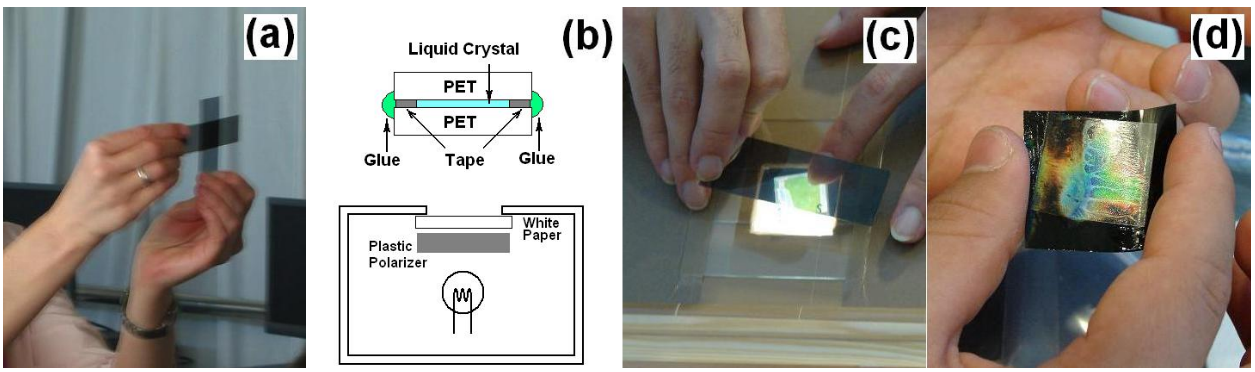

Figure 3: (a) Two plastic polarizers. (b) Structure of LC cell (above) and a box that emits polarized white light (below). (c) Demonstration of liquid crystal cell with a polarizer on top. (d) Students make their own liquid crystal cell.

Before discussing liquid crystal (LC) displays, we emphasize that liquid crystals are everywhere and that in fact we use them in the display of mobiles, laptops, calculators, watches and so on. With a drawing in a slide, we show that liquid crystals consist of long molecules in liquid, and with application of voltage or heat one can align them in such a way that they transmit or reflect light with certain polarization and wavelength of light.

While showing a slide that presents the structure of a LC, we show a LC cell. As shown in Figure 3 (b), this LC cell has E7LC [4] sandwiched by 2×2 cm polyethylene terephthalate (PET) plates, and is glued to keep the LC between the plastic plates. When the cell is placed on the light source with one polarization, still the cell looks transparent. However, upon placing a polarizer on the other side of the LC cell, it shows different colors depending on the angle of the polarizer in the plane parallel to that of LC cell as shown in Figure 3 (c). Students learn that due to the orientation of LC molecules the polarization is rotated differently for different colors or wavelength. Thus one can change colors by changing the angle of the polarizer. Moreover, we explain that in LC displays, each pixel, which corresponds to a LC cell, changes its color by voltage instead of rotating the polarizer. This is because voltage changes the orientation of the LC molecules, which rotates the polarization of light with specific color, and enables us to extract specific colors by tuning voltage.

After a talk, we give students LC kits provided by the OSA Rochester section [5]. Students make their own LC cells that change their color depending on the temperature to understand that a certain temperature can orient the LC to reflect certain colors of light. They are amused and excited by learning what a LC is and how it works. They put the cell on their hands and compare the difference of temperature on their body with that of other students. The tools used for this demonstration are listed in Table 1.

3.2 Reflection and refraction

With a triangle prism, we demonstrate refraction and reflection of light (Figure 4 (a)). When red light from a laser pointer is directed to the prism, students witness the light is bent the interface of air and prism, and thus they learn about the concept of refraction and the refractive index of materials. Moreover, depending on the angle of incidence, light that travels in the prism passes through the other side of the prism and goes out, or the light is reflected at the other interface of the prism. In this manner, the total-internal reflection of light is demonstrated in a simple experiment.

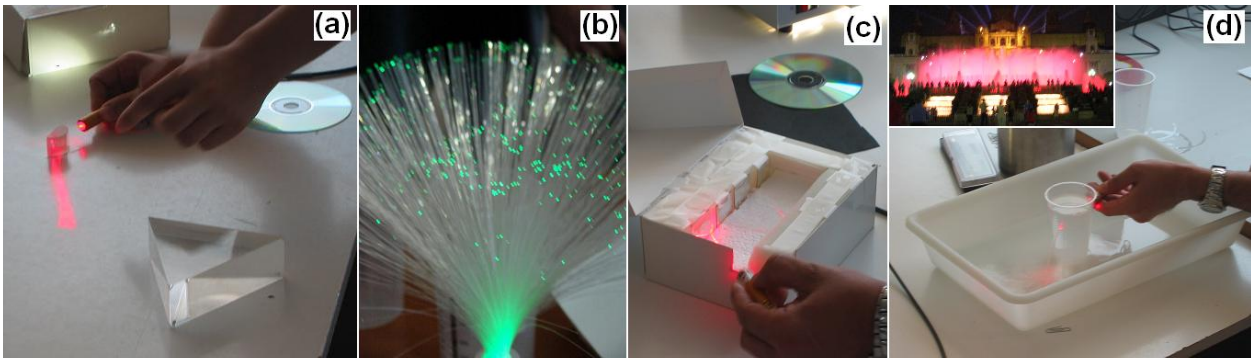

Figure 4: (Color images) Reflection and refraction of light by (a) a laser pointer and prisms, (b) optical fibers, (c) a box with mirrors, and (d) a cup with water and the inset is the fountain of Montjuic.

After understanding reflection and refraction, students are exposed to various applications of the phenomena. As in Figure 4 (b), we present optical fibers that connect long-haul communication system in which the data that encodes their voice may be carried as a form of light signal when they call someone in the North America from Europe. We stress that information in internet is carried in the same way as well. In order to understand the guiding of light by total-internal reflection, we let student play with a laser pointer and a foam box that has a hollow space with mirrors on both sides of the hollow space as shown in Figure 4 (c). With this simple gadget, the guiding of light by a series of reflection is visualized for students, and they learn how light from one end of the fibers propagates and comes out from the other end of the fibers.

We also perform an experiment on the guiding of light in flowing water. A plastic cup with a small hole in which water comes out is used. One of our volunteers shines a laser pointer toward the hole and demonstrates the red light of the pointer follows the path of flowing water. They are also explained that the fountain of Montjuic (See the inset in Figure 4 (d)), a famous touristic spot in Barcelona where the water of the fountain changes its color with music, works in the same principle as fiber optic cables.

As another everyday application of reflection, a volunteer explains optical data storage, such as CDs and DVDs that utilize reflection of laser to read information from the disc. Students learn that there are pits on disc surface which reflect laser to the detector in a different way depending on the shape and location of pits. In this manner information from the disc is optically read in terms of the sequence of the pits. The required kit for this session is shown in Table 2.

3.3 Stereoscopic vision

We perceive 3D image as superposition of two slightly different images obtained from both eyes. With one eye it is hard to obtain information about the distance of the image, though we can see the image in 2D. To demonstrate this concept, one volunteer asks a student to close one of his or her eyes and try to touch the finger of the volunteer from the side. Most of the students find themselves unable to touch the finger of the volunteer, and realize that it is hard to perceive the distance to the finger with one eye. Moreover, a volunteer asks a student to look at two rings of metal wire with one eye as in Figure 5 (a) and to tell which ring, either small or bigger one, is closer to the student, which turns out to be quite challenging to distinguish with one eye. Thorough those experiments, students realize that it is handy to have two eyes in order to comprehend the sense of distance.

Then, each student receives 3D images and 3D glasses. In the easiest form, these 3D pictures are essentially two blue and red pictures that are put together but slightly shifted when they are printed on a sheet of paper. Suppose the

Table 2: Materials for the experiment of polarization and liquid crystal. Note that optical fiber cables do not necessarily have to be the ones for telecommunication. For demonstration purpose, optical fibers for decoration are sufficient.

Materials	number
Triangular or semi-cylindrical prism	1
CD or DVD	1
A box with mirrors	1
Optical fiber cable	20-30
Plastic cups with a hole and a bucket with water	2-3
Red laser pointer	1

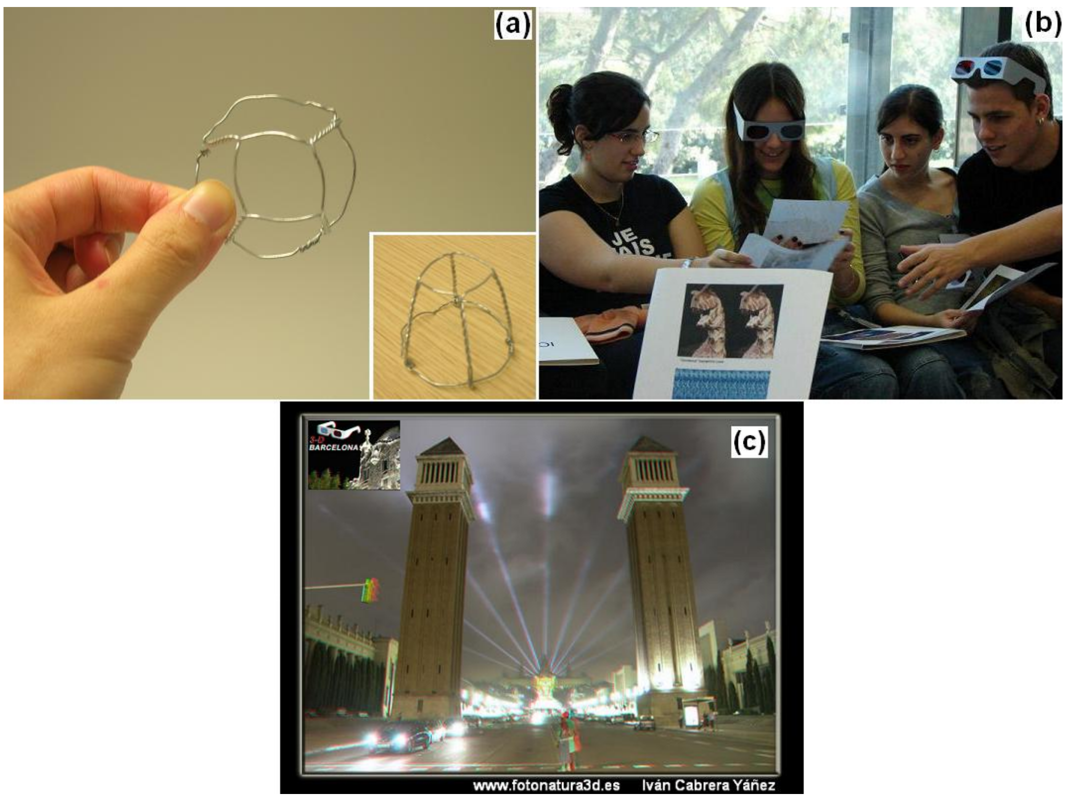

Figure 5: (a) Two rings of metal wire. (b) Demonstration of stereoscopic vision with 3D glasses. (c) An example of 3D pictures [6].

Table 3: Materials for the demonstration of stereoscopic vision.

Materials	number
Color photos for 3D image	50
3D glasses	15
Metal wires with two rings	5
A projector and a laptop to show 3D movie	1

3D glasses are such that the right eye see through a red filter and the left one a blue filter. Since these two colors are complementary, it is then possible to include the two pictures on one single 3D picture and print it on a piece of paper. The red picture will only be seen by the left eye with the blue filter. The reason for this is that the right eye with the red filter does not distinguish between red and white. Hence the eyes see two pictures with slightly different angles of the same scene, which enables our brain to give us a sense of depth and a sense of stereoscopic vision. Because of the complementarity of these colors, the same principle also applies to movies. Apart from the internet, we got the 3D pictures through a collaboration with a local photographer who specializes in 3D imaging [6]. The required kit for this session is shown in Table 3.

3.4 Concluding remarks

After the demonstrations, students, teachers and volunteers gather and review what the students learn, by asking the three question that we asked at the beginning. Then, we take 5 minutes to get feedback from students who write their opinion on sheets of papers so that we can improve our presentation. Some of the high school teachers who came along with students asked about the materials used in demonstration so that they could perform some of the experiments at school. We also provided them with take-home materials, such as liquid crystal cells and 3D pictures.

Figure 6: Participants of the first 'The Day of the light' from ICFO OSA student chapter

4. Conclusion

This program has the advantage of not being lengthy, which allows school teachers and students to attend it without sacrificing regular curricular activities. The workshop does not require sophisticated equipment so that teachers and students can easily learn how to reproduce the demonstration themselves. With this aim, they are provided with take-home materials, such as liquid crystal cells and 3D pictures, a well appreciated conclusion. Finally, our volunteers are post-graduate students who are close to the age of students so that they feel more friendly and comfortable in comparison to their teachers.

Acknowledgement

This program is supported by funding by ICFO, OSA, and by the Government of Catalonia (Generalitat de Catalunya). We would like to acknowledge active members who help organize this activity, Xavier Vidal, Clara Ines, Noelia Gonzalez, Maurizio Rhigini, Sandro Perrone, Giorgio Volpe, Sibylle Braungardt, as well Prof Luis Torner (ICFO Director and chapter advisor) Prof. Dmitri Petrov for laboratory tour, Dr Silvia Carrasco, Laura Grau, and Mı́riam Aguilar for administrative support. We include a snapshot of some of the volunteers for this workshop in Figure 6.

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Project LITE: Light Inquiry Through Experiments

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Abstract: "Project LITE: Light Inquiry Through Experiments" is a science education project aimed at developing interactive hands-on and eyes-on curriculum, software and materials about light and optics. These are being developed for use in undergraduate astronomy courses, but they can also be used to advantage in physics, chemistry, Earth science and psychology courses throughout the K-12 and undergraduate curriculum.
OCIS code: (000.2060) Education

1. Introduction to Project LITE: Motivation and Need

The only encounter that many undergraduates have with science during their college careers occurs in elective science distributional courses. These courses typically have lectures, discussion sections and, if offered at all, several in-school laboratory exercises. Such courses usually do not give students a chance to actually *do* science. A sports analogy might be trying to teach students basketball without actually letting them dribble or shoot the ball. Hands-on, inquiry-based, constructivist learning can offer students a unique opportunity to directly explore phenomena and gain insight into the nature of science. However, learning from direct experience can be time consuming and expensive. In order to provide students with a more rewarding learning experience, we have been developing inexpensive educational software, devices and activities that can be used in a wide range of introductory science courses and settings. These materials center on light.

1.1. Why Focus on Light?

As we move into the 21st century, college students rarely have the opportunity to examine in depth the towering intellectual achievements of the 20th century concerned with the nature of light, even though some of these ideas are now almost a century old. Students who take high school and introductory college physics courses mainly encounter 18th century Newtonian mechanics, 19th century electricity and magnetism, and a bit about waves, vibrations and thermodynamics discovered during those centuries. But when do they learn about the great 20th century discoveries concerning light that derive largely from quantum theory and special relativity? Our understanding of *light* is, of course, inextricably woven into our understanding of *matter*. Light is a key component of many modern technologies and is used as the primary tool in many sciences ranging from astronomy to zoology. Without some familiarity with the properties of light, students cannot be expected to fully grasp modern science or the plethora of technologies surrounding them including LEDs in many devices, holograms on credit cards, lasers (in CD players and printers), computer screens and the fiber optics carrying the internet. Because of its centrality to human experience and great aesthetic and intellectual appeal, courses dealing with light can reach a broad spectrum of non-science majors. Students with few science prerequisites and knowledge only of pre-calculus mathematics can learn a great deal about light.

1.2. Project LITE Educational Goals.

The American Astronomical Society Education Office recently conducted a survey of faculty members [1]. It found that light and the electromagnetic spectrum were "by far the most frequently cited topics" in a list of subjects that professors felt their students should understand. The two-part survey queried 29 college and university professors attending a national workshop on astronomy education, and also analyzed 37 college astronomy syllabi posted on the Web. Among the findings: of six topics deemed "highly essential" – electromagnetic spectrum, radiation, redshift, Hertzsprung-Russell diagram, stellar evolution and mass – half were directly concerned with light and many other topics, such as the meaning of the H-R diagram and evidence for the expansion of the universe, require an understanding of the properties of light. The study also found that (in 2001) 38% of the students of the professors surveyed are *required* to use the Internet as part of their course activities. Informal inquiries indicate this percentage has since increased to nearly 100%. In an independent survey [2] of 44 instructors attending three national workshops called "Teaching Astronomy Conceptually", Zeilik and Morris-Dueer reported that in ranking 200 concepts often taught in "Astronomy 101" courses, the electromagnetic spectrum was ranked the highest. Project LITE is developing innovative materials about light, directly addressing 5 of the 6 "highly essential" topics cited in the AAS study along with many others. The LITE outcomes are being designed for use in the context of the large (typically 50 – 200 students per class per semester) and popular (estimated nationally at 250,000 students per year) introductory college astronomy courses for non-science majors. Some of the LITE software and devices are also valuable for astronomy majors' courses.

Up until now, Project LITE has largely been guided by two core strategies: (1) make optimal use of personal computers and peripheral devices as *actual experimental laboratories*; and (2) provide intellectually exciting and pedagogically sound laboratory exercises – for both in-school use and as "homelabs" - that guide students in an inquiry based manner to discover for themselves the most important ideas about light. These goals have been accomplished by developing software that controls the optical emission of computer screens and by developing associated optical materials and devices. Because of light's broad accessibility and great intellectual and pedagogical value as a subject, we plan to expand our development of hands-on (actually eyes–on and mice-on!) activities about the nature of light for use in a wide variety of astronomy, physics, chemistry, teacher training, and even psychology courses.

The technological developments of Project LITE have been guided by past and current research on student learning, particularly well documented in the physics education research literature. Students come to most subjects, including light and optics, with many preconceptions and/or misconceptions. In studies of K - 12 students, a variety of these notions have been uncovered. For example, studies have found that many students believe that the color of an object is independent of its source of illumination and that light exists only where it can be seen. Some students suggest that colored lights combine in the same way that colored paints do. A particularly egregious misconception held by many young people - especially for night joggers or bike riders - is that light colored objects can be seen even in total darkness. Studies of misconceptions held by college students about geometrical optics have also been carried out [3], as well as studies of misconceptions about topics related to physical optics [4]. However, no equivalent study has been conducted concerning student misconceptions about light in the context of astronomy (prior to the one we are doing).

From our personal experience, gathered over three decades of teaching undergraduate astronomy courses, we have found that concept oriented demonstrations, along with direct manipulation and experimentation, can be effective in helping students learn. For example, the fundamental means by which astronomers gain an understanding of astronomical objects is from the application of Kirchhoff's laws of emission and absorption of radiation. Despite lecture presentations and textbook discussions, students often come away stating that atoms actually emit absorption lines - that is, that atoms have the astonishing ability to emit blackness! We have developed simple demonstrations to help clarify the actual origin of absorption lines [5]. These can be used to help students understand how the interaction of light with atoms can lead to the formation of optical absorption lines.

Still, even clear and simple lecture demonstrations alone do not guarantee that all or even most students achieve a reasonable understanding of the material covered. Consider, for example, a careful demonstration in lecture showing that for a thermal blackbody radiator, red means cooler and blue means hotter (which is the very opposite of a lifetime of miscues indicating that red means hot and blue means cold). Some students then deduce that the reason the Sun appears red at sunset is because it cools off! Therefore a major aim of Project LITE is to test the idea that with a set of well-designed hands-on laboratory explorations, more students will come to understand fundamental aspects of the physical world through personal experience. Exciting laboratory exercises can also motivate students to pursue their own open-ended explorations of topics regarding light, color and perception that interest to them.

1.3. Project LITE Educational Materials Development Goals.

(A) Homelabs. "Homelabs" are a major focus of the project. In mathematics courses, students learn the subject best by solving problems. In English courses, students write essays. Ideally, these activities serve the dual purposes of developing technical proficiency while also stimulating creativity. In mathematics courses, having done many problems, students can confront new problems and, hopefully, solve them. In English courses, students learn the rules of grammar, spelling and punctuation, but also learn to express themselves clearly through the very act of writing. Likewise, we are investigating the idea that students can learn about the natural world the way scientists do: by doing experiments, creating models, and comparing the two. We have developed "homelabs" - inquiry based, take-home hands-on experiences. These include "guided discovery" activities, as well as more open-ended investigations. For example, we have students observe and measure the spectra of carefully chosen sources using a diffraction grating and then explore lights of their own choosing. Later they can do more quantitative studies using a direct view spectrometer or a spectrophotometer. Light and optics are particularly amenable to such homelabs, since the required materials are interesting, inexpensive and safe. The idea of homelabs for science learning is not without precedent (cf. [6], [7], [8] and [9]). However, none of these projects dealt mainly with light and, to the best of our knowledge, no university non-majors science course to date has made extensive use of homelabs as a major component of the learning experience. Furthermore, no one has previously developed homelabs that *combine* computer hardware and software with real optical materials.

Is there evidence that homelabs are effective in enabling student learning? To date there have been very few controlled experiments with the use of take home laboratory experiences in universities. The electromagnetism Project ZAP at M.I.T. and Caltech [8] and the Carnegie-Mellon University "reform" electromagnetism curriculum [9] are two curricula that have employed homelabs. In the latter project, the developers found evidence for a significant increase in both student understanding and retention by comparing students taking either the traditional or the reform curriculum. It was found that all students (not just the most highly motivated) improved an average of one grade level (i.e., B to A or C to B) in their performance, and that the improvement in learning was manifest in both the short term (3 months later) and long term (2 years later) (Chabay, private communication). These results were from a calculus based *majors* course.

(B) In-School Laboratory Exercises. One of the main reasons why many colleges and universities do not have a hands-on component for non-majors science courses is the lack of space, equipment and teaching assistants to run effective in-school laboratories. The majority of introductory college astronomy courses have only lectures. A prime motivation for the LITE homelabs is to relieve this problem. However, as a complement to lectures, classroom demonstrations and homelabs, we have also been developing hands-on activities that make use of in-school laboratory facilities. These include, for example, an inexpensive handheld binocular spectrometer that we have already developed for semi-quantitative spectroscopic observations, as well as an inexpensive PC coupled USB spectrophotometer that we have developed. There is evidence at the high school level, that organizing students into teams significantly enhances learning. Peer instruction has also shown success at the college level (cf. [11] and [12]). Some of the LITE products, such as the USB spectrophotometer, have been developed for use by students doing in-school laboratory exercises, either in groups or individually. We are interested in finding out whether working in groups leads to significantly greater student understanding, or whether, at the college level, students can learn the most important ideas and concepts just as well by working on their own either in school or at home.

(C) Lecture Demonstrations. Many colleges and universities teach large numbers of students with a limited number of faculty and few laboratory resources. Large introductory science lecture courses are likely to continue in the near future so good, effective lecture demonstrations will continue to be of value in teaching. Project LITE has developed new, often-interactive, lecture demonstrations that employ novel software and optical materials. These are aimed at exciting students' interest; dramatically demonstrating phenomena that are difficult to duplicate at home; and providing impetus, even in large lectures, for discussions between students, and between students and the instructor. Examples of such demonstrations can be found in references [5] and [13]. Several studies have found that interactive lecture demonstrations requiring active participation by students (e.g., making predictions of outcomes) can be very effective learning tools (cf. [14] and [15]).

2. Results To Date of Project LITE

There have been eight outcomes to date: (1) development of a kit of optical materials, software and 6 associated laboratory exercises; (2) development of the "Spectrum Explorer" software; (3) invention of a handheld binocular spectrometer; (4) development of an inexpensive electronic computer controlled and powered USB spectrophotometer; (5) development of a suite of over 250 controllable computer visual perception applets; (6) formative evaluation of learning gains by students resulting from use of the Project LITE materials; (7) development of a "Light and Spectroscopy Concept Inventory" to assess the effectiveness of education about light in various academic settings; and (8) dissemination of the LITE outcomes. Each of these is discussed below.

2.1 LITE Kit, Software and Homelabs

Our goal is to have students work directly with light and optical phenomena. Because of the wide availability of computers, and because a computer screen is itself a controllable source of light, we have developed computer software and a kit of inexpensive optical materials to allow students to directly experiment with light. One of the entirely novel and innovative aspects of Project LITE lies in this unique ***coupling*** of computers with inexpensive hands-on optical materials. Students can use the Project LITE software we have developed in conjunction with the materials contained in the LITE Optics Kit (shown in Figure 1 below), either in their homes or in school, to explore for themselves a range of actual light, optics and visual perception phenomena. We have already developed six laboratory exercises that take advantage of this concept for use in introductory undergraduate astronomy courses. The labs are about: (1) geometrical optics (lenses); (2) physical optics (diffraction); (3) color - of materials, the sky and stars; (4) fluorescence and phosphorescence; (5) emission, absorption and blackbody spectra; and (6) polarization of light. The Project LITE Web site http://lite.bu.edu contains all of our software developed to date.

Before elaborating on the innovative nature of our approach to computer assisted science education, we note that there are many fine examples of computer software on the Web that ***simulate*** optical phenomena on computers. For example, the "Visual Quantum Mechanics" software found at http://perg.phys.ksu.edu/vqm/ developed by Dean Zollman at Kansas State University takes advantage of the ability to display and move objects on a screen. The Project "CLEA" labs found at http://www.gettysburg.edu/academics/physics/clea/CLEAhome.html - developed by Laurence Marschall at Gettysburg College - simulate astronomical observations. The FSU National Magnetic Laboratory site - http://micro.magnet.fsu.edu/primer/lightandcolor/index.html - contains, among many applets about light, elegant simulations of diffraction and interference. And the "Physics Education Technology" (PhET) site http://www.colorado.edu/physics/phet/web-pages/index.html at the University of Colorado, developed by Nobel Laureate Carl Weiman and his collaborators, has excellent simulations of a wide variety of physical phenomena, including several about light. By contrast with these and all other light and optics Web sites of which we are aware, the Project LITE site is the ***only*** one that makes use of the emissive optical properties of a computer screen. That is, many of the LITE applets are designed to enable students to perform actual experiments directly ***with the photons*** coming from the screen.

We have developed the Project LITE Optics Kit (Figure 1) to be used with the LITE web site.

Figure 1. Project LITE Kit designed to be used in conjunction with applets viewed on a computer screen.

The LITE kit contains optical elements that were carefully selected to match characteristics of computer screens - both CRT and LCD. The kit currently contains 21 optical elements: 6 colored and 2 neutral density filters for uses as varied as color subtraction, viewing 3-D images of comets and other astronomical objects and for testing stereopsis with both random dot stereograms and the Pulfrich phenomenon; 3 polarizers, quarter wave plate and birefringent material for studying a variety of physical and perceptual phenomena involving polarized light; 2 sheets of Mylar mirror for studying multiple reflection, anamorphosis and kaleidoscopic image making; 2 plastic lenses for studying geometrical optics (and making a Keplerian telescope); a translucent sheet for viewing screen images projected by the lenses; fluorescent and phosphorescent plastics for studying atomic excitation; and a diffraction grating. The parts are all contained in a CD case, which is part of the kit: as a structural element - to hold the translucent screen for projection; to hold the two mirrors for studying reflection; and as a birefringent material that displays physical stress. The cost for all of the components in the kit is under $5. How can these materials and software be combined? As an example, consider the Fluorescence applet. By placing the fluorescent plastic included in the kit in front of the screen, students find that only light containing photons that are energetic enough can excite the atoms in the plastic to fluoresce. This is both an actual physical demonstration and a model for astrophysical objects such as planetary nebulae. The Monitor Spectral applet can be used to enable students to determine for themselves the actual spectrum of the CRT screen phosphors or LCD screen pixels (and compare between monitors) using the diffraction grating included in the LITE kit. This applet is also used for the quantitative experimental study of diffraction. By moving the grating towards and away from the screen and by changing the color of the displayed line of light, students see that the angle of diffraction is directly proportional to the wavelength of light. Using the screen spectra displayed elsewhere on the LITE Web site, students can experimentally determine the line spacing of the grating. Other applets help students to explore topics as varied as color mixing and Mach bands. Each activity employs the computer as an actual optical device, not just as a simulator. However, where needed, we have also developed software that takes advantage of the computer's computational and display potential to enable students to analyze data and simulate optical phenomena that are difficult or impossible to explore directly. We turn to that software now.

2.2 Spectrum Explorer Software

We have been developing a software applet/application that we call the "Spectrum Explorer" (SPEX) – see Figure 2.

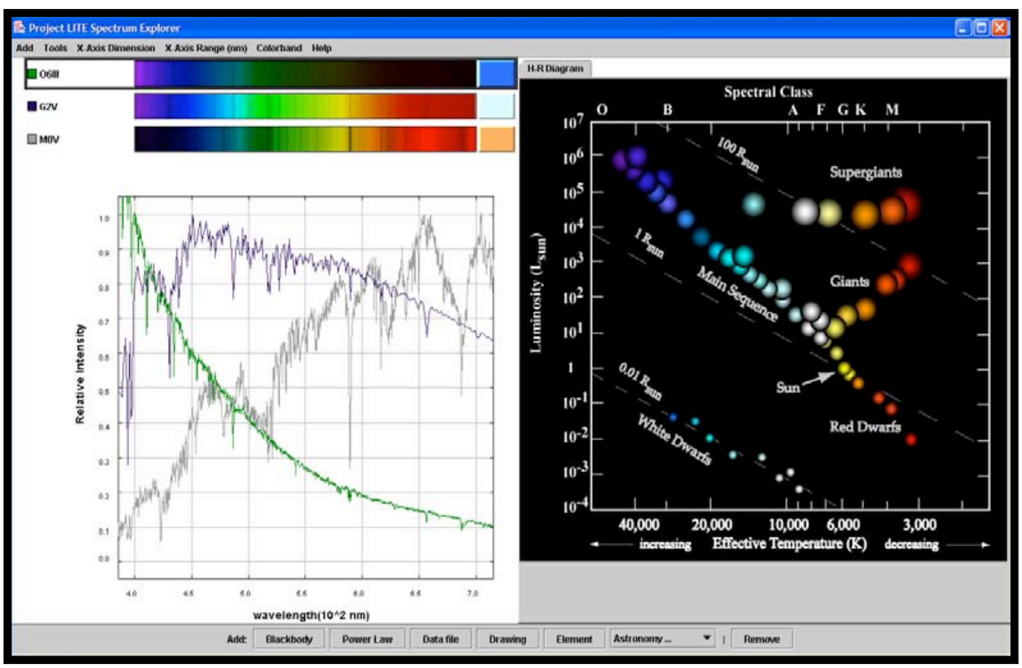

Figure 2. SPEX screen showing stellar spectra that are coupled to the interactive H-R diagram.

At its core, it is a spectrum display and analysis JAVA program that can be run either as an applet on the Web or as a downloadable application. It displays normalized and un-normalized spectra, with intensity plotted as a function of wavelength, frequency or photon energy. It simultaneously displays spectra as a graph and as a colorband. It shows connections to the underlying physics by including numerous scientific and pedagogical components. It can plot blackbody spectra of any temperature. It displays emission line spectra of any ionization state for all elements in the periodic table. It can plot power law spectra with adjustable spectral indices. It can apply a Doppler shift to spectra. It contains a freehand drawing tool, pop-up tool tips, right-click menu options on the color band, and the ability to make any spectrum editable by the user. SPEX contains measuring tools, zoom capabilities, and even a tool to sonify spectra (that is, to allow students – including the visually impaired – to *hear* light spectra). SPEX also has printing and exporting capabilities when being run as an application. It is our aim that SPEX will become for the display, manipulation and analysis of electromagnetic spectra what "PhotoShop" is for the processing and analysis of images, or Microsoft Word is for the manipulation of words (though, hopefully, SPEX is more user friendly than is Word). We have incorporated into SPEX many astronomical features including an interactive H-R diagram, a stellar evolution animation and an interactive Hubble tuning fork diagram. Current SPEX astronomical databases include stellar spectra of all spectral types, planetary nebula and supernova spectra, and plots of high-resolution Solar spectra centered on H-alpha and the sodium D doublet. Pilot testing of the software has been done from 2003 - 2007 with over 1,000 students in 100-level astronomy courses. It has also been used extensively in lectures. Students report that they like the look and feel of the interface and that the software is easy to use.

2.3 Binocular Spectrometer

We have developed a unique quantitative handheld visual band spectrometer. The instrument employs a binocular design. Its main advantages are ease of use and effectiveness in making quantitative measurements. Our design alleviates common difficulties with alignment and with poorly lit wavelength scales that students report when using traditional monocular spectrometers. Novel features that enhance its efficacy include the use of an efficient holographic transmission diffraction grating, a variable-width entrance slit, and adjustable illumination of the wavelength scale. The binocular design eliminates the need to squint and significantly reduces eyestrain. Binocular viewing also appears to improve sensitivity to differences in contrast, resolution, and color. Two features that contribute to the ease of use and uniqueness of our instrument are the adjustable slit and removable scale flap. A variable slit gives the user the ability to adjust the width of the entrance slit to suit each individual task. While a narrow slit is beneficial for studying bright sources, it can also make aligning the instrument on a narrow source a very difficult task for a novice user. Students using the Project LITE binocular spectrometer will be able to open the slit wide to align the instrument and then narrow it down to achieve the best results for their quantitative measurements. A flap over the wavelength scale can be lifted up or secured down in order to allow the user to customize backlighting on the scale. The background can be fully illuminated by ambient light or made entirely black for qualitative spectroscopy – a feature particularly useful for observing narrow absorption lines such as the solar Fraunhofer lines. Boston University (assignee) on behalf of E. Weeks and K. Brecher (inventors) filed U.S. Patent Application No. 10/954,388 for the "Binocular Spectrometer" in 2004. The formal Notice of Allowance from the U.S. Patent Office was made in February 2007 with the patent number to follow in summer 2007.

2.4 Spectrophotometer

A second educational spectrometer was also developed. We want to know whether students will benefit from the hands-on nature of collecting, manipulating, and analyzing their own quantitative spectra. However, the high cost of commercially available USB based spectrophotometers currently available (>$1,000 - $2,000) has prevented their wide scale use in college astronomy education. We have worked with a team of four undergraduate senior electrical engineering majors to develop a relatively inexpensive (~$100) PC USB spectrophotometer. The prototype Project LITE spectrophotometer employs a 2048-pixel linear CCD array as a detector and connects to personal computers through a USB port. Light can enter the device either through a simple slit or through a fiber optic cable and be dispersed onto the detector by a diffraction grating. The spectrophotometer outputs a two-column stream of data (wavelength and flux) in real time and interfaces with the Spectrum Explorer software.

2.5 LITE Vision

As part of Project LITE, we developed a suite of applets about visual perception. Though at first glance this might seem out of place in the framework of what has been primarily an astronomy and physics educational materials development project, it is, in fact, quite valuable. For example, following nine chapters devoted to the physics of light and optics in the first volume of the Feynman Lectures on Physics, there are two chapters devoted to color and the mechanisms of vision [16]. The authors remark, "There are many interesting phenomena associated with vision which involve a mixture of physical phenomena and physiological processes, and the full appreciation of natural phenomena, as we *see* them, must go beyond physics in the usual sense. We make no apologies for making these excursions into other fields, because the separation of fields, as we have emphasized, is merely a human convenience, and an unnatural thing. Nature is not interested in our separations, and many of the interesting phenomena bridge the gaps between fields". Throughout history, astronomers and physicists have made many of the major contributions to the understanding of vision. Newton showed that white light could be separated into colors that are mainly a psychophysical phenomenon, remarking, "these rays are not colored". Young, Maxwell and Helmholtz in the 19th century, Mach, Schrodinger, Land and many other physicists in the 20th century added major insights into vision.

The LITE vision applets, like the astronomy and physics applets, use the computer to produce the *actual* phenomena. Over the past three years we have developed and posted on the LITE Web site more than 250 Flash and JAVA applets that elicit visual phenomena, the most extensive collection developed to date. The opening screen for the LITE vision applets is shown in Figure 3 below. The applets (which can also be run as applications) are all

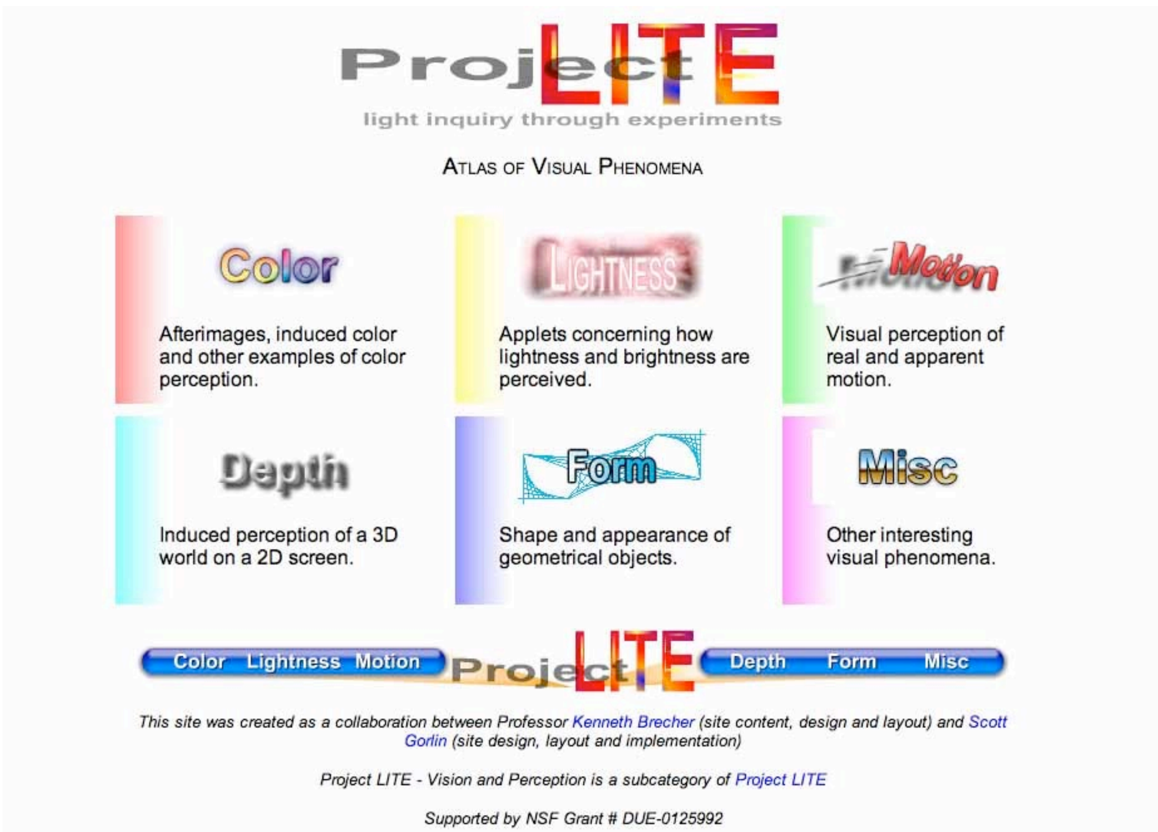

Figure 3. LITE Vision Flash applets opening screen.

controllable allowing students to manipulate and vary the stimuli for a range of visual phenomena that cannot be achieved by viewing only a printed page. These applets - which involve color, lightness, motion, form and depth - are already being used in introductory psychology courses (which are taken by over a million students in the U.S. each year), as well as in more advanced courses on sensation and perception (at BU, Harvard, and elsewhere) and in informal settings (e.g., the Exploratorium). The LITE Vision Web site is included in the list of demonstrations on the vision science Web site (http://www.visionscience.com/). Results of our vision efforts have been presented at meetings of the Vision Sciences Society (VSS), the European Conference on Visual Perception (ECVP) and at the American Astronomical Society (cf., for example, [17], [18], [19], [20]). The applets are also being used in astronomy courses to clarify the relation between the perception of color and the wavelength of light. An understanding of what the “color” of stars means – e.g., as employed in constructing the H-R diagram and as is shown in a color patch in SPEX - depends on understanding the connection between visual perception and the instigating physical stimulus.

2.6 Formative Evaluation

To assess the effectiveness of the LITE materials, we initially developed diagnostic tests consisting of open-ended conceptual questions. Through a systematic study that included multiple rounds of clinical interviews, open-ended written surveys, as well as multiple-choice testing [21], we identified commonly held misconceptions and reasoning difficulties that introductory astronomy students have with concepts relating to: the nature of the electromagnetic spectrum, including the interrelationships of wavelength, frequency, energy, and speed; interpretation of the Doppler shift as an indication of motion; the correlation between peak wavelength and temperature of a blackbody spectrum; relationships between luminosity, temperature, and surface area of a blackbody emitter; and the connection between spectral features and underlying physical processes. Interview questions consisted of the original diagnostic test questions as well as follow-up inquiries to ascertain the depth of student knowledge and/or misconceptions regarding each of those topics. We looked not only at whether students answered questions correctly, but also whether or not they arrived at the correct answers with the proper reasoning. Based on the tests and interviews, average learning gains at BU on the questions ranged from 15% - 20%.

2.7 Light and Spectroscopy Concept Inventory (LSCI)

Physics Education Research has benefited immensely from the development of the Force Concept Inventory (FCI) (cf. [22]). This 29-item multiple-choice survey is usually administered at the beginning and end of introductory physics courses and has been able to reliably document gains in student understanding of force and motion resulting from various educational interventions. Working with T. Slater and E. Prather (University of Arizona) we have developed a "Light and Spectroscopy Concept Inventory (LSCI) (cf. [21], [23] and [24]). The concept domain addressed by the LSCI has been shaped by the concepts that are most commonly taught in the introductory college astronomy survey courses, such as properties of the electromagnetic spectrum, Doppler shift, Wien's law, the Stefan-Boltzmann Law and Kirchhoff's Laws of spectral analysis. The LSCI contains 26 research-based multiple-choice questions that target known student alternate conceptions and reasoning difficulties associated with the selected light topics. The LSCI was administered to approximately 500 students taking introductory astronomy courses at 12 participating colleges and universities in the Fall semester of 2005. We received post-test results for 387 students at 11 of the colleges and universities. Preliminary, but statistically significant, results (cf. [22] and [24]) found that overall learning gains by the BU students using the LITE materials were among the highest of the colleges tested, though part of this result may arise from different pre- and post test sample sizes. We found national pre- and post instruction LSCI averages of 24% and 39%, respectively. This can be compared with pre- and post-instruction national averages of 32% and 47%, respectively, found using the Astronomy Diagnostic Test (ADT) [25]. The LSCI was given to 1500 students at 20 other colleges in Spring 2006. Pre- and post test averages were 25% and 40%, respectively, consistent with the first trial. The combined results are now being prepared for publication [26].

2.8 Presentations and Dissemination of Prototype Materials

We have presented the Project LITE outcomes to college scientists and educators, as well as to K - 12 teachers, at meetings of the Optical Society of America, Astronomical Society of the Pacific, American Association of Physics Teachers, American Astronomical Society and American Physical Society. The LITE materials have been used with over 200 teachers in Summer Teacher Workshops at the Exploratorium. They were used with 20 teachers at a Chautauqua teacher workshop, and with 150 university instructors in an ASP Cosmos in the Classroom Symposium. Without exception, the software and materials have been greeted with enthusiasm. All of the software is posted on the LITE web and is freely downloadable. The first six laboratory exercises are being posted on the LITE Web site. Several science education apparatus manufacturers have expressed interest in producing and distributing the LITE kits.

3. Conclusion and Brief Plans For Future Development of Project LITE

Project LITE has developed a novel coupling of original software with inexpensive optical materials that can be used in optics education at a variety of educational levels. Though originally developed in response to the need for such hands on and eye-on experiences in introductory undergraduate astronomy courses, these materials can also be used in a wide variety of other educational settings, including K-12 and undergraduate chemistry, physics, Earth Science and psychology courses, as well as in more informal settings. In the future, we plan to expand our development activities to include other input and output devices for computers including printers, webcams and inexpensive USB based photometers. We also plan to develop simple inexpensive devices that can be used to allow students to explore for themselves a wide range of visual phenomena such as depth perception which require other modes of exploration outside the two dimensional realm of computer screens.

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VIII.

Hands-On Optics Science Camps and Clubs

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Abstract: Hands-On Optics (HOO) is a National Science Foundation funded program to bring optics education to traditionally underserved middle school students. We have developed six modules that teach students optics concepts through hands-on, inquiry-based activities. The modules have been used extensively in after-school and non-school settings such as in the Boys and Girls Clubs in South Tucson, Arizona and the Boys and Girls Club in Sells, Arizona on the Tohono O'odham reservation. We will describe these programs and the lessons learned in these settings. These modules also form the basis for a week-long optics camp that provides students with approximately 40 hours of instruction time in optics. We will provide an outline of the activities and concepts covered in the camp. These camps provide an ideal way to encourage interest in optics before career choices are developed.

1. Introduction

Hands-On Optics (HOO) is a four-year National Science Foundation funded program to bring optics education to traditionally underserved middle-school aged and younger students (ages 8-14) (Pompea et al. 2005a). We have developed six activity modules and classroom ready kits that teach students optics concepts through hands-on, inquiry-based activities. Our intent is to expose young children to optical phenomena to build scientific interest and literacy. Our belief is that this can be done quite effectively at science centers, after-school programs, in clubs, and in competitions (Pompea and Hawkins 2001, Pompea et. al. 2005b)

HOO has been a collaboration among the International Society for Optical Engineering (SPIE), in Bellingham, Washington; the Optical Society of America (OSA) in Washington, DC; and the National Optical Astronomy Observatory (NOAO) in Tucson, Arizona. HOO was originally designed for middle school-aged students who are in after-school or science museum programs. HOO has also been used formally in classrooms. This paper addresses the use of HOO in an informal setting– Boys and Girls Clubs and camps devoted to optics. At Boys and Girls Clubs, the HOO program has been successfully adapted to a younger age group (8 years old and up).

Since the Summer of 2006, the Hands-On Optics program has successfully partnered with the Boys and Girls Club of South Tucson and the Boys and Girls Club of Sells, Arizona to present an optics program on a year-round basis. Boys and Girls Club is a private organization that offers after school and summer programs. We have conducted three semesters of programs at both locations covering a variety of topics in optics, including the law of reflection, multiple reflections and kaleidoscopes, lenses and telescopes, polarization, infrared and ultraviolet light, and optical communication using amplitude modulation.

These modules also form the basis for our week-long optics camps for the Girls Scouts and for underserved Tucson students in the "GEAR-UP" program. These camps provide students with approximately 40 hours of instruction and activities in optics. In this paper, we will provide an outline of our pedagogical approach, specific optics activities, strategies for cooperative learning, learning objectives and misconceptions covered, and a synopsis of assessment approaches. We will discuss the challenges involved with bringing Hands-On Optics to these venues as well as the lessons learned. We will also discuss future plans to make Hands-On Optics a continuing presence at these camps and clubs.

2. Summary of Hands-On Optics Pedagogical Approach

The Hands-On Optics program (HOO) provides opportunities for kids to succeed in collaborative learning and problem solving through inquiry-based, hands-on optics activities and projects. HOO increases science and technology knowledge for students, and increases the awareness of optics as a discipline and career that crosses numerous fields.

There are formative assessment opportunities throughout the modules to gauge student comprehension and these are well suited for the informal camp environment. All of the modules follow a "Learning Cycle" framework (exploration, concept introduction, concept application) similar to that of Karplus and Their (1967) and the BSCS 5 E's instructional model (Bybee, 1997). We have adjusted the learning style framework to one that best fits the target audience. In each module, students explore ideas through hands-on experiences, formulate and test hypotheses, solve problems, and create explanations for what they observe:

Module 1 starts with students engaging a scientific question, "Does light reflect in a predictable manner?" They take data to verify the law of reflection and then extend their new understanding and abilities to a hands-on application called "Hit the Target."

Module 2 begins with students engaging a scientific question, "How do multiple mirror systems work?" They take data to verify predictions and then extend their new understanding and abilities to a hands-on application–building a kaleidoscope.

Module 3 begins with a demonstration to start students investigating how light bends. Through multiple activities they begin to understand image formation using lenses and mirrors. They build a refracting telescope and measure its resolution.

Module 4 begins with students engaging in a scientific question, "What is polarized light and how can it be used?" They collect data to verify their hypotheses then extend their new understanding to the hands-on applications, "I'm Under a Lot of Stress Here" and "Tape Art Challenge." In these activities they analyze stress in plastic materials using polarized light and create colored art using polarization.

Module 5 starts by allowing students to explore the properties of waves using slinkies. The students then learn that visible light comprises only a small portion of the electromagnetic spectrum by attempting to make a model of the EM spectrum. Students then explore different substances and how they interact with infrared, visible and ultraviolet light. Finally, students engage in a series of short activities using infrared and ultraviolet light.

Module 6 engages students in exploring possible answers to the question, "How can we use light to communicate?". Through the "Laser Communication Challenge" activity, they demonstrate understanding of how light can travel through long distances to successfully transmit information.

3. Optic Camp Learning Objectives and Authentic Assessments

The turnkey program comprises a comprehensive, ready-to-use collection of six modules, each complete with a toolkit that includes an activity book and all the optics materials needed to allow 30 students to explore and manipulate light in challenging ways. The module titles are *Laser Challenges*, *Kaleidoscope Adventures*, *Magnificent Magnifications*, *Peculiar Polarizations*, *Ultraviolet and Infrared Light*, and *Communicating over a Beam of Light*. Because the activities and kits were developed by educators at an astronomical observatory, many of them have an astronomical focus. As part of their learning objectives within the different HOO modules, participants explore

- Directing laser light to try to hit a target
- Using multiple mirrors to make one of several types of kaleidoscopes
- Forming upside-down images of the world using lenses and mirrors
- Building a telescope
- Using polarized light to navigate like a honeybee and to create art
- Using infrared light to measure temperatures
- Exploring phosphorescence, fluorescence, triboluminescence, and chemiluminescence
- Communicating over a long distance by sending their voices over a beam of light

Although many students attend multiple sessions of our programs, many students attend the sessions intermittently. One technique we have used is to pose a "Question of the Day" that students have to answer at the end of the period. We gave each student a Passport. The Passport contained the student's name, picture, and pages on which to write their answer to each day's question. The Passports provide a record of what students learn during the program.

Other assessments are built into the modules. For example, the culminating activity of Module 1, "Hit the Target", shows you very quickly if students understand the law of reflection and how to measure angles. Students first position 2 mirrors (then 3 or more) with a laser to hit a stationary target without turning on the laser until the setup is complete. The laser has to be at least 4 feet from the target and one foot away from any mirror.

4. Hands-On Optics at the Boys and Girls Clubs

Over the past year the NOAO science education staff has had the opportunity to work with children ages 7 to 14 years old attending the South Tucson and the Sells Boys and Girls Clubs. The children that attend the South Tucson Boys and Girls Club are from the surrounding Hispanic community. The Sells Boys and Girls Club is situated on the Tohono O'odham Indian Reservation, an hour and a half southwest of Tucson. It is in the closest town to Kitt Peak National Observatory. The Boys and Girls Club environment offers an ideal opportunity to provide effective local outreach in optics education, to develop further materials in different informal education settings, and to aid in adapting these materials for use with younger audiences.

Metrics and Logistics

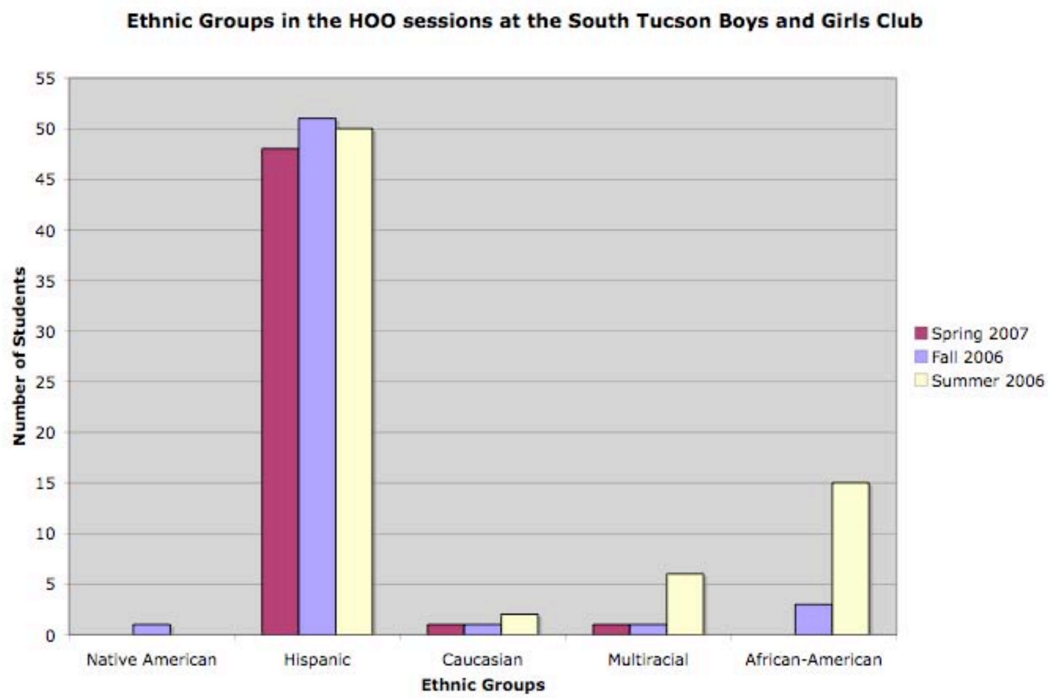
In South Tucson, two 1.5 hour sessions were held each week over the summer of 2006. The sessions were delineated by age. One class each week was geared toward 11-14 year olds and the second class each week was adapted to 7-10 year olds. Participation was good: 73 children participated in the program for an average of 22 students each day. There were an equal number of boys and girls participating and twice as many 7-10 year olds as 11-14 year olds. As a capstone, 18 children with the highest attendance record traveled to Kitt Peak National Observatory (run by NOAO) for the Nightly Observing Program at the visitor center telescope.

At the Boys and Girls Club in Sells (on the Tohono O'odham Reservation), 1.5 hour sessions were held every *other* week during the summer, since travel time was more than 1.5 hours one-way. There were a minimum of 15 children at each session. Their ages were mostly between 7-12 years old. (The older children were attending a newly-opened recreation center nearby.) The HOO program was well received. Of the 37 children who attended, 90% of them had consistently participated in HOO and 90% of them wanted the program to continue.

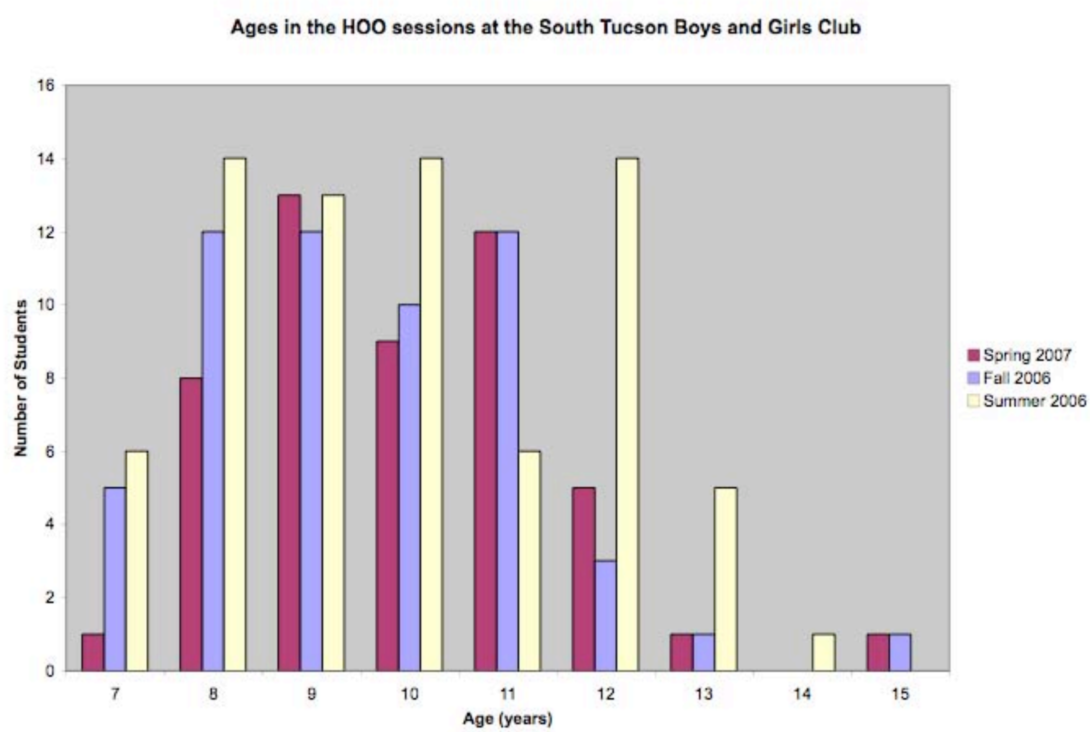
Many of the same children attending the Fall 2006 HOO sessions at the Boys and Girls Club of South Tucson had experienced Modules 1-6. Therefore, new activities centered on the concepts of making images and optical illusions through hands-on experiments and demonstrations were alpha-tested in 9 out of the 11 weekly Fall classes. During the 11 weeks 57 predominantly Hispanic children (90%) ages 7 to 15 years old were reached. On average, 15 children attended per week. Since 80% of the children were between the ages of 8 and 11, the activities were developed accordingly to be age-appropriate.

Figure 2. Students from the Boys and Girls Club in South Tucson enjoy the capstone activity for high attendance: a trip to Kitt Peak National Observatory.

At the Boys and Girls Club in Sells, about half of the children who attended in the summer also attended in the Fall of 2006. The children voted to experience the same content (the 6 HOO Modules) as was offered in the summer. (They enjoyed the lasers in particular.) Sessions took place every other week for 1.5 - 2 hours per session. 12 to 15 children on average attended each session for a total of 6 sessions. The children were between 7 and 12 years old and ethnically Native American. One of the last sessions included a special viewing of the transit of Mercury across the Sun through telescopes that used optics now familiar to the students.



The first bar graph illustrates the majority of the children in the HOO program at the South Tucson Boys and Girls Club are primarily of Hispanic ethnicity: 2 out of 3 children during the Summer of 2006 and 9 or more out of 10 during the ensuing academic year. This can be compared to 100% of the students in the HOO program at the Sells Boys and Girls Club of Native American ethnicity.



The second bar graph illustrates a shift in age demographics between the Summer of 2006 and the ensuing academic year. The number of students in the age range from 12 -15 diminished significantly. The range of ages from 7 to 11 did not change drastically over the three sessions. This presented an opportunity to adapt the once-middle-school-focused activities to a younger target audience.

For three months during the Spring of 2007 (mid-January to the end of April), HOO sessions at the Boys and Girls Club in Sells occurred late afternoon every other Wednesday for an hour and a half to 2 hours each time and at the South Tucson Boys and Girls Club every Friday evening for the same length of time. To entice the students at the start of every semester to participate in the HOO program, all the students in South Tucson were invited to a set of optics demonstrations that showcased the upcoming HOO sessions. Subsequently, Modules 1 through 5 were offered in sequence during 12 Spring sessions. By this point, which activities worked best from the first 5 modules were well established as were which were most appropriate for the younger age group. The table below lists the showcase and activities for fourteen 1.5 hour sessions, of which 12 were done during the Spring of 2007.

Boys and Girls Club Spring 2007 Semester Plan

Session	**Module:** Activities
Showcase	**Optics Showcase:** Laser Challenges Kaleidoscope Adventures Magnificent Magnifiers Peculiar Polarizations Ultraviolet and Infrared Light
1^{st} Session	**Laser Challenges:** Laser Stations; Measuring Angles
2nd	**Laser Challenges:** Mission Impossible
3rd	**Laser Challenges:** Hit the Target
4th	**Kaleidoscope Adventures:** Titanium Dioxide, COOKBOOK, Right is Right
5th	**Kaleidoscope Adventures:** Dollar out of Penny, RRReflections
6th	**Kaleidoscope Adventures:** Making Kaleidoscopes, Periscopes
7th	**Magnificent Magnifiers:** Light through acrylic block, Focal Point, Focal Length
8th	**Magnificent Magnifiers:** Simple Magnifiers
9th	**Magnificent Magnifiers:** Making Telescopes
10th	**Peculiar Polarizations:** Cookie Rack, Stress Tests
11th	**Peculiar Polarizations:** Polarization Exploration Stations
12th	**Peculiar Polarizations:** Tape Art
13th	**Ultraviolet and Infrared Light:** Fluorescence and Phosphorescence Stations
14th	**Ultraviolet and Infrared Light:** Tribo- & Chemiluminescence (e.g., CSI) and Fluorescent Minerals

5. Student Feedback

Very positive comments about the program were noted by Boys and Girls Club staff members. The main Boys and Girls Club staff member in South Tucson said. "The kids who took the HOO sessions will come up to me at random times to tell me something they learned, and all of them are always asking 'When is science class?' We have a group of 7 year olds who all want to turn 8 so they can take the class."

Figure 3. Students from the South Tucson Boys and Girls Club receive their Hands-on Optics "Masters of Reflection" certificates.

Another remark from a Boys and Girls staff member was "One new young man who is 11 wasn't really sure he wanted to come to the class, and I told him to try it because I thought he'd like it. Part way through he came over to me and said "this is really cool - I didn't know you could do all this stuff with lasers". These "aha" moments for the kids are the reason it is so important to keep providing them these opportunities - you truly are making a difference in the life of these young people by giving them this exposure to science."

An article in the Arizona Daily Star dated October 31, 2006 summarizes the excitement of and effect on the children that the program has had at the Boys and Girls Clubs. See http://www.azstarnet.com/metro/153595.

6. Extended Optics Camps

The HOO program "experience" at the Boys and Girls Clubs during this past year (June 2006 to the present) has afforded insight into how to create summer camps on optics. In this section we share our logistical set-up, ideas on the informal curriculum and field trips and facts about the program and the audience it serves.

In Summer 2007, the National Optical Astronomy Observatory (NOAO), in collaboration with BIO5, Tucson Gaining Early Awareness & Readiness for Undergraduate Programs (GEAR-UP), and the Flandrau Science Center on the University of Arizona (UA) Campus in Tucson, will offer three week-long camp sessions in optics to disadvantaged middle school students. Through a combination of hands-on, inquiry-based science activities, UA campus field trips, and science center experiences, students will be immersed and engaged in the process of doing science via optics and exposed to science resources available at The University of Arizona.

The primary goals of this program are to:

- Engage middle school students in the process of doing optics;
- Excite middle school students about science and technology;
- Expose middle school students who might otherwise be unlikely to attend college to educational opportunities available at The University of Arizona;
- Educate middle school students about career opportunities in optics.

Logistics

Three week-long summer camp sessions will be held at Flandrau Science Center from June 4-8, June 11-15, and June 18-22, 2007. The camp will run from 9:00 am to 4:00 pm, Monday through Thursday; on Friday, the session will end later in the evening due to a Kitt Peak field trip. Twenty students recruited from GEAR-UP middle schools in Tucson Unified and Sunnyside Unified School Districts will attend each session. A van provided by the camp and driven by the GEAR-UP staff will transport students between their middle school and the UA campus each day. Each week, one full-time teacher and two optics counselors (optics students who have been trained in the HOO curriculum) will lead the camp's activities. In addition, a GEAR-UP coach will be assisting in each camp. Lunch is provided daily at the campus cafeteria. The entire program is free to the students.

Curriculum

The Hands-on Optics, minds-on science summer program will utilize the "Hands-on Optics" (HOO) curriculum developed by NOAO. The Hands-on Optics program targets middle school students and is designed to inspire an interest in science and technology by bringing optics-related activities into after-school, summer, and science center programs. The program will utilize its six modules that address basic optics concepts such as reflection, image formation, colors and polarization, ultraviolet and infrared phenomena, and communication over a beam of light. Each day at camp will address a different module and contain exciting challenges and competitions that engage students and allow them to test their newly acquired skills.

In each camp session, HOO module activities and competitions will be supplemented by demonstrations and activities at Flandrau Science Center and a variety of campus field trips. Flandrau Science Center experiences include the Design Garage, in which students will have the opportunity to interact with a set of prototype exhibits, the Planetarium, and the Digital Dome. Potential UA field trip destinations include: the UA Mirror Lab which makes mirrors for telescopes with 8.4 meter objectives, a bio-imaging laboratory, the "cave" (a virtual reality facility at the Learning Technologies Center), the Center for Creative Photography, and the lunar and planetary laboratory. Campus field trips will complement the program's activities and provide the students with much-needed exposure to campus life at The University of Arizona. In addition to daily, on-campus field trips, each camp session will culminate in an evening field trip to Kitt Peak, offered to all campers and their families.

Participants

About 20 middle school students (incoming 8th-graders) from GEAR-UP schools in Tucson Unified and Sunnyside Unified School Districts will attend each week-long camp session. GEAR-UP is a government grant-funded program designed to increase the number of low-income, first-generation college-bound students who are prepared to enter and succeed in postsecondary education. The program serves a cohort of 3,600 students in 14 middle schools in the Tucson and Sunnyside Unified School Districts. GEAR-UP program coordinators have worked with the teachers at these schools to identify the students who will most benefit from this summer science camp experience.

One Day in the Life of an Optics Camp

GEAR-UP Hands-On Optics Camp
Day One: Laser Challenges

Time	*Event*
8:00-9:00	Arrival
9:00-9:15	Introductions (Who are we, what is HOO), Icebreaker: "Repeat Game" with name and favorite thing in science
9:15-9:45	Laser Safety, Mission Impossible Teaser The students will try to do mission impossible in groups of 5 without any information on how light reflects. Each group must come up with two questions they'd want to answer by the end of class that would help them do this activity better. Examples: Does light reflect in a predictable manner, if so, how? Does laser light always go in a straight line?
9:45-10:15	Bouncing Ball and Mirror, Mirror on the Wall (in groups) Instead of this being a demonstration, the students will be given the materials and will work together to see if a tennis ball bouncing on a floor is similar to flashlight reflecting from the mirror and if so, how it can be quantified.
10:15-11:15	Measuring Angles and Milky Water Demonstration As written in Module 1, only the main demonstration will be done in a fish tank rather than the small plastic containers

11:15-11:50 40 Minutes of group project time:
Group 1: Writing – "Letter to my cousin"
Group 2: Art – create a poster of today's concepts
Group 3: Career – research careers in optics with magazines, book, internet?
Group 4: Math – research the math connections of the day
Group 5: Telescope – spend time building the telescope and writing notes for the next group to continue

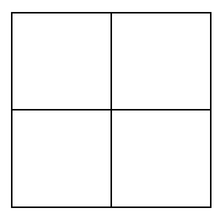
11:50-12:00 Morning Wrap-Up
Briefly wrap up morning activities, discuss lunch rules, and discuss field trip details and rules

12:00-12:45 Lunch

1:00-3:00 Field Trip

3:00-3:40 Hit the Target
groups of 4, ~5 minutes to discuss strategy based on what they've learned and what materials they are provided with, ~10 minutes to do a two mirror setup, ~10 minutes to do a three mirror setup, ~10 minutes for all groups to share strategies

3:40-4:00 Mission Impossible Conclusion, Wrap-up, discussion of next day's acitivties: Magnificent Magnifiers
Mission Impossible will be done with the same 4 groups of 5 as in the morning. The floor will be taped off as shown with the big square measuring 8ft by 8ft and each smaller square 4ft by 4ft. Each group is in charge of one square.



4:00-5:00 Departure, Deflexion Game

Next Steps for Optics Camps
The optics summer camp program will evolve based on the amount of feedback from the camps in June. In light of that, a similar version of the program is planned for a 4-day optics camps for the Sahuaro Girls Scouts of Tucson at the beginning of August. It will be a resident camp at their Tucson "Hacienda" facility for 40 girls, ages 11-17. Two optics counselors (optics students trained in the HOO curriculum) will lead the camp's activities. A trip to Kitt Peak National Observatory to participate in the Nightly Observing program is being planned as the culminating activity.

7. Lessons Learned

A variety of lessons have been learned from our ongoing educational partnership with the Boys and Girls Club. One lesson learned includes being prepared with a translator for every session so that the responsibility does not fall on a young bilingual student who is unfamiliar with the technical terms and is learning the material for the first time. Another lesson learned is to have one person to constantly be responsible for enforcing established classroom rules. A third lesson learned is to spend the first few minutes allowing the students to explore whatever hands-on items are a part of the activity before formally starting the activity. This encourages the students to ask their own questions and find out their own answers. Another lesson learned is to remain aware of the different types of learners especially when assessing their understanding of new concepts. For instance, each student was given a "passport" that had one or two questions on the main concept taught each session. Not only was the way the material was taught important, but how we accepted the answers to assessment questions was equally important. By being sensitive to the different types of learners, the assessment questions in the passport could be answered in words or as a drawing or even verbally.

On the subject of the passports, students from the Sells Boys and Girls Club had a more challenging time completing the questions. We determined upon observation that some participants were more successful working in groups. Alternative forms of assessment for the Sells Boys and Girls Club is under consideration.

There are a few procedural tweaks to each of the modules that also fall under lessons learned. Instead of listing all of them here, we are in the process of incorporating them into the latest version of the modules. However, here is one example of an on-site adjustment to an activity. To reinforce the concept of light bending as it passes from one medium to another, we did the kinesthetic activity where the students walk at one speed until hitting an imaginary barrier (e.g., concrete to grass or dirt). The first student encountering the barrier walks slower, then the second, then the third, causing the line to "bend" and form a new direction through the new medium. This demonstrates why light moving slower through glass than it does through air, for instance.

8. Summary and Future Plans for Optics at the Boys and Girls Clubs

The HOO program has been successful nationally. Our adaptation of the program for local Boys and Girls clubs has also been successful. The national HOO program has laid the framework for major dissemination in Arizona of the Hands-On Optics kits and educational modules and for delivery of the accompanying educator professional development program. NOAO has recently been awarded a Science Foundation of Arizona grant to bring the program, which teams educators with optics industry volunteers, to primarily rural after-school programs to ten rural locations around the state. The Hands-On Optics program will provide kits to these sites and activities suitable for more than 40 hours of informal instruction and relate optics to a variety of technical and scientific fields.

Our proposed program will target rural audiences who historically have been underserved in exposure to science and engineering education programs. HOO will use a volunteer network of technically trained "resource agents" to interact with and mentor the HOO kids at Boys and Girls Clubs. These resource agents can be members of the optics professional societies (Optical Society of America, SPIE–the International Society for Optical Engineering, related technical societies such as IEEE, or member of the optics industry (e.g. Arizona Optics Industry Association). Other technically trained people can also serve as mentors. Graduate and undergraduate students have successfully served as optics resource agents in other locations. The HOO project will team optics "resource agents" with informal science center educators to deliver the HOO project to the target audience. The optics resource agents will also receive training on how best to serve in this role.

9. Where can I get more information about HOO?

The Hands-On Optics program actively maintains a web site. The web site lists upcoming events and workshops as well as provides information on how to obtain the kits. You can find our web site at http://www.hands-on-optics.org.

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IX

The Development of a Low-Cost Laser Communication System for the Classroom

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Abstract: Hands-On Optics (HOO) is a National Science Foundation funded program to bring optics education to underserved middle school students. We have developed the culminating module (Module 6) on laser communication. Students learn how lasers can be modulated to carry information. The main activity of this module is the construction of a low-cost laser communication system. The system can be built using parts readily available at a local electronics store for approximately US $60. The system can be used to transmit a person's voice or music from sources such as an mp3 player or radio over a distance of 350 feet. We will provide detailed plans on how to build the system in this paper.

1. Introduction

The Hands-On Optics project is a four-year informal science program is designed to bring the excitement of light, color, and optics technology to tens of thousands of underserved middle school-aged students nationwide. The HOO project[1] has developed six hands-on activity modules intended to engage and enrich the math/science learning experience for students in the middle grades. Each module offers six to seven hours of exploratory science activities that can be grouped into 30- to 90-minute sessions. The project is aimed at after-school, museum, and science center settings but can be adapted for the formal education classroom.

Module 6 focuses on laser communication. The first activity addresses laser light illustrating the differences between white light and monochromatic light as well as coherent light and incoherent light. The second activity lets the students explore using light to transmit data in the form of Morse Code. The students then learn how to build the laser communication system. The students are given the challenge to communicate over the longest distance possible using the largest number of optical devices. The module culminates with a demonstration of fiber optics.

The problem we encountered with this module was the cost of the laser communication system. Companies such as Arbor Scientific[2] sell ready-made laser communication kits. The kit consists of a 0.8mW Helium-Neon laser ($475) and a Laser Voice Transmission Package ($139) consisting of a microphone, an amplified speaker, and a small photocell. The total price of $614 was too costly for use in our kits, necessitating the development of a lower cost system. Other laser communication systems have been described by Thomas Petruzzellis[3] and Gordon McComb[4]. Although these systems are robust, the circuits are more complicated and above the abilities of middle school students to construct them.

2. The Low-Cost Communication System

Conducting a web search led to a potential solution to the problem. We found a posting on ihacked.com[5] by Simon Quellen Field. He described a technique using an audio output transformer from Radio Shack® to modulate a standard laser pointer. We designed a system around this concept. Our design was modified quite a bit during our testing to optimize its performance.

For our receiver, we used the same receiver as the NASA SOFIA Active Astronomy Infrared Kit[6]. The receiver consists of a small solar cell and a Radio Shack® Amplified Speaker connected by a shielded audio cable. The solar cell is very sensitive, and the system has been extensively tested by teachers in educational settings.

The transmitter was more problematic. The original design used a laser pointer wired to an external battery pack. In order to make the transmitter easier to assemble, we decided to use a clip-activated laser pointer. You can insert this laser into a circuit simply by attaching a wire to the clip and a second wire to the laser body.

An amplified sound source is required to modulate the laser. We found that an MP3 player or CD player would work. However, we wanted the students to be able to transmit their own voice. Two solutions were found. The first is a device called the Gossip Gizmo from Radio Shack® . The Gossip Gizmo (catalog # 63-1121) is a small amplified microphone. Unfortunately, the Gossip Gizmo is difficult to obtain in large quantities. The second microphone we tried was the Pocket Size Stereo Amplified Listener (catalog # 33-1096). It should be noted that although this microphone gives good performance with the laser communication system, the resulting transmission is not in stereo.

The other piece of the circuit is an audio output transformer from Radio Shack® (catalog #273-1380). The audio output transformer is an 8Ω to 1000Ω transformer. The 1000Ω side has an extra wire called a center tap. The center tap is connected to the transformer halfway through the coils.

Figure 1: The receiver unit (photo courtesy the SOFIA project)

To assemble the receiver, the solar cell is connected to the amplified speaker. We have used a shielded audio cable with tinned leads and test leads to make the connection as shown in Figure 1.

To hook up the circuit, connect the microphone to the 8Ω side of the resistor. The laser is connected to the center tap of the 1000Ω side of the resistor and one of the end wires. One of the wires is connected to the laser's clip and one is connected to the laser's body. For the wire connected to the clip, be sure it does not accidentally touch the laser body and create a short circuit (you will not damage the laser, but it will not modulate and the system will not work).

Point the laser at the solar cell. Turn on the sound amplifier. Speak into the sound amplifier. If you hear a high-pitched squeal, you are getting feedback. Turn down the sound amplifier. This system is very sensitive. If the laser is close to the solar cell, you will need to have the volume on the amplifier set very low to avoid feedback.

A circuit diagram for the set up is shown in Figure 2.

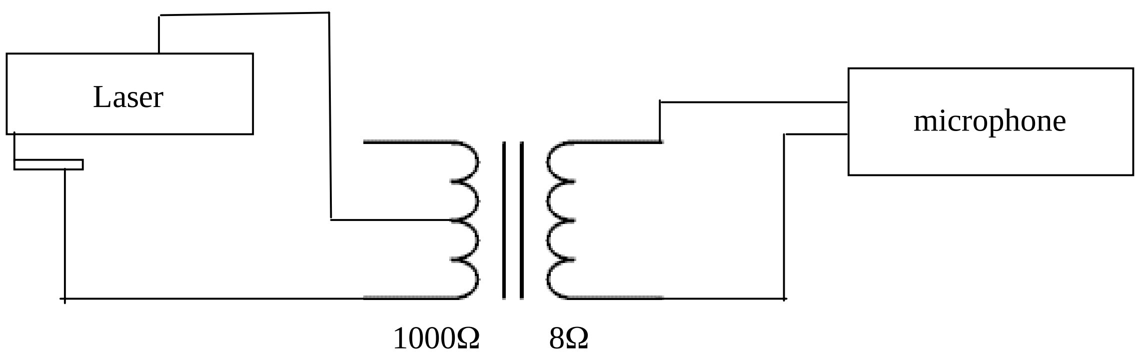

Figure 2: A circuit diagram for the transmitter.

2.1 Further Development of the Laser Communication System

Julia Nichols, an undergraduate student in the University of Arizona College of Optical Sciences, was tasked with simplifying the connections for the laser communication system. She mounted the solar cell on the side of a small plastic box and connected the wires to a 1/8" jack on the side of the box. This setup allows a simple audio cable to connect the receiver to the speaker/amplifier.

She devised a similar system for the transmitter. The audio output transformer is mounted inside a small plastic case. A 1/8" jack connects to the microphone. A small piece of copper cladding is connected to the audio output transformer. The circuit is completed by sliding the laser and its clip around the copper cladding as shown in Figure 3.

Figure 3: The new communication system

This system eliminates the alligator clips. The alligator clips frequently would come off the wires, especially in student use.

The new system is being manufactured by Green Valley Electronics in Tucson.

3. Performance

The laser communication system has been tested in a variety of lighting conditions. It does not need a dark room and will work in full sunlight. The system has a range of over 350 feet.

The beam will diverge noticeably as the distance traveled increases. Eventually the beam is too dim to see. However, the solar cell may still pick up the beam and produce sound from the speaker even when the beam has diverged beyond the point where it is visible.

We have not had any laser failures or problems with the modulator. The solar cell is somewhat delicate and should not be dropped.

4. Classroom Use

We have been experimenting with competitions where students attempt to communicate over the longest possible distance. They receive points for the distance traveled, reflections off of mirrors, and use of lenses in the system. The competition allows students to use some of the skills they learned in previous modules and apply them to laser communications. Our use of competitions to foster learning in optics is described in a previous ETOP paper[7].

The basic concepts of reflection must be used to direct the beam when it reflects off of mirrors. Reflections are necessary as the range of the system is much longer than can be accommodated in classrooms. As the beam diverges, you can use lenses to focus the beam onto the solar cell, extending the range of the transmitter. One group of teachers at a workshop even used a filled water bottle as a convex lens to focus the beam.

We have also tested the system using a Vernier Lab Pro[8] and light sensor. We used the light sensor to measure the intensity of the beam as a function of time, much like an oscilloscope. You could clearly see the intensity of the beam rising and falling. We also did some Fourier transforms of different waveforms and they looked the same as they would coming from a conventional microphone.

5. Conclusion

We have created a robust laser communication kit with high educational value. It has proved to be popular with students and has encouraged the problem-solving/challenge atmosphere we desire for our Hands-On Optics modules. The kit is inexpensive and can be assembled with easily available items. Most importantly, the kit provides the opportunity for high-quality open-ended experimentation by students on laser communication. This exploration of a modern, important technology is especially valuable as it provides a means to apply most of the optics concepts already explored in earlier Hands-On Optics modules.

Appendix: List of Parts and Suppliers

Item	**Price**	**QNTY**	**Part #**	**Source**
Laser Pointer	$15.95	1	Infiniter Super NBK with Clip Activation	store.greenpearle.com
Speaker/Amplifier	$12.00	1	277-1008	Radio Shack® www.radioshack.com
6 ft shielded audio cable	$2.99	2	42-2371	Radio Shack® www.radioshack.com
Test Leads	$0.52	6	278-1156	Radio Shack® www.radioshack.com
Audio Output Transformer	$2.99	1	273-1380	Radio Shack® www.radioshack.com
Listen Up Sound Amplifier	$9.99	1	63-1121	Radio Shack® www.radioshack.com
Solar Cell	$6.00	1	3-300	www.solarworld.com

All items in US $

References

[1]S. M. Pompea, , A. Johnson, E. Arthurs and C. E. Walker . “Hands-On Optics: An Educational Initiative for Exploring Light and Color in After-School Programs, Museums, and Hands-On Science Centers”, Proceedings, Ninth International Topical Meeting on Education and Training in Optics and Photonics, Marseille, France 2005

[2]Arbor Scientific, PO Box 2750 Ann Arbor, MI 48106 (734) 477-9370 http://www.arborsci.com

[3]T. Preruzzellis, *Optoelectronics, Fiber Optics and Laser Cookbook*, McGraw-Hill, 1997

[4]G. McComb, *Lasers, Ray Guns and Light Cannons*, McGraw-Hill, 1997

[5]http://www.i-hacked.com/content/view/162/44/

[6]SOFIA Infrared Astronomy Kit is available from Astronomical Society of the Pacific
390 Ashton Avenue San Francisco, CA 94112 (415) 337-1100

[7] S. M. Pompea, C. E. Walker, and C. Peruta, “Design and Evaluation of Optics Student Competitions and Contests for Maximal Educational Value”, Proceedings, Ninth International Topical Meeting on Education and Training in Optics and Photonics, Marseille, France, 2005.

[8]Vernier Software & Technology 13979 SW Millikan Way Beaverton, OR 97005-2886 888.837.6437 http://www.vernier.com

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I.

International Photonics Training: a Case Study

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Abstract: From 2004, the *Center for Science Education and Training (CSET)* participated to the European Union-funded educational network "Hands-on Science". The aim of the Romanian team was to transform teachers and students from end-users of educational aids to active designers and developers of instructional materials. Several science fields were identified, including photonics. The team at CSET is now focusing on: lasers and their applications, optical fiber communications, solar energy as a sustainable source, and the use of optical spectroscopy in physics and chemistry. CSET initiated an international collaboration with the New England Board of Higher Education (NEBHE) in Boston, Mass., when the Center enrolled an experienced Romanian high school science teacher in a twelve-week "Introduction to Photonics" laboratory-based professional development course. The course was developed by NEBHE through an Advanced Technological Education (ATE) program grant from National Science Foundation and is designed for high school and community college educators from both science and technology instructional areas. The paper reports the experience of this international participation which was made possible since the course is delivered via the Internet by Three Rivers Community College, Norwich, Conn. Its impact on photonics education in Romania and the USA is analyzed, as the participant teacher shares her experiences with teachers and faculty in the "Introduction to Photonics" course and with those enrolled into the Romanian "Hands-on-Science" program.

1. Introduction

In the last five years, Europe designed a coherent strategy and adopted several programs aiming to the accelerated development of education at all levels (pre-university, university, vocational training, lifelong learning), and focusing on the implementation at continental scale of the new, knowledge-based society, ready to be a major competitor on the global labour market. During the Lisbon meeting (March 2002), Heads of State and Government of the European Union established a new strategy for Europe's development. They aimed to make the European Union "the most dynamic and competitive knowledge-based economy in the world" by 2010. This set of ambitious reforms at the national and European level will be reached by establishing an effective internal market, by boosting research and innovation and by ***improving education*** among other measures [1], [2]. The role of education within the Lisbon strategy is pointed out by the conclusions of a report for a European Council meeting held in Brussels (February 2002) as "the essential role to be played by education and training in improving the level of qualifications of the population. It seeks to respond not only to the challenges issued by the Lisbon European Council in March 2002 .... but also to the wider needs of citizens and society. Education and training are thus a basic priority area in the Lisbon strategy" [3]. Within this frame, the quality of the education and training in Europe by 2010 will be proved by the fact that "Europe will be recognized as a world-wide reference for the quality and relevance of its education and training systems and institutions". The implementation of the Lisbon Agenda in the field of education and its main direction of action are defined in the programme "Education and Training 2010" [4]. The official documents recognize that an adequate **supply of scientists is crucial for a knowledge-based economy**, and for this reason, the Council has set two objectives: "to bring about an increase of at least 15% in the number of graduates in these fields by 2010 and at the same time to redress the imbalance between women and men" [5].

An European Commission document issued in 2002 indicates clearly some paths to follow in the field of education along with some precise targets [6]:

- "Europe must do more to encourage children and young people to take a greater interest in science and mathematics, and to ensure that those already working in scientific and research fields find their careers, prospects and rewards sufficiently satisfactory to keep them there. Motivating more young people to choose studies and careers in the scientific and technical fields in a short and medium term perspective";
- "By 2010, the percentage of low-achieving 15 year-olds in reading, mathematical and scientific literacy will be at least halved in each Member State, compared to the year 2000";
- "By 2010, the EU-average level of participation in lifelong learning should be at least 15% of the adult working age population (25-64 age group) and in no country should it be lower than 10%".

The 2003 Working Group on "Increasing Participation in Math, Science and Technology" (MST) made five recommendations for schools to follow in teaching science and technologies [7]: "the teaching of mathematics, ***science and technology*** should be an entitlement for all children from the early stages of education and should be mandatory at all levels; more effective and attractive teaching methods should be introduced in mathematics, scientific and technical disciplines at both primary and secondary level, in particular by linking learning to ***real-life experiences, working life and society*** and by combining classroom-based teaching with extra-curricular activities; the professional profile and practice of MST teachers should be enhanced not only by providing them with opportunities and incentives for updating their knowledge of both content and didactics of MST through the provision of effective initial and ***in-service training*** and by ***improving teaching resources***, but also through the provision of incentives and special measures to ensure their long-term commitment to the teaching profession; measures involving ***teaching methods***, pedagogical tools and assessment measures for special needs groups such as high and low achievers and pupils from ethnic minority backgrounds should be addressed along with measures to address gender-specific attitudes to mathematics, science and technology; strong and effective partnerships between schools, universities, ***research institutions***, enterprises, parents and other players should be strongly supported and encouraged at all levels, both to improve the quality and attractiveness of teaching and to effectively prepare young people for working life and ***active citizenship***."

In this context, the National Institute for Laser, Plasma and Radiation Physics' Center for Science Education and Training - CSET, near Bucharest (Romania), started two national level educational projects. The projects are: the Romanian part of the European Comenius network "Hands-on Science" [8], and the Romanian project "Science Education and Training in a Knowledge-Based Society – SET 2010" [9]. The paper addresses the methods used and presents some of the achievements in the frame of the two projects. CSET initiated an international collaboration with the New England Board of Higher Education (NEBHE) in Boston, Mass., USA when the Center enrolled an experienced Romanian high school science teacher in a twelve-week "Introduction to Photonics" laboratory-based professional development course. The course was developed by NEBHE through an ATE grant from the National Science Foundation and is designed for high school and community college educators from both science and technology instructional areas. This collaborative work constitutes the case study for our paper.

2. Brief history and the background

The two above mentioned projects support in a complementary manner science education in schools, at all levels, in various fields: physics, chemistry, biology, environmental issues, human physiology, consumer protection, etc. Our efforts are focused on building a bridge between academia and research institutes on one side and the pre-university teaching infrastructures on the other side.

The main themes of the Comenius network are:

- to invite local communities and authorities to be involved in debates on science education;
- to promote and deliver training courses for school teachers and educators in different languages and countries on science related curricula;
- to promote Hands-on-Science contests and fairs at national and EU level;
- to promote science clubs activities in schools;
- to develop and disseminate new ICT and multimedia education materials;
- to create a network of teachers interested in MST subjects to serve as possible disseminators;
- to organize international conferences and thematic workshops on this subject.

As it concerns the national project “SET 2010” its target is more general: the science education in the context of lifelong learning and scientific literacy. Within this project framework the major goals of our activities are:

- to promote European best practices and to establish a partnership between the Romanian teams and advanced networks in Europe, in the field of education, for the technical and scientific knowledge and lifelong learning;
- to develop a regional network (in the Balkan area and in East and Central Europe) aimed to increase the quality of science teaching at the pre-university level;
- to develop a collaboration with the “Hands-on Science” European network using real and virtual experimentation;
- to support European level dissemination of key results regarding science education in Romanian schools.

In designing the working plan for Romanian participation in the projects, we focused on several options that can bring maximum benefit to both the project and the country, on its way to EU integration:

a. to build strategic partnerships with organizations and companies which can assist us to run the project, either through direct financial support or by associating the project name with their image;
b. to support the inclusion of virtual instrumentation programming teaching in high schools;
c. to assist high schools in developing virtual experiments;
d. to encourage high school teachers to train students in developing their own experimental set-ups and training aids;
e. to prepare teaching materials in electronic and multimedia format;
f. to facilitate access to experiment-based teaching to less favoured groups;
g. to disseminate project results though lectures, conferences, communication sessions.

The major directions of action for the next 2-3 years are: the use of IT in developing and running experiments in school labs, 3D graphics and animation as a teaching aid, education for a sustainable development, the training of school students in modern electronics and robot programming.

Since the “Photonics21” European Technology Platform and the “Strategic Research Agenda in Photonics” [10] were launched in April 2006, interest in photonics education increased. The Agenda states “*Photonics differs from the fundamental subjects of physics, chemistry, biology and mathematics, in that it is highly interdisciplinary. In most member states of Europe today, 1st and 2nd level education (primary and secondary school) deals only with the core sciences, not interdisciplinary ones. This however offers a great opportunity for photonics, since it is ubiquitous and all pervasive presence means that it is part of all the basic sciences, an awareness of photonics can be introduced by appropriate outreach activities in schools. We need to “spread the word” about photonics, both in schools and to the general public*.” For this reason, we started to focus our efforts towards education in modern optics and photonics.

As in the case of other educational fields in which we are active, in photonics education we combine different approaches:

- demo and inquiry-based sessions, when students either present to their fellows a subject related to optics and photonics in order to complete the information they receive during school courses, or have direct investigations on a specific topic;
- organization of temporal exhibitions;
- science club activities, where students demonstrate their abilities to develop simple training aids, set-up their own experiments or build quite complex optical instruments to be used in future science projects;
- organization of science fairs and students’ contests;
- development of advanced experiments that demonstrate links between photonics and other natural sciences;
- visits at the Institute through an “open doors” programme;
- institute support in preparing school textbooks;
- organization of nation-wide events focusing on optics/ photonics;
- participation in international conferences/ exhibitions/ workshop.

Generally, demo sessions are run for half a day during weekends. Participants are teachers and students from the same neighbourhood. During these events the mean form of communication is PowerPoint presentations prepared by students after ample documentation using the Internet. In some situations dedicated experiments are also shown to the audience. Figure 1 ***a*** presents the life dissection of a bull’s eye. The biology teacher explains the role that each constituent part of the visual system plays in forming the image (Figure 1 ***b***). In some cases, a small exhibition that focuses on a specific subject, accompanies the event. In Figure 1 ***c*** students are introduced to educational instruments used to teach optics.

a b c

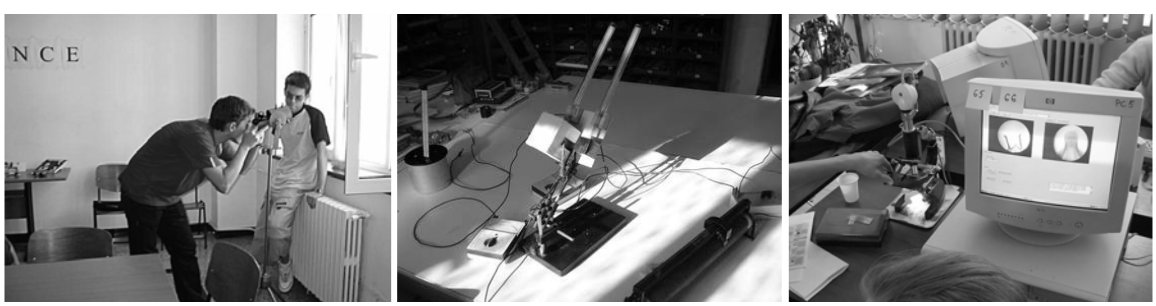
Figure 1. Life demo of the structure and functioning of the visual system in the animal kingdom (***a*** and ***b***); exhibition of instruments for teaching optics (***c***) – photos from D. Sporea's collection.

Partner schools in our projects organize science club activities in the afternoons. Here students are taught to develop their own experimental set-ups and instruments, which are also used during class work or to start some small research projects. This approach is helpful since most of the ordinary schools lack the necessary teaching aids. Younger students are first introduced to simple experimental schemes that use light sources (Figure 2 ***a***) or to basic optics (Figure 2 ***b***).

a b

Figure 2. An eight years old student playing with optoelectronic circuits (***a***); a simple experiment in optics built by a 10 year old student (***b***) – photos from D. Sporea's collection.

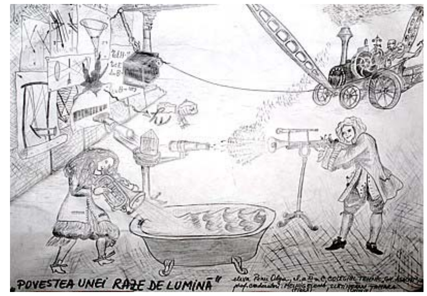
Students 15 – 17 years old are assisted by their teachers to develop more sophisticated experiments. Figure 3 ***a*** shows the award winning team of a theoretical high school in Bucharest with the telescope they built to participate in a science club on astronomy. Romanian students took part with their experiments to international science projects. Figure 3 ***b*** shows the instrument used to evaluate the solar constant during an international investigation run by students. By coupling a webcam to a microscope, a PC assisted image processing tool was developed to study plants and small insects (Figure 3 ***c***).



a b c

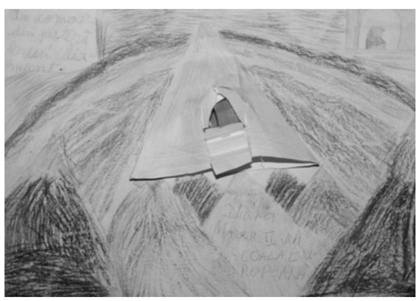
Figure 3. High school students operating the telescope they developed (***a***); set-up to measure the solar constant (***b***); a complex PC-based image processing set-up used to study biological specimens (***c***) – photos from D. Sporea's collection.

We use different means to introduce students to optics from an early age. One example is an exhibition we organized that focused on light and colors which used photos and drawings done by the students. In most of the cases students brought their own perception and understanding of the subject. In Figure 4 ***a*** the author intended to offer an overview of the illustration of light in ancient times, while the drawing in Figures 4 ***b*** summarizes a short history of scientific discoveries in optics. In some artistic products imagination plays the major role. The rainbow is perceived as being the light spread by a diamond embedded into a hill (Figure 5 ***a***). The author of the drawing in Figure 5 ***b*** also proved to be an active militant ecologist – the light bulb includes a windmill device, under the title "Towards a *greener* light".



a b

Figure 4. Light as it was illustrated in ancient times (***a***); a brief history of optics discoveries (***b***) – photos from D. Sporea's collection.



a b

Figure 5. Rainbow generated by the diamond buried into a hill (***a***); "Towards a *greener* light" (***b***) – photos from D. Sporea's collection.

In order to call the general public's attention to the important *partiture* this form of energy (Light) plays in our life, this March, we organized a nation-wide symposium on this subject. The programme included real and virtual experiments, scientific presentation delivered either by scientists (a lecture on the Sun presented by a researcher at the National Institute of Astronomy, talks on lasers, holography, optical communications) or by groups of teachers and students. As the event was open to all types of schools (theoretical, vocational, school of arts) the contributions (over 160 with more that 260 authors) included not only science and technology related subjects but also essays, poetry, and drama. To illustrate the fascination of this event, it is worth mentioning some interesting discussions that took place on the place of mirrors in the lyrics of the most renown Romanian poet, the opposition between light and shadow crossing four centuries of painting, and a very interesting artistic interpretation of a Sun eclipse (Figure 6 ***a***). There was also an interesting tale, written and played by some 16 years old students, on modern lighting (Figure 6 ***b***). The response to this event was so strong that one high school dedicated a full issue of its school magazine to "Light" and another one designed a wall calendar.

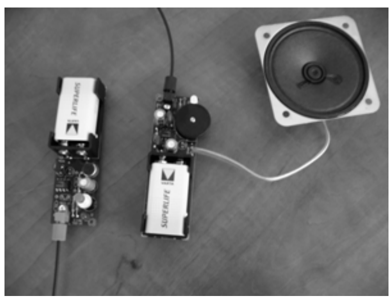
We started a programme in two high schools in Bucharest to assist with teaching photonics by providing optics and optical communication training kits, a small footprint spectrometer and different sensors. Until now, they organized science club activities with these kits (Figure 7 ***a***) and set up some experiments by connecting the sensors to a PC with an USB data acquisition board from National Instruments. The graphical program LabVIEW was used to collect and to process data (Figure 7 ***b***).

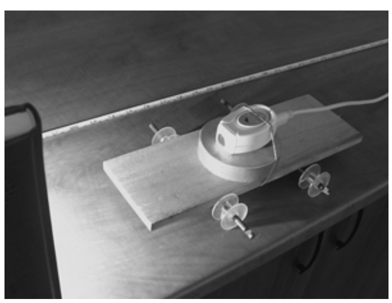
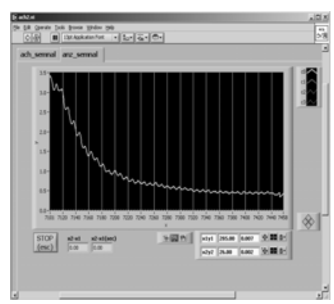
a b

Figure 6. Scientific facts facing an artistic interpretation on a Sun eclipse (***a***); "Lighting" drama on a scientific subject (***b***) – photos from D. Sporea's collection.

Projects results were disseminated at national and international conferences and workshops [11 – 14] and a booth was organized in Brussels, at the invitation of the European Commission, during the Conference "Communicating European Research".

a b

c d

Figure 7. Photonics related experiments at Theoretical High School "Grigore Moisil" in Bucharest: Voice communication using an optical fiber link (***a*** and ***b***); experiment with optical sensors controlled in LabVIEW (***c*** and ***d***) – courtesy of high school teachers Mihaela Garabet and I. Neacsu.

3. The training course on photonics – the case study

Coming back to the European Union's policy in education for the next decade we have noticed several points of interest: the need to address science education through extra curricular teaching programmes, the importance of hands-on training, the development of lifelong leaning strategies to be applied, and the stringent requirement to assist teachers in developing new methods of teaching applied sciences, sciences closely linked to everyday life. Through our efforts, we addressed these issues to some extent by using IT in the lab. As it concerns photonics, the major drawback is related to the lack of the appropriate support and means to further educate teachers in this subject. Teacher training and lifelong learning must be part of our strategy to support science education in our schools. As the funds to develop schools' educational infrastructure are limited (laboratory equipment, training aids, and kits to set-up experiments), it is quite difficult to improve science education. In any case, we were open to any opportunity to overcome this situation.

By mid-October 2006 D. Sporea, the national coordinator of the "Hands-on Science – Romania" network, learned about the PHOTON2 photonics education project offered in the States by the New England Board for Higher Education in cooperation with Three Rivers Community College (TRCC). We contacted the project Principal Investigator (PI) Fenna Hanes and we agreed to collaborate.

PHOTON2 is a three-year curriculum and professional development and laboratory improvement project of the New England Board of Higher Education. The project, funded by the Advanced Technological Education (ATE) program of the National Science Foundation (NSF) began in September 2003 and completed at the end of August 2006. A one-year "no-cost" extension is in progress to complete all activities and reports by summer 2007.

The goal of the PHOTON2 project is to:

1. Adapt the successful PHOTON (September 2000 - 2003) instructional materials, laboratory equipment kit and "alliance" model to a web-based distance-learning environment.
2. Disseminate PHOTON instructional materials, laboratory equipment kit and "alliance" model, (the inclusion of teachers/faculty and career counselors from consortia of secondary and postsecondary institutions) to a national audience.
3. Evaluate the effectiveness of a web-based distance-learning program that methodically applies adult collaborative learning principles for future replication.

PHOTON2 utilizes 21st century web-based technology to deliver a one-semester web-based professional development course "Introduction to Photonics Technology." The course instructional materials had been implemented and field-tested by teachers and faculty in middle, secondary and postsecondary institutions in New England during the previous Project PHOTON.

Phase 1 of the project included a series of two-day regional introductory workshops. The purpose of the 2-day workshops was to introduce the educators to the online learning environment, course material and laboratory equipment to establish a professional rapport with the PHOTON2 instructional team and other participants and to assess the learning environment at each regional site. Each of the two-day workshops included a tour of a local photonics company in an effort to solicit industry participation in the program and to provide career and guidance counselors with career awareness in the photonics field. A partial list of companies included, Cisco Systems, Veeco Instruments, Photomachining, Coherent Laser, Trex Enterprises, and several others. Collaborations established with photonics companies and industry associations (OSA and SPIE) in Project PHOTON were continued and expanded from a New England to a national focus.

In Phase 2 the PIs developed the PHOTON2 web-based distance-learning course, "Introduction to Photonics." Under the leadership of Co-PI Judith Donnelly, TRCC in Norwich, Conn. delivered the course through the Connecticut Distance Learning Consortium.

Each participating institution was provided with a complete set (15 chapters) of field-tested optics and photonics course notes and a $4000 custom industry quality optics lab kit. Half the cost of the kit was provided by the grant, the schools or a school partner matched the other half. The kit includes a field-tested lab manual with 25 laboratory experiments ranging from simple demonstrations of refraction and diffraction to building and aligning a Michelson interferometer. The kit is accompanied by two a set of CD-ROM videos in which PHOTON2 instructors provide step-by-step instructions for performing each experiment. A set of 13 introductory-level Explorations completes the instructional materials. Throughout the project, the project instructional team provided technical assistance through an active industry mentored listserv, via email, phone and site visits.

In Spring 2004, Cohort I, the first of two cohorts, consisting of five regional "alliances" each comprised of high school teachers, community college faculty, career and guidance counselors, and industry representatives was formed. Each of the five alliances, representing institutions from New England (Connecticut, Massachusetts), California, Arizona, Texas, and Pennsylvania, participated in a two-day face-to-face regional introductory workshop.

Research has shown that although there are many positive aspects to distance learning, there are challenging pedagogical aspects to achieving successful learning experience. PHOTON2 addressed these challenges by applying adult learning principles in the design and development of the new web-course.

Under the direction of Co-PI Nicholas Massa and Marijke Kehrhahn, research was conducted at the end of the fall 2004 semester to better understand the relationship between learner interaction, self-regulatory development, critical thinking skills, and learning outcomes and to guide the implementation of the PHOTON2 web-based course for Cohort 2.

Based on preliminary findings from Cohort 1, several changes were made to the PHOTON2 web-course. First, the 2-day regional introductory workshops were held closer in time to the beginning of the course (within 4-8 weeks) so that participants would not lose their momentum and motivation for taking the course nor their skill at navigating the course. Second, the course was opened for participation one week before the actual start date for the course so that participants could log on and introduce themselves to the larger group in an effort to increase the amount of social rapport. Third, the scope of material to be covered during the semester was reduced.

By reducing the amount of material covered, more time was able to be spent on core concepts with the hope of fostering deeper learning, and as a result, increase the likelihood that the material would (or could) be applied in participants' classrooms. Last, and most important, the format of the PHOTON2 web-based course was modified from a traditional instructor-centered format in which all course activities and discussions are centered on the instructor, to a learner-centered approach, where the role of the instructor shifts from leader to facilitator. The purpose for this change in format was to increase the level of learner-to-learner interaction in an effort to create a more collaborative learning environment where learners would work together to construct knowledge and ideas through interactions and responses from others.

Of the 23 teachers who started the course for Cohort I, one withdrew for personal reasons and four changed to audit status because of situational constraints. Of the remaining 18 participants, complete data sets were obtained for 15 participants.

During spring semester 2005, Project PHOTON2 delivered the second offering of the "Introduction to Photonics" professional development course via distance learning to Cohort 2. Cohort 2 participants also attended introductory workshops similar to those attended by Cohort 1. Participants formed into four alliances of high schools and colleges from New England (Connecticut, Maine, New Hampshire, Vermont); California; Tennessee and Alabama; and Hawaii.

Of the 28 teachers and faculty who started the course for Cohort 2, four withdrew for personal reasons within the first two week of the course and three changed to audit status because of situational constraint, and three did not complete the course for other reasons. Of the remaining 18 participants, complete data sets were obtained for 13 participants for analysis. A comprehensive paper, *The PHOTON2 Web-Based Professional Development Model: A Year in Review*, that describes the research component of Project PHOTON2, was presented at ETOP 2005 by PHOTON2 PI Nicholas Massa and can be viewed on the NEBHE web site, **www.nebhe.org/photon2.**

Requests for offering the distance learning course surfaced as the project progressed and word of the course and the PHOTON2 materials spread. Consequently, outreach was begun in fall 2006 to offer a class in spring 2007. This time the course was opened up to educators outside of the PHOTON2 cohort.

NEBHE agreed to enrol one Romanian school teacher in the twelve week "Introduction to Photonics" professional development course offered in spring 2007. This decision to participate was both a big chance and a great challenge for the Romanian teacher selected to learn about a very modern field from an experienced team. The course was delivered on-line, hence the costs were diminished. Participation in this course was a challenge as he/she had to confront cultural and language barriers, a shifted learning programme and lack of the appropriate instructional aids.

Another challenge was for the Romanian network coordinator to find the appropriate person to take advantage of this experience. After several trials and discussions Mrs. Elena Vladescu was selected for the course, as she has a good command of English, is a very active person within CSET network and is very dedicated to hands-on science [15]. Another reason for selecting her was the fact that we wanted to encourage teachers from small communities to join the stream. She teaches at a vocational school in a small town 200 km from Bucharest. By appointing her to this task, we also send a signal to her fellow teachers spread across the country that they are not abandoned and that they too have a future in the educational system where there is starting to be a shortage of qualified and dedicated persons in the field of pre-university education in Romania.

The Romanian teacher participating in this course also lacked the technical equipment required by the course curriculum (the advanced PHOTON kit for optics). We were only able to assist her with the OSA Discovery kit for basic optic teaching. Nevertheless, she managed to use this kit extensively and produced her own built experiments.

During the course she delivered demo sessions to her class, using the new skills she acquired.

As the course progressed, we all realized the great benefit it was bringing to the Romanian education community: a completely new (for us) approach on science teaching emerged – the focus on experiments and direct hands-on involvement of the trainees. For us, it was a surprise as the Romania system is traditionally more linked to the theoretical approach in teaching science. Another big surprise for the Romanian participant to the course was the testing part of the course since she was taking the course for credit. She passed all the examination with the highest marks, despite language barriers, which can impinge on the perception of questions to be solved. In the mean time, she proved to be very active and imaginative in dealing with the tests and in designing her own experiments.

We disseminated the course results and Elena's training experience through a 20 minutes presentation she gave at our national educational symposium on "Light". Her presentation had a big impact as the audience was tuned to this subject, and because we succeeded in bringing a large number of participants to her presentation. The attendees were very interested in the subject and she spent time during the break explaining the details of the experiments she had run. Encouraged by this interest, we decided to add the presentation of all the experiments she developed during her training as well as additional tips and assistance to Elena's teaching web site.

For the Romanian site, the experience with this internationally delivered course underlined several points:

- The course was not an easy one, but it has no extremely difficult parts. It was evaluated as not an easy one, as far as it is quite demanding and you have to manage very carefully your resources and your time. The course is quite demanding, there are a lot of things you have to learn and you need to spend a lot of time studying.
- The overall organization of the course was excellent; it operates as a clockwork mechanism.
- The novelty of teaching optics in schools appeared to us in connection to the practical approach of the course. In Romania, by tradition and because of the lack of funds, physics and chemistry teaching has a pronounced theoretical approach. The way optics (and more generally science) is introduced in classroom in the States is focused on the interest the student has on the subject in relation to his/her future job opportunities and the labour market request.
- In the States, the basic curricula is quite the same as in Romania, but it is not so packed.
- This novel approach pushed Elena further in designing her lesson plan. In any case, this experience during the course she took change the way she is approaching optics teaching. She started to include more experiments, simple to built ones, using trivial materials and the OSA Discovery kit. Her students became more interested into optics and assisted her during the experiments. This "cooperation" opens channels also for discussion and enquiries from the students' part.
- We were also impressed by the very friendly connection established with tutors. In another way, the course made possible for the Romanian teacher to establish a close contact with her tutors, and she was impressed by the possibility to discuss openly subjects of common concern.
- A little bit of contrast appear as Elena's fellow teachers attending the course were not as communicative with her as expected. May be some time there is a lack of interest from their part even towards the course.
- The biggest technical difficulty was related to the horary shift fact which affected the Romanian teacher participation to chat activities (7 hours shift in relation to the tutors and up to 12 hours with respect to some attendees from Hawaii). Nevertheless, special chat sessions were organized on Saturdays, so she can participate, too. As Elena misses an Internet connection at home she had to spend quite a lot of time at school, at the library or in an Internet Cafe.
- Another drawback in relation to her participation concerns the limited technical means she has for the experiments. Elena dreams to have access to various light sources, a spectrometer, an interferometer, unlimited around the clock Internet access, and may others. She realized to acute need for technical support in Romanian schools.
- Elena managed quite well in handling lessons in English and proved her language skills during all the tests, but she still faced difficulties when slang and jargon terms are used. In such situation both tutors and fellow students offered assistance.
- The course was also a proof on the consistency of science teaching in Romanian universities. From this point of view, her background from the university helped her a lot. In fact, in Romania ALL science teachers in high school have a master degree in the science they are teaching.
- The communication level with all the tutors was excellent and very supportive. In spite of the fact the course is based on a collaborative approach very few attendees established a close link with her. This fact it is not so common for Romania, where generally people are very open and communicative.
- Elena dedicated most of her time to this course, as it was a demanding and unusual activity for her. She took all the challenges (without any complex or bias) and done her best to be involved in all activities. She even contributed to some improvements in the experiments they were running.

4. Conclusions

The ~~a~~ Romanian teacher's participation in NEHBE's "Introduction to Photonics" on-line course, primarily designed for the American "market", proved to be a very helpful experience for the Romanian "Hands-on Science" network community. It underlined one more time our limits in training teachers through in-service training programmes. This experience also demonstrated the acute need to change teaching methods in Romania, by accentuating the practical aspects and the hands-on methods. In the mean time, we have to change our old way of science education as our students will have to face a much higher competition in a global job market. Following this experience, we plan to continue cooperation with NEBHE, and to develop two to three small centers, at a national level, with the appropriate teaching aids ready to replicate, at least partially, the teaching methods Elena has learned.

At the international level, outreach on engineering education listservs, that reach educators across the globe, became reality and the rest is history to be written.

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II.

Development of an Industry Based Laser Manufacturing Degree Program

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Abstract: In 2005, Connecticut's Regional Center for Next Generation Manufacturing (RCNGM) surveyed companies representing a cross section of the laser manufacturing industry in New England. A technician competency profile was created as a result of a detailed job skills survey and intensive personal interviews with company personnel. Three Rivers Community College subsequently developed a Laser Manufacturing Option to the Manufacturing Engineering Technology A.S. degree based on the competency profile, with new and revised courses featuring an emphasis on interdisciplinary skills and knowledge across several disciplines.

1. Introduction

1.1 The problem: The need for a skilled manufacturing workforce

Manufacturing was central to Connecticut's past and is critical to its economic future. The state that was home to Samuel Colt, Eli Whitney and the first submarine now produces jet engines, helicopters, nuclear submarines, fuels cells, space suits, fabricated metals, electronics and pharmaceuticals in its 5400 manufacturing companies. Although the popular perception of manufacturing is "dirty, dark and dangerous" with no future as jobs decline or are outsourced, high tech manufacturing, including the use of lasers for cutting, drilling, welding and sintering, is central to the state's economy.

In response to a 2005 survey by the Connecticut Business and Industry Association (CBIA), nearly half of Connecticut's manufacturing firms reported that job applicants did not have the skills necessary for open positions and another 19 percent reported having difficulty finding any applicants at all. [1] In addition to the difficulty of finding new employees, the state's employers face the problem of an aging workforce and large numbers of impending retirements. (Connecticut has the nation's seventh oldest workforce) It is not surprising that the availability of a workforce skilled in new technologies is a prime concern of the state's manufacturers.

1.2 The Community Colleges' response: The Regional Center for Next Generation Manufacturing

The driving force behind the creation of the Regional Center for Next Generation Manufacturing (RCNGM) was the success of the College of Technology (COT), a virtual organization of the twelve Connecticut Community Colleges. COT was created by the state legislature in 1992 when the state's five technical colleges were merged with its twelve community colleges. The COT's unique infrastructure provides seamless career pathways with multiple entry and exit points leading to credit certificates and Associate of Science, and Bachelor of Science degrees in engineering and technology. There are 2 COT pathway programs, Technological Studies and Engineering Science. The Associate of Science degree in Engineering Science seamlessly articulates to engineering programs at five universities, while the innovative curriculum of the Technological Studies pathway includes five industry-driven technology electives.

Although COT was originally charged with developing 2+2 pathways from the community colleges to four-year university programs, the Technological Studies pathway in particular quickly became the practical choice for creating new programs to meet technical workforce needs. Unlike a full Associate degree program that can take years to be approved, elective options to the Technological Studies degree can be implemented in a matter of months, allowing Connecticut's Community Colleges to respond quickly to changing industry needs.

Beginning in 2001, COT and CBIA received two grants from the Advanced Technology Education (ATE) project of the National Science Foundation (NSF) to develop curriculum in cutting edge technologies and to provide faculty professional development, in large part through paid externships at local companies. Teachers from high schools and community colleges who completed industry externships created new work-based curriculum that was shared statewide through the COT's virtual network.

The creation of the Regional Center for Next Generation Manufacturing was, then, the next logical step to address the critical need for a workforce educated for the new manufacturing environment. The Center was funded by the National Science Foundation's ATE program in 2004, and its goals are: to develop programs in new technology areas with input from industry; to prepare faculty to implement industry-driven, next generation manufacturing coursework and laboratories; to make young people aware of opportunities in the new manufacturing workplace; and to increase collaboration between schools and manufacturers.

Around the same time (2005), the newly formed Connecticut Center for Advanced Technology (CCAT) received funding from the U.S. Air Force Office of Scientific Research/ National Aerospace Leadership Initiative to develop a Laser Applications Laboratory to conduct applied research on laser materials processing for military and commercial products. With so much research and development activity directed at laser material processing, it was natural that the RCNGM begin the process of developing a laser manufacturing curriculum for Connecticut's Community Colleges.

2. Developing an industry-driven laser manufacturing curriculum

The first step in developing an industry-driven curriculum was to determine the educational and skills outcomes necessary for new employees of the laser industry. Rather than request a large number of companies fill out a simple check-off list, we decided to conduct in-depth interviews with a small number of companies. This allowed follow up questions to clarify or expand upon survey items, and the company representatives were able to bring up competencies we had not considered in forming our survey.

During the Summer and Fall of 2005, a skills/needs assessment was conducted with nine laser companies using a modified DACUM ("Developing a Curriculum") approach. The selected companies represented a cross sectional sample of the laser manufacturing industry in the New England region involved in the manufacturing, use, and/or system integration of lasers (OEMs). These companies included:

JDSU Corporation	Bloomfield, CT
IPG Photonics Corporation	Oxford, MA
Coherent Laser	Bloomfield, CT
Zygo Corporation	Middlefield, CT
OFS Optics	Avon, CT
Photomachining Corporation	Pelham, NH
Rofin-Baasel Corporation	Boxborough, MA
Prima Laser	Springfield, MA
CT Center for Advanced Technology	East Hartford, CT

Representatives from each company, including engineers, technicians and managers, responded to a DACUM survey, personal interviews, telephone interviews, or a combination of these, in which they were asked to provide detailed information describing job functions, tasks and duties deemed critical for a laser technician at their particular company. Anecdotal data was also compiled with regard to ancillary tasks and duties required of laser manufacturing technicians at each company in an effort to provide depth and breadth to the survey data. Sample job descriptions from companies that were hiring at the time were also collected. Survey data, interview data, and job descriptions were examined for common core competencies as well as industry-specific knowledge and skill requirements. The results were then integrated into a draft Laser Manufacturing Technician Competency Profile, in which critical job duties and tasks are tabulated; and a draft Laser Manufacturing Technician Competency Outline, in which detailed and measurable performance indicators (sub-tasks) for each job task were compiled. The draft Laser Manufacturing Technician Competency Profile and Outline were subsequently redistributed to each participating company for validation in which a 5-point Likert scale was used to rate the importance of each task and subtask (1 = not important; 5= very important).

In addition to survey and interview data compiled, competencies obtained from the National Skills Standard in Laser Machining (NSF-ATE: Machinetool Advanced Skills Technical Education Resources (MASTER) Project, 1997) as well as the National Photonics Skill Standard for Technicians (CORD Communications, 2003) were used to triangulate the survey data. Both the MASTER Laser Machining Skill Standard and the CORD National Photonics Skills Standard detail the skills and knowledge required of the laser technician resulting from comprehensive DACUMs conducted on a national level with over 100 companies. [2,3]

The Laser Manufacturing Technician Competency Profile and Outline formed the foundation for the Regional Center for Next Generation Manufacturing (RCNGM) Laser Manufacturing Technician A.S. Degree curriculum. (Table 1) A course crosswalk template was also developed which provides a cross-reference linking the tasks and subtasks identified in the competency profile to the core technical courses in which those skills are to be developed as well as the exit-level proficiency for each measurable task and subtask (i.e., concept introduced, reinforced, or mastered). [4]

Table 1. RCNGM proposed Laser Manufacturing A.S. Degree Curriculum. Course IDs, where indicated, are common to all twelve Community Colleges.

Course ID	Title	Credits
General Education Courses		
ENG 101	Composition	3
ENG 202	Technical Writing OR	
ENG 102	Lit and Comp (for transfer students)	3
MAT 137	Intermediate Algebra	3
MAT 186	Pre-Calculus	4
MAT 163	Statistics	3
PHY 121	General Physics I	4
PHY 140	Introduction to Optics	4
	Humanities Elective	3
	Fine Arts Elective	3
	Social Science Elective	3
Technical Core Courses		
PHO 230	Laser Electronics	4
PHO 240	Introduction to Lasers	4
CSA 105	Introduction to Software Applications	3
CAD106/107	Computer Aided Drafting	3
EETXXX	Electric Circuits and Systems	4
PHO XXX	Opto-electronics	3
EETXXX	Data Acquisition and Control	3
MFGXXX	Next Generation Manufacturing	3
MFGXXX	Metrology	4
MFGXXX	CNC Laser Materials Processing	4
	Total Credits	68

3. Implementation at Three Rivers Community College

Three Rivers Community College in Norwich, Connecticut offers associate degrees in twelve technology and engineering technology areas, and one- or two-semester certificate programs in many of the same technologies. The college has the state's only two-year photonics program, the Associate in Science (A.S.) degree in Laser and Fiber

Optic Technology (LFOT). Since 1999, graduates of the LFOT program have been working at companies that manufacture lasers, such as Coherent, IPG Photonics, Zygo and Trumpf. The program emphasis is on electronics and optics, important to laser manufacturers, but the program does not address the needs of laser users and integrators. The laser manufacturing curriculum proposed by the RCNGM provided a unique opportunity for the college to create an interdisciplinary program involving optics, lasers, electronics, material processing and manufacturing that could be exported to the other Community Colleges through the COT.

3.1 Interdisciplinary curriculum team to the rescue

The Three Rivers Technology Department began in the 1960s as a State Technical College, and for the most part, the autonomous technology programs worked together only when forced to by the college administration. In 2005, in response to low enrollments and a need to improve efficiency as the college plans to move to a new campus, the Director of Engineering Technology announced a reorganization of the department into "clusters" of several programs with similar courses and student outcomes. The manufacturing-related cluster, or the "Gang of Four" as it came to be called, included Laser and Fiber Optic Technology, and the TAC/ABET accredited Electrical, Mechanical and Manufacturing Engineering Technologies. The first project undertaken by the group was the creation of a laser manufacturing program.

3.2 Ideal world meets reality

The four program coordinators of the manufacturing-related cluster met weekly throughout the spring of 2006 to implement the RCNGM laser manufacturing program. A totally new associate degree program was out of the question; approval by the appropriate college committees, the Board of Trustees for the Community-Technical Colleges, and the State Department of Higher Education would take up to two years (or more) to obtain. There were other constraints as well, some imposed locally by the college and some by the state governing boards:

- No associate degree program may have more than 68 total credits
- One third of credits must be in general education areas- math, science, humanities, social science
- A fine arts course must be included, as well as two or more English communications courses
- No new full-time faculty could be hired
- Any new lab facilities or equipment would need to be grant funded or donated by industry.

The program coordinators decided to create a fifteen-credit elective option to the existing Manufacturing Engineering Technology program, while, at the same time, updating other courses in the program to reflect the current manufacturing workplace. This decision was not without its own constraints: only fifteen credits of an associate degree program may be changed without the approval of the Board of Trustees. The group used a combination of reformulated and/or renamed "old" courses (which needs only the approval of the college's Curriculum Committee) and a small selection of new courses to accomplish their goal. In some cases, changes will be made over two years, to keep to the fifteen-credit limit. The long-range plan is to use the basic degree structure to support additional options, for example, a Mechatronics option to build on the automated controls courses.

Table 2 shows the Manufacturing Engineering Technology degree program and the Laser Manufacturing Option, which was approved by the Board of Trustees in the summer of 2006. It should be noted that students entering the program are required to have passed College Algebra and Physics I (Mechanics) before entering the program. Students may do this through the Tech Prep program at their high school, or as additional courses taken at Three Rivers.

Much compromise was required on the part of each of the four technology programs, including eliminating some cherished traditional courses, cutting back on the number of credits for some courses, and combining similar courses previously taught in separate departments (in some cases, by assigning two faculty to "team teach" a course.) The revised degree and option reflect the enthusiastic agreement of all program coordinators involved to update and streamline courses and to create shared interdisciplinary courses wherever possible. Among the course revisions were:

- Introduction to Photonics. This was a 5 contact-hour course (3 hour class/2 hour lab) in the Laser and Fiber Optic Technology program. To fit in the new Laser Manufacturing Option, one hour was removed creating a 2 hour lecture/2 hour lab course. The new format allows the course to be taught in two 2- hour blocks, using a modified "studio physics" format. Each class block consists of a short (10-15 minute) introduction, followed by an inquiry based hands-on activity. The last ten minutes of class are used to report out to the group and present conclusions. This format has proven to be much more efficient than the traditional lecture/laboratory, and the same amount of material is covered in less time with no loss of student comprehension.

- Circuits and Systems. Previously, the introductory electric circuits sequence was a traditional DC circuits course (first semester) followed by AC circuits (second semester). The revised courses are a one-semester introduction to both DC and AC circuits, followed by a second semester of more rigorous circuit analysis. This approach has several benefits: the course now may be used as the course for non-majors in programs like Mechanical Engineering Technology, increasing class size; first semester students, often weak in math, have a semester to strengthen math skills before studying more complex electrical systems; and the revised course is a better fit to the high school electronics courses for which the college grants Tech Prep credit.
- Laser Safety, a one day seminar course, was expanded to a one-credit Laser and Lab Safety course, required of all Manufacturing and LFOT students.

Table 2. The Three Rivers Community College Implementation of the Laser Manufacturing A.S. Degree Program. The current Manufacturing Option (right hand side) is slated to become a Mechatronics Option.

Manufacturing Engineering Technology Core Program

Course ID	Title	Credits
General Education		
_________	Fine Arts Elective	3
_________	Science Elective	4
_________	Social Sciences Elective	3
ENG K101	Composition	3
ENG K202	Technical Writing	3
MAT K167	Principles of Statistics	3
MAT K186	Precalculus	4
Technical Core Courses		
TCN K105	Laser and Lab Safety	1
BMG K218	Operations Management	3
CAD K106	Computer-Aided Drafting/Lab	1
CAD K107	Computer-Aided Drafting Lab	2
EET K105	Electric Circuits & Systems	3
EET K106	Electric Circuits & Systems Lab	1
EET K264/265	Automated Controls I and Lab	4
MEC K114	Introduction to Structural Mechanics	3
MEC K152	Fundamentals of Eng. Graphics	1
MEC K153	Fundamentals of Eng. Graphics Lab	2
MFG K102	Manufacturing Processes	3
MFG K103	Manufacturing Processes Lab	1
MFG K118/119	Computer Controlled Laser Material Processing/Lab	3

Manufacturing Option Courses			**Laser Manufacturing Option Courses**		
EET K266/267	Automated Controls II /Lab	4	PHO K101	Introduction to Photonics	3
MEC K250/252	Strength of Materials/Lab	4	PHO K140	Optoelectronics/Lab	4
MEC K262/263	Materials Science/Lab	4	PHO K230	Laser Electronics	4
MFG K214/215	Tool Design/Lab	3	PHO K240	Introduction to Lasers	4
Option Total:		**15**	**Option Total:**		**15**
Degree Total:		**67**	**Degree Total**		**67**

3.3 New Courses

Of course, it is impossible to create a meaningful new program option without adding new courses. In response to the RCNGM industry survey, an optoelectronics course was created as a parallel course to the standard Electronics I taken by Electrical Engineering technology students, but emphasizing applications in optoelectronics. At the same time, the content of the Laser Electronics course was changed to include more high power and RF electronics. These courses will be part of the LFOT program as well as the new Laser Manufacturing Option

3.4 Computer Controlled Laser Material Processing

The capstone course created for the program is Computer Controlled Laser Material Processing. The course covers the mechanics, components, characteristics and control of lasers used in the processing of engineering materials. Students study specific processes such as athermal processing, surface hardening, cladding, joining, cutting, marking and welding and are exposed to computer numerical control (CNC) concepts and programming. The course is taken by both Manufacturing and LFOT students, leading to an interesting mix of abilities; some students are well-versed in laser technology while others have in-depth knowledge of manufacturing processes.

To support the laboratory, the RCNGM purchased a large format 45 Watt CO2 engraver for use in the Three Rivers Manufacturing Laboratory. Students use the laser to study the effects of changing laser parameters when processing (raster engraving or vector cutting) a variety of materials. In one such experiment, students were instructed to design a procedure to methodically investigate the raster settings of speed and power for 3 types of material. Additional tests were performed at fixed speed and power settings with variations in resolution from 75 to 1200dpi, and in a third investigation, the effects of changing lens focal length and engraving with both focused and defocused lens were also studied. Students examined the materials processed by the laser by creating photomicrographs using microscopes equipped with digital cameras and image analysis software.

The investigations required students to devise a graphic to be engraved that would allow them to effectively study the parameters being changed. The test pattern was applied repeatedly with different settings of power, speed and resolution for each material and for several focal length lenses, with results organized in a matrix format. Because of the relatively low power, the laser is restricted to various types of wood and plastic, but students were still able to draw conclusions about the "best" settings for different materials. For example, they noted that high powers used with acrylic resulted in fine drops of molten plastic being sprayed onto the surface. One group reported, " An earlier attempt to engrave wood at 100% power and 10% speed made it clear that some combinations would result in fire, the byproducts of which would be fouled lenses and destroyed samples."

Figure 1. Student study of laser engraver speed and power on wood sample, photographed at 60X.

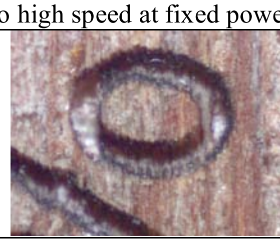
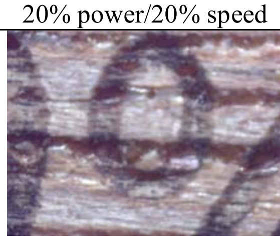
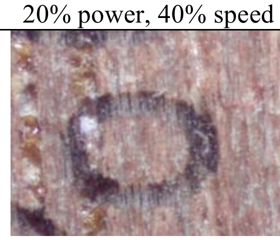
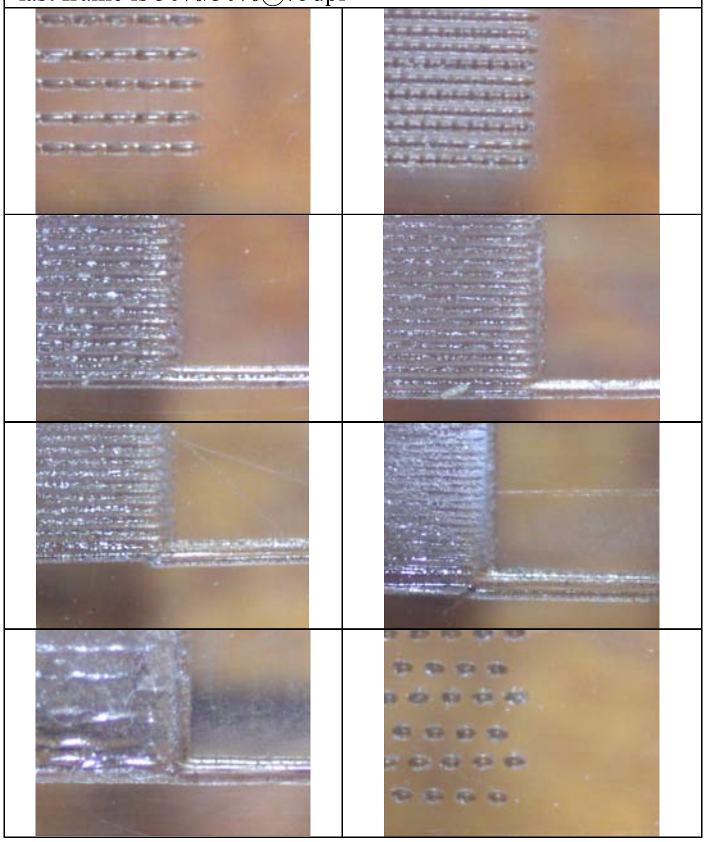
Sequence of images from low to high speed at fixed power.	
	
20% power/20% speed	20% power, 40% speed
	
20% power/80% speed	20% power/100% speed

Figure 2. Student study of laser engraver resolution on acrylic. This portion of the test graphic was a solid rectangle, and the photographs are at 200X.

Resolution patterns, 75, 150, 200, 300, 400, 600, and 1200 dpi, executed at 90%power/90% speed. For comparison, the last frame is 30%/30%@75dpi



4. Statewide Dissemination

Not many of the Connecticut Community Colleges have the resources to implement the entire A.S. in Manufacturing and the Laser Manufacturing Option. However, through the College of Technology Technological Studies program, they are able to implement the key courses. Three Rivers is committed to assisting sister colleges by offering optics and laser courses by distance learning on the Internet or through hybrid online/onsite delivery.

4.1 Introduction to Photonics Online

Introduction to Photonics has been offered as an online laboratory course since 2001. Students perform experiments designed for a "home lab" environment, using commonly found supplies and the Optical Society of America's Optics Discovery Kit (available from Edmund Optics). The course was completely redesigned as a result of the NSF/ATE project PHOTON2, which incorporated adult learning principles and created a collaborative version of the course for online teacher professional development. Based on the PHOTON2 experience, the course is now less instructor-centric, and requests student collaboration on home labs. It is an ongoing challenge to convince technology students of the value of teamwork and collaboration.

4.2 Introduction to Lasers Hybrid Course

In Fall 2007, Introduction to Lasers will be offered as a hybrid online/onsite course. Current plans include the podcasting of Power Point based lectures, and some limited use of online computer controlled experiments. On-campus classes will still be held for traditional day students, mainly to discuss and review the online podcasts, and most labs will be held on campus in the evening. Quite a few students who have expressed interest in taking the course are working for companies that build lasers, for example, Trumpf or IPG Photonics. Three Rivers is exploring the possibility of granting credit to such students for the laboratory portion of the course. There is ample precedent for credit for industry experience offered by technology programs at TRCC.

6. Marketing- Where are the students?

Despite the difficulties manufacturers are having in finding qualified employees, the perception that manufacturing has no future makes it difficult to recruit students to manufacturing programs. Along with the RCNGM, Three Rivers is embarking on a vigorous marketing program to encourage young people to explore careers in high tech manufacturing. Through a DVD produced by the RCNGM and available through online streaming video, newspaper articles, personal visits to high schools, radio interviews, and a three-day "Laser Camp" at the college, the message is, "There's a great future in Connecticut manufacturing-and it's not your grandfather's factory job any more!" Time will tell if the message is heard by prospective students and heeded.

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III.

The Spectrum of Courses offered by the Center for Biophotonics Science and Technology (CBST)

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Abstract: The National Science Foundation (NSF) funded Center for Biophotonics Science and Technology CBST) provides a number of short to full-length courses on the subject of biophotonics. A middle school summer camp and various versions of multi-year high school courses are currently in progress. Two courses define a Biophotonics Option within the Photonics Technology Degree Program at the Central New Mexico Community College. CBST also collaborates with the Integrated Studies Honors Program (ISHP) at UC Davis to provide an introductory course to some of the top students in the freshman class. Advanced undergraduate and graduate courses are provided at UC Davis and sister institutions within CBST.

1. Introduction

The Education and Human Resources Program of the Center for Biophotonics Science and Technology (CBST) is committed to the goal of increasing the quality and quantity of science education experiences available to a diverse population of students, educators, and the public. We are accomplishing this by developing and implementing an innovative program that establishes pathways to careers in the emerging field of biophotonics. Applications of biophotonics range from using light to image or selectively treat tumors, to sequencing DNA and identifying single biomolecules within cells.[1] The CBST educational program is a comprehensive educational package that links *"the learning years to the earning years."*

The inauguration of the Science and Technology Center (STC) program at the National Science Foundation in 1987 represented a fundamental shift in scientific funding policy in the United States,[2] viz., a move from individual principal investigators to large, multi-investigator, multi-institutional centers. Well established by 2002, the STC program added six new centers, including CBST for which the University of California, Davis was the lead campus. Partner institutions included Lawrence Livermore National Laboratory, UC Berkeley, UC San Francisco, Alabama A&M University, Stanford University, University of Texas at San Antonio, Fisk University and Mills College. Roughly 100 researchers, including physical scientists, life scientists, physicians and engineers, are collaborating in this rapidly developing area of research.

CBST is now in its fifth year of operation. Science and Technology Centers have typically operated for a ten-year period. Although the earliest STC's have now finished their NSF funding cycles, many have been institutionalized as permanent research centers. There are currently 17 STC's funded by NSF. A benefit of the community of STC's is networking and collaboration among different centers. The Center for Adaptive Optics, started in 2000 and headquartered at the University of California, Santa Cruz, has been an especially useful collaboration for CBST. Similarly, the annual meeting of the NSF Research Center Educators Network (NRCEN), a gathering of educational specialists from the various STC's and similar NSF-funded centers such as Engineering Research Centers (ERC) and Materials Research Science and Engineering Centers (MRSEC), is a highly effective forum for sharing best practices for educational programs.

CBST currently provides educational opportunities from a middle school summer camp to advanced graduate courses. Pre-college courses tend to provide a stimulating access to the sciences (evenly balanced between the physical and biological sciences) while undergraduate courses provide a general introduction to the field of biophotonics and graduate courses give advanced training in specific topics within the field.

2. Pre-College Programs

A 20-hour summer program for middle school children will be taught for the second time in summer 2007 in collaboration with the California State University, Sacramento (CSUS) Academic Talent Search program. The 2006 program was oversubscribed and there have been requests to run multiple 20 student sessions in summer 2007. Materials used for this group are based on our previously tested high school activites.

The High School Biophotonics Research Academy is a high school enrichment program that challenges students' ideas about careers in science and demonstrates the relevance of biophotonics in medicine, industry, and research. This program engages students in inquiry-oriented activities and research projects. The curriculum is steered by emerging conceptual models of biophotonics, emphasizes information technology, scientific inquiry, and biology/physics/chemistry concepts through studying the applied field of biophotonics. Program designs include (1) after-school programs, (2) in-school elective courses, and (3) integration as a module or unit in an existing course.

Fig. 1. High School Biophotonics Research Academy students touring the Center for Biophotonics Science and Technology at the University of California Medical Center.

During the first year, the students (1) engage in inquiry-oriented activities, (2) work in small research teams to design a systematic biophotonics investigation, (3) are introduced to industry and research opportunities through field-study trips and interactions with CBST research scientists. The year culminates with a research symposium and a publication of the students' research reports. Students who successfully complete the first year may be offered an opportunity to continue their study for a second year during which they will continue their research and compare a competitive biophotonics science fair project. They may also apply for internships as available.

The Program is a collaborative effort among CBST, Center High School in Antelope, California, Mills College (a women's college in Oakland), East Oakland Community High School, Sacramento High School (a St. Hope Academy school), the UC Davis Cancer Center, the UC Davis Medical Center, Capitol Center MESA, the Edward Teller Educational Center, the Lawrence Hall of Science, and local industries indicating an interest in partnering with the project.

Four modules constitute the completed 200+ hour curriculum draft. During 2005-2006 the Research Academy model was implemented as an after school program at Center High School, and as a year-round elective course at East Oakland Community High School. Seventy percent of student participants in these programs came from underrepresented groups (25 out of 36). Eight second-year students participated as "Research Associates" in the Academy; two competed in the Junior Science and Humanities Symposium; six students competed in the Sacramento Regional Science and Engineering Fair (winning first and second place in the team science event); three also competed in the California State Science Fair; six plan to pursue STEM fields. Four Undergraduate Mentors (three from underrepresented groups) supported these academy programs. High School Research Academy in Biophotonics presentations were given at various national science education meetings. Evaluation outcomes indicate (1) significant changes in students' understanding of the processes, skills and values of science; (2) significant change in students' understanding of the discipline of biophotonics; (3) changes in students' course choices for math/science (increase in AP course choices); and (4) change in students' interests in pursuing STEM-related majors and careers.

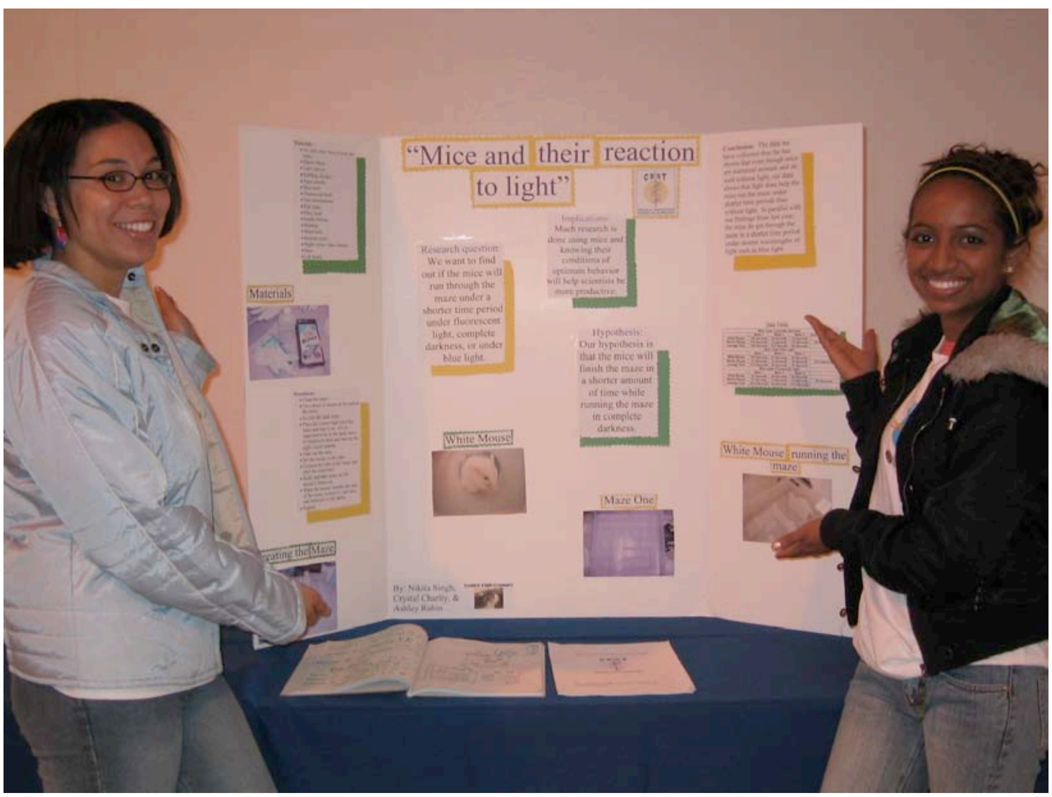

Fig. 2. Two High School Biophotonics Research Academy students displaying the results of their research project.

3. Community College Program

For the job market in the United States, a serious undersupply of workers is projected for jobs requiring an associate degree or equivalent advanced training (Table 1).[3] A similar shortfall has been specifically identified for photonics technicians (Table 2). From its inception, CBST has included in its educational mission the training of a technician workforce for the field of biophotonics. In exploring potential partner institutions for CBST, it became clear that one of the most mature photonics technician training programs in the USA is that at the Central New Mexico (CNM) Community College in Albuquerque, New Mexico. The administration and staff at CNM saw significant benefits from including a biophotonics option in the Photonics Technology degree program in order to enhance the career options for their graduates.

Table 1: The Workforce Gap*

Where 9th Graders Are Headed	*versus*	Where the Jobs Are
28% will enter a 4-year college		20% require a 4-year college degree
32% will enter an associate degree program or advanced training		**65% require an associate degree or advanced training**
10% will lack the skills needed for employment		15% require minimum skills for employment
30% will drop out of the system before completing high school		

* Richard W. Judy and Carol D'Amico, *Workforce 2020: Work and Workers in the 21st Century*, Hudson Institute, Indianapolis, IN, 1997.

Table 2: Estimated Demand for Photonics Technicians*

Estimated demand for technicians in 2005	52,200
Number of technicians in 2000	19,900
Post-secondary technician graduates 2000 – 2005	8,000
Net shortfall in 2005	**24,300**

* Center for High-Technology Materials, University of New Mexico.

A Biophotonics Option was developed within the long-established Photonics Technology degree program at CNM within two years. Representatives of CBST and CNM first met to discuss areas of mutual interest in October 2003 at the Education and Training in Optics and Photonics (ETOP) Conference in Tucson, Arizona. A formal Letter-of-Intent was signed between the two groups in February 2004 by Dennis Matthews, Director of CBST and Don Goodwin, Dean of the Technologies Department at CNM. The Letter-of-Intent included an agreement that CBST and CNM would cooperate to assess the demand for technicians in the biophotonics field, comparable to the estimate shown in Table 2 but specifically focusing on biophotonics. In addition, CNM agreed to develop biophotonics courses appropriate for a Biophotonics Option with support from the resources and personnel of CBST.

Various exchange visits between representatives of CBST and CNM were carried out through the remainder of 2004, culminating with the design of both the Biophotonics Option and specific courses for that option. A press event announcing the collaboration between CBST and TVI was held in Albuquerque, New Mexico in October 2004 and the first, prototype course on "biophotonics" was offered at CNM beginning in January 2005. In February 2005, Dr. Marco Molinaro, Chief Educational Officer of CBST, met with this class to discuss internship opportunities (Fig. 3).[4] The core of the Biophotonics Options is the courses PHOT 227L (Introduction to Biophotonics) and PHOT 228L (Biophotonics Applications) that students can select from the list of electives in the Photonics Technology Degree Program. The successful implementation of the Biophotonics Option within the Photonics Technology Degree Program was reported at the October 2005 ETOP Conference in Marseilles, France.[5]

CBST is now exploring the possibility of replicating the CNM courses at a Northern California community college. A greater effort, however, is focused on recruiting science and engineering community college students from Northern California to UC Davis and our sister four-year campuses within CBST.

Figure 3: Discussion of internship opportunities at the Center for Biophotonics Science and Technology (CBST) with the "Introduction to Biophotonics" class at the Central New Mexico Community College (CNM). Dr. Marco Molinaro, Chief Educational Officer for CBST is fourth from the right.[4]

3. Freshman Honors Course

The Integrated Studies Honors Program (ISHP) at UC Davis is the oldest residential living/learning program in the University of California system, having been started in 1969. A steady increase in selectivity has led to the program being a cornerstone of campus efforts to recruit freshmen of exceptional talent. The traditional program goals are to provide excellent, personalized teaching; to integrate course offerings in the humanities, social sciences, and natural sciences; and to create a small residential community. These high achieving freshmen generally continue to be high achievers throughout their career at UCD. They graduate at a much faster pace than the general population. Also, one should note that the gpa at graduation for UCD students averages near 3.10. For the ISHP students, the average gpa at graduation is typically between 3.5 and 3.7. A significant fraction of each class (typically about 25%) graduates with a gpa above 3.90. The ISHP provides a close-knit community to a total of 114 students, the number available in the relatively new Bryan Miller Hall in the Segundo dormitory complex. Typically, a majority of the ISHP students receive Regents Scholarships, the most prestigious scholarships provided by the campus.

Each quarter, each ISHP freshman selects one of five different four-unit courses under the general label of IST 8. Each IST 8 class has been pre-approved for General Education credit and is in the area of science/engineering (IST 8A), humanities (IST 8B), or social sciences (IST 8C). Each IST 8 class is capped at 25 students.

The course, IST 8A (Shedding Light on Life), was patterned after the research themes of CBST along with the background needed to comprehend a broad definition of biophotonics. The course represents a general introduction to light, lasers, biology basics, and light/tissue interactions. Applications to diagnostics (tags), bioimaging, and therapies are illustrated, along with discussions of genes, cancer, and bionanophotonics. To engage the students, several experiential hands-on sessions are provided including student group research projects involving spectroscopy of living matter and light/tissue interactions.

The individual topics within the course are referenced to the introductory textbook on biophotonics by Paras Prasad.[1] As the Prasad text is targeted to a more advanced audience, the lectures are intended to be self contained, with the outside reading in Prasad most beneficial for biological science and other science/engineering majors. All lectures are prepared as PowerPoint presentations and archived, video and Powerpoint, for convenient access by the students. Guest speakers from within the CBST community of scientific researchers are carefully selected as those who give effective introductory lectures. The IST 8A instructors work with the guest speakers to ensure that PowerPoint presentations for their talks are also archived.

The students in the class have access to a large body of archived material from the Education Program of CBST, as well as the PowerPoint lectures from their instructors and guest speakers. The archived material is especially useful to the students as they prepare a required term paper worth 25% of their course grade. All of the archived material on the Education site of the CBST web site is available to other interested educators (http://cbst.ucdavis.edu).

As noted earlier, the annual meeting of the NSF Research Center Educators Network (NRCEN), a gathering of educational specialists from the various STC's and similar NSF-funded centers is a highly effective forum for sharing best practices for educational programs. In that forum, we became aware that an Engineering Research Center at the University of Illinois has a similar course to IST 8A for honors students interested in the theme of their center (earthquakes).

Of special note about IST 8A is the fact that about half of the students are non-science majors taking the course as a General Education elective, while the other half are science and engineering majors taking the course because of their specific interest in the topic of biophotonics.

The ISHP students are selected on purely academic standards and are not a particularly diverse group. Nonetheless, the IST 8A class has attracted a large number of female students (as high as 67 % in one recent class). Furthermore, the students have been active ambassadors for CBST, with several groups going out to the predominantly Hispanic Douglass Middle School in Woodland, California (ten miles north of Davis) and presenting introductory biophotonics concepts to seventh and eighth grade science students. CBST educators provide the IST 8A students with an introduction to learning theories and teaching techniques prior to the classroom visits. Groups of students have also presented to the general UC Davis student body and at community colleges with highly diverse student bodies in the Sacramento area.

Fig. 4. IST8A students with middle school science teacher (on the left) after a presentation to her class.

4. Other Undergraduate Courses

In Spring of 2007, a one-unit seminar was offered within the Integrated Studies Honors Program for the first time as a follow up to the IST8A course described in section 3. The goal of this seminar was to engage some of the brightest freshman students at UC Davis in the development of tutorials and narrative elements for the CBST-led website BiophotonicsWorld.org. The seminar involved mostly students who had not taken IST8A and focused on creating public-friendly information on biophotonics for use on BiophotonicsWorld and elsewhere. The course was divided into two parts: 1) enhancing the twenty IST8A topical papers from the previous quarter by clarifying terms and making them accessible to the public and 2) creating a biophotonics primer in print and for the web.

A one-unit freshman seminar course open to the general campus population on the theme of “biophotonics” was taught for the fourth time in the Fall of 2006. The course introduced students to research in biophotonics and supplied some basic understanding of the underlying science. The course also introduced students to CBST and the opportunities for undergraduate interactions with the educators and researchers there. Several researchers from CBST presented their work. Students that participated were required to write two one-page papers on these presentations. In addition, the students were required to ‘interview’ a researcher connected with CBST and give a class presentation on their research as well as write a short paper on that topic. Several students from prior offerings of this course have successfully applied to the CBST summer internship program. The seminar will continue to be taught yearly. CBST scientists from the Department of Applied Science are involved in the teaching of EAD 172, a three-unit course on “Optical Methods for Biological Research.” The course is an elective within the Optical Science and Engineering major and serves as an excellent opportunity to expose these students to research opportunities within CBST.

5. Graduate Courses

CBST scientists are also involved in the teaching of EAD271, a graduate course on “Optical Methods in Biophysics” and the graduate level version of the EAD 172 course described in section 4. The course is also cross-listed as Biophysics 271 for students in the Biophysics Graduate Group. The course also serves as a portal to the Designated Emphasis in Biophotonics (a minor for graduate students majoring in a related field such as Biophysics, Biomedical Engineering, or Applied Science). Students in the Designated Emphasis in Biophotonics also participate in the joint seminar series Biophotonics 290/Biophysics 290 that provides 30 seminars per academic year.

CBST Director Dennis Matthews and Associate Director for Science/Education Integration Frank Chuang, MD, Ph.D., lead a course EAD 289 entitled “Special Topics in Biophotonics.” The course is cross-listed as Biomedical Engineering 289. The course is available to all graduate students from the various CBST-affiliated institutions. The goal is to introduce new graduate students to the depth and diversity of current biophotonics research being conducted through CBST, as well as recruit new graduate students to CBST. This course focuses on familiarizing students with the fundamental principles, new tools and techniques that make-up the growing field of biophotonics. Through a combination of lectures, discussions, hands-on lab tours and research assignments, students learn about biophotonics in much greater detail. As five institutions (UCD, UCLA, University of Nevada-Reno, University of Toronto, and the Lawrence Livermore National Laboratory [LLNL]) were involved as participants and provided co-teachers, televideo was extensively utilized. Copies of lectures are available on the http://cbst.ucdavis.edu website. Streamed video of the lectures is also available.

Fig. 5. CBST Director Dennis Matthews lecturing in the graduate course, EAD289 on “Special Topics in Biophotonics.”

Finally, Professor Anup Sharma of Alabama A&M has developed a new course on "Nanophotonics." This three-unit physics course (PHY692) serves to introduce his students to the new field of nanophotonics and covers topics such as quantum-confined materials, nanocomposites, nanolithography, and nanobiophotonics. The initial offering in Spring 2007 has enrolled 12 graduate students, with several expected to engage in biophotonics research.

ACKNOWLEDGEMENTS

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IV.

Infusing Photonics to Increase Enrollment in Electronics Engineering Technology

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Abstract: During the last 15 years most of the electronics engineering technology programs across the nation have experienced a constant decline in enrollment. Today's high school students do not seem to consider a career in electronics engineering appealing enough to commit to a field of study in desperate need of new students. They still associate electronics programs with the electronics section of a department store; televisions, stereo systems, DVD and VCR players, and other disposable electronics. While the downward trend continues across the nation, Indian River Community College (IRCC) has been able not only to stop it but to reverse it by attracting a new generation of students. By introducing high school students to new and emerging technologies, their perception of established degrees has changed and their interest has been stimulated. Photonics is one of those technologies capturing students' attention. IRCC, a partner college in the National Center for Optics and Photonics Education (OP-TEC), with the assistance of other colleges like Camden County College which already offers an Associate in Applied Science degree in Photonics, has created a Photonics specialization under the Electronics Engineering Technology program. The targeted marketing of this new specialization has led to an increase in enrollment of 50% in 2005, 80% in 2006, and for 2007 it is projected it to be over 100%. An interesting comparison can be made concerning enrollment at colleges with a full AAS program in photonics like Camden County College and IRCC which uses photonics as an enabling technology. This analysis could lead to a new approach in restructuring engineering technology degrees with the infusion of photonics throughout many technology fields. This presentation will discuss the plan of action that made possible this initiative at Indian River Community College and new program directions at Camden County College, Blackwood, New Jersey.

1. Introduction

Photonics education has been delivered in two modes: the full fleshed AAS degree in photonics/optics as at Camden County College, and the infusion of photonics courses in existing engineering AAS degrees as at Indian River Community College. Below we will examine both approaches.

1.1 The IRCC approach.

Beginning with the 1990s, the state of Florida experienced a constant decrease in the enrollments of electronics engineering technology (EET) programs [1]. This decline in enrollment was not only local to Florida, but was common throughout most of the United States of America [2]. Even though everyone understands that the type and the kind of electronic equipment and devices we use in our daily routines are on the rise, we yet experience a reduction in interest in the study of electronics engineering. At many community colleges across the nation, electronics programs shut their doors without much of a struggle. Indian River Community College could not accept defeat without putting up a good fight. The problem was examined from all its angles in order to figure out its root causes, and then a solution and a strategic plan was devised. Out of the traditional electronics program the Robotics and Photonics Institute (RPI) was created and started in the fall of 2006 with 100% capacity. The photonics curriculum was developed with assistance from OP-TEC which offers a complete series of books with associated laboratory experiments in basic optics and lasers [3]. We are now in the middle of our recruiting campaign for the fall 2007 term which is going so well that we will have the luxury of selecting the best 24 out of a total of 60 applicants. This paper presents the successful approach of Indian River Community college in solving a problem that has distressed many electronics departments of community colleges throughout the United States.

1.2 The Camden County College approach

This paper will also discuss existing full photonics technology programs, particularly at Camden County College, Blackwood, New Jersey, and their attempt to maintain adequate enrollment numbers. It is our hope and desire to help any other college that is experiencing similar problems as we did both as photonics infusion programs or full photonics AAS degree programs and provide advice and suggestions on how to overcome them.

The photonics/fiber optics department of Camden County College was started in 1976 and has steadily grown to be one of the most advanced centers of learning and training in photonics and fiber optics in the country. In 1989, it moved into its own building - the Laser Institute of Technology for Education and Research. Over these three decades, the department has received many grants from federal and state organizations as well as photonics industries. Dr. Fred Seeber, Professor Emeritus of Photonics/Physics, is the main architect of the growth of this department and has chaired it for nearly three decades. The department can boast of practically every type of laser system and detectors. In the fiber optics division, every type of equipment necessary for optical communications is available. The faculty, both full-time and adjunct, are well qualified, and most of them possess doctorates and many years of experience in their specialty.

Student enrollment has fluctuated over the years with enrollment levels as high as 50 students per semester to about 15 each semester. Currently a total of 27 students are enrolled in the program. The cause of this fluctuation is difficult to determine not only at CCC but at many other full AAS Photonics programs around the country. Some have suggested that four year institutions have started their own programs offering degrees in photonics engineering and technology. Others point to the curriculum difficulty and prerequisite requirements of a photonics program as compared to others offered at the community colleges. A main focus of OP-TEC is to try to determine some of the causes related to low enrollment figures. The lack of enrollment is certainly not because of the job market. It has been generally strong in most areas of the photonics industry. Graduates have done extremely well in their careers, many of them graduating from four year colleges and universities and becoming presidents of their own start up companies or attaining high positions in established firms.

2. The problem as identified by IRCC

The low enrollment in the electronics programs is caused by the following factors: the students do not understand the depth and breadth of the electronics industry, curriculum was not updated to include the new technologies, and the marketing of the electronics programs was non-existent or inadequate. Even though many educators identified one or more of these problems the bureaucratic system of most community colleges was slow to react and remedy the problem fast enough before the "death" of the program [4].

2.1 Students do not understand the depth and breath of the electronics industry

The electronics industry has been around for more than 100 years and became the under-grid of almost all modern technologies such as telecommunications, biomedical, biotechnology, genetics, computing, industrial automation and controls, robotics, electro-optics, lasers, fiber optics, entertainment electronics, warfare and anti-warfare electronics, electronic publishing, laboratory instrumentation, and many others. To most people though, the word electronics brings to mind the electronics section of a department store, and that is where the problem begins. The department store electronics belong to the consumer electronics sector which needs no technicians any more because of the disposable nature of these products. The word electronics has been stereotyped to the television, VCR, DVD, audio systems, and all the other home appliances that the cost of repair is higher than the cost of a newer appliance with more features and usually cheaper than the one it is replacing. To change this stereotypical misconception an intensive educational and, at the same time a promotional campaign has to be undertaken. All promotional material produced needs to avoid association with the consumer electronics sector, but present and emphasize the new technologies of lasers, photonics, robotics, biotechnology, medical electronics etc.

2.2 Modernizing and revisiting the curriculum

Many instructors and institutions are reluctant to change the curriculum. They are so adamant about not modifying the curriculum, they almost consider blasphemous any attempt to change it [4]. The Photonics Advisory Committee at Camden County College consists of members from both the photonics industry and universities. Former Camden

County College graduates sit as members of this important committee. The committee meets at least once a year and its recommendations are incorporated into the curriculum. It is these individuals who can advise the faculty of a photonics program about how to proceed in the future. The curriculum must change every so many years in order to add the new technologies in our AS or AAS degree programs. The fact that these degree programs have to remain at the length of two years and at a fixed number of credit hours makes it imperative that we revisit the existing curriculum and remove what is no longer needed to make room for the new knowledge. In the 1970's, for example, in a digital electronics course we taught the discrete transistor circuitry that made up an individual AND gate. In the 1980's we stopped teaching what is "under the hood" of the AND gate because we had to make room for decoders, encoders, multiplexers and demultiplexers. As more digital devices have been invented we had to always go back and take something out in order to make room for the new. The same systematic approach has to be applied to the entire electronics program. First the new technologies that need to be introduced have to be identified, and then a review of the curriculum has to take place, to determine what has to be removed without loss in quality of the technician we will produce. All the core courses of DC and AC circuits, Discrete and Integrated Analog circuits, need to be revaluated, their scope has to be aligned to the needs of today's industry, and all the non essential circuit analysis and design needs to be removed to make room for the new courses. The fields of photonics and robotics are very attractive and are very well received by young and older prospective students. Courses in these modern specialties need to be added to the curriculum, and promotional materials need to be produced showing that education in these new technologies will lead to high wage paying jobs in the service area of the college and beyond.

2.2 Marketing of the modernized program

Most community colleges spend very little in the marketing of their electronics programs and do not have a professional marketing person or even a marketing department. The marketing effort in most of the colleges with enrollment problems consists of creating unattractive, single color brochures that are stacked up in a few display areas around the college. In some colleges an additional effort is made to take these brochures to different area high schools and distribute them to students. Community colleges will seldom place ads on television or on the radio for marketing programs and recruiting students. In contrast to this, private electronics colleges advertise on television regularly on prime-time, and on the radio more frequently. Even though the cost of attending these private colleges is usually more than four times the cost of a community college, the private schools have not experienced as dramatic a decrease as community colleges have. The reason is the intense and effective marketing effort of the proprietary colleges. These for-profit colleges have a coordinated marketing campaign consisting of attractive colorful print publications, professionally produced interactive websites, and trained marketing people who are paid well only if they produce results. Community colleges can stand against this professionally organized campaign of the proprietary schools by selling their strong points, which are: much lower cost to the student, better equipped labs, better educated faculty which typically has higher scholarly credentials, and accreditation by high caliber accreditation boards. This has to be emphasized with appealing colorful print and electronic promotional material.

3. The Idea of the Robotics and Photonics Institute

At Indian River Community College, the electronics department, in consultation with its industrial advisory committee, decided to infuse the emerging fields of robotics and photonics into the traditional electronics engineering technology AAS degree program.

The electronics program consists of 68 credit hours out of which 15 are devoted to general education courses. The remaining 53 credit hours are technical courses required to produce a quality technician. The 53 credit hours of technical courses had been divided into two groups: the major field core and the major field electives, as shown in figure 1.

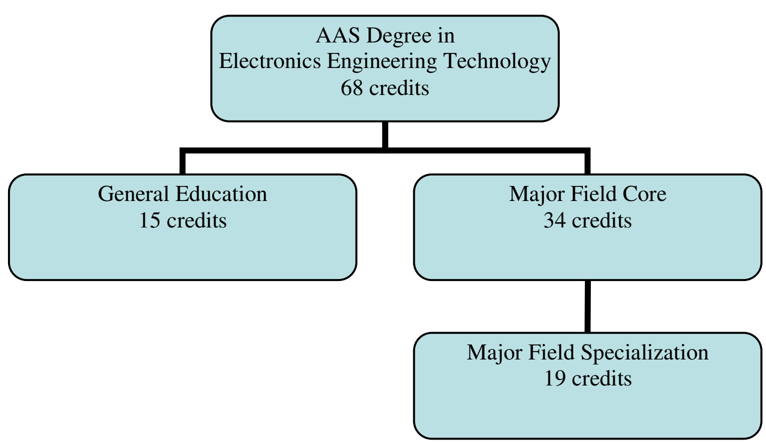

Figure 1. Breakdown of the Electronics Eng. Tech. Program

In the major field electives group, we had the specializations of telecommunications, computer support and biomedical options. We added the Photonics option and the Robotics/Manufacturing option. Each one of these options consists of a group of courses totaling 19 credit hours as shown in figure 2.

CET	1112C	Logic Circuits I	3 credits
CET	1113C	Logic Circuits II	3 credits
CET	1440C	Computer Aided Schematic Design	3 credits
EET	1015C	DC Circuits	4 credits
EET	1025C	AC Circuits	4 credits
EET	1215C	Introduction to Electronics	3 credits
EET	2141C	Electronic Devices I	4 credits
EET	2142C	Electronic Devices II	4 credits
MTB	1321	Technical Mathematics I	3 credits
MTB	1322	Technical Mathematics II	3 credits
SPECIALIZATION ELECTIVES - 19 credits			
COMPUTER SUPPORT OPTION			
CET	1041	HTI+ Certification	3 credits
CET	1178	A+ Certification Training I	3 credits
CET	1179	A+ Certification Training II	3 credits
CET	1588	Network + Certification	4 credits
CET	1854	Introduction to Wireless Technologies	3 credits
EET	2930	Special Topics in Electronic Engineering	3 credits
TELECOMMUNICATIONS OPTION			
CET	1854	Introduction to Wireless Technologies	3 credits
EET	2325C	Communication Circuits I	4 credits
EET	2335C	Communication Circuits II	4 credits
EST	2220	Fiber Optics and Data Communications	3 credits
CET	1854	Introduction to Wireless Technologies	3 credits
EET	2930	Special Topics in Electronic Engineering	2 credits
PHOTONICS OPTION			
EST	2210	Introduction to Photonics	3 credits
EST	2215	Geometrical Optics	3 credits
EST	2220	Fiber Optics and Data Communications	3 credits
EST	2230	Laser Technologies	3 credits
EET	2930	Special Topics in Electronic Engineering	6 credits
BIOMEDICAL ELECTRONICS OPTION			
EST	2424	Biomedical Electronics	3 credits
EST	2427	Advanced Biomedical Electronics	3 credits
EST	2408	Biomedical Seminar	3 credits
HSC	2531	Medical Terminology I	3 credits
EET	2930	Special Topics in Electronic Engineering	6 credits
ROBOTICS/MANAFACTURING AUTOMATION OPTION			
EST	2630	Manufacturing Processes	3 credits
EST	2631	Advanced Manufacturing Processes	3 credits
EST	2676	Introduction to Robotics	3 credits
EST	2678	Industrial Robotics	3 credits
EET	2930	Special Topics in Electronic Engineering	6 credits

Figure 2. The modified AAS Degree Program

After the student completes the general education and the major field required core, he can choose any one of the four specializations or "cherry pick" courses from the four specializations, totaling 19 credit hours. After studying the needs of the local industry and carefully planning a marketing campaign, we decided to create the Robotics and

Photonics Institute that would consist of the 15 credit hours of general education, the 40 of major required courses, 12 hours of photonics and 7 hours of robotics as shown in figure 3.

MAJOR FIELD REQUIRED COURSES - 34 credits

CET	1112C	Logic Circuits I	3 credits
CET	1113C	Logic Circuits II	3 credits
CET	1440C	Computer Aided Schematic Design	3 credits
EET	1015C	DC Circuits	4 credits
EET	1025C	AC Circuits	4 credits
EET	1215C	Introduction to Electronics	3 credits
EET	2141C	Electronic Devices I	4 credits
EET	2142C	Electronic Devices II	4 credits
MTB	1321	Technical Mathematics I	3 credits
MTB	1322	Technical Mathematics II	3 credits

PHOTONICS/ROBOTICS SPECIALIZATION COURSES - 19 credits

EST	2210	Introduction to Photonics	3 credits
EST	2215	Geometrical Optics	3 credits
EST	2220	Fiber Optics and Data Communications	3 credits
EST	2230	Laser Technologies	3 credits
EST	2676	Introduction to Robotics	3 credits
EST	2678	Industrial Robotics	3 credits

Figure 3. Robotics and Photonics Curriculum

4. Marketing and Promotional Campaign

Colorful flyers were produced which explained the program in detail, educating the reader about the many high wage jobs awaiting upon graduation. A point was made to compare the high cost of the proprietary schools to the cost of attending IRCC. The newly packaged program was marketed as the Robotics and Photonics Institute (RPI), a selective admission program that required an application process with minimum entrance requirements. The courses for RPI were scheduled Mondays through Fridays from 8:00 a.m. to 12:15 p.m. and the applicants commit to taking all the courses as a cohort group from the beginning to the end of the degree. The RPI was presented by a college recruiter to four high schools and the workforce retraining office. An open house event, which many students and parents attended, took place in the Spring semester of 2006, and three one-week summer camps in emerging technologies were offered in July 2006. The local newspapers were contacted and three different articles were published about the new program between April and July of 2006. The RPI term by term schedule is displayed in figure 4.

FIRST YEAR							
FALL TERM	Days	Time	Cr	**SPRING TERM**	Days	Time	Cr
EET1215C Intro to Electronics	M/W	8:00-9:15	3	CET1140C Schematic Design	M/W	8:00-9:15	3
MTB1321 Tech. Mathematics I	M/W	9:30-10:45	3	MTB1322 Technical Mathematics II	M/W	9:30-10:45	3
CET1112C Logic Circuits I	M/W	11:00-12:15	3	CET1113C Logic Circuits II	M/W	11:00-12:15	3
EET1015C DC Circuits (Fall A)	T/R	8:00-11:00	4	EET2141C Electronic Devices I (Spring A)	T/R	8:00-11:00	4
EET1025C	T/R	8:00-	4	EET2142C Electronic Devices	T/R	8:00-	4

AC Circuits (Fall B)		11:00		II (Spring B)		11:00	
		Term Total:	17			Term Total:	17
SUMMER TERM							
ENC1101 English Composition I			3	PHY1020 Principles of Physics			3
SECOND YEAR							
FALL TERM	Days	Time	Cr	**SPRING TERM**	Days	Time	Cr
EST2542 Programmable Logic Controllers I	M/W	8:00-9:15	3	EST2544 Programmable Logic Controllers II	M/W	8:00-9:15	3
EST2676 Introduction to Robotics	M/W	9:30-10:45	3	EST2630 Manufacturing Processes	M/W	9:30-10:45	3
EST2210 Intro to Photonics	M/W	11:00-12:15	3	EST2215 Geometrical Optics	M/W	11:00-12:15	3
Social/Behavioral Science Elective	T/R	8:00-9:15	3	Humanities Fine Arts Elective	T/R	8:00-9:15	3
Humanities Fine Arts Elective	T/R	10:00-11:15	3	EET2930 Special Topics (Spring I)	T/R	9:30-10:20	1
		Term Total:	15			Term Total	13
						Program Total:	**68 Cr**

Figure 4. Photonics and Robotics Institute Program of Study

Camden County College Programs

The photonics AAS degree program in both Laser/Electro-Optics Technology Degree and Fiber Optics Technology Option Degree Camden County College are listed below.

Photonics
Laser/ Electro-Optics Technology Option
Degree: Associates in Applied Science

Code	Course	Credits
First Year /	First Semester	
LFO-101	Introduction to Photonics & Photonic Safety	4
MTH-125	College Algebra & Trigonometry or	
MTH-140	Calculus I[1]	4
ENG-101	English Composition I	3
PHY-101	Physics I or	
PHY-201	Physics III[1]	4
....	Humanities Elective	3
		18
	Second Semester	
EET-101	Electrical/Electronic Principles	4
MTH-132	Statistics for Technology or	

MTH-150	Calculus II[1]	4
ENG-102	English Composition II	3
LFO-201	Photonics Materials	3
PHY-102	Physics II or	
PHY-202	Physics IV[1]	4
		18
Second Year / First Semester		
LFO-211	Photonic Optic Principles & Components	4
LFO-212	Pulsed & CW Lasers	3
LFO-231	Photonic Measurements	3
EET-211	Electronics I	3
LFO-241	Intro to Fiber Optics	3
HPE......	Health & Exercise Science Elective	1
		17
Second Semester		
LFO-292	Photonics Seminar	1
LFO-221	Photonic & Electro-Optic Devices	3
LFO-251	Laser Electronics or	
EET-212	Electronics II	3
……….	Social Science elective	3
....	Computer Programming Elective	3
HPE......	Health & Exercise Science Elective	1
		14

[1]All students transferring to Rowan University or NJIT must take the Calculus I, II track and Physics III, IV track.

Photonics
Fiber Optics Technology Option
Degree: Associates in Applied Science

Code	Course	Credits
First Year / First Semester		
LFO-101	Introduction to Photonics & Photonic Safety	4
MTH-125	College Algebra & Trigonometry or	
MTH-140	Calculus I[1]	4
ENG-101	English Composition I	3
PHY-101	Physics I or	
PHY-201	Physics III[1]	4
....	Humanities Elective	3
		18
Second Semester		
EET-101	Electrical/Electronic Principles	4
MTH-132	Statistics for Technology or	
MTH-150	Calculus II[1]	4
ENG-102	English Composition II	3
LFO-201	Photonics Materials	3
PHY-102	Physics II or	
PHY-202	Physics IV[1]	4
		18
Second Year / First Semester		
LFO-211	Photonic Optic Principles & Components	4
LFO-241	Introduction to Fiber Optics	3
LFO-231	Photonic Measurements	3
EET-211	Electronics I	3
....	Social Science Elective	3
HPE......	Health & Exercise Science Elective	1

		17
	Second Semester	
LFO-292	Photonics Seminar	1
EET-221	Digital Circuits	3
LFO-294	Fiber Optic Project	3
LFO-242	Advanced Fiber Optics	3
....	Computer Programming Elective	3
HPE......	Health & Exercise Science Elective	1
		14

[1]All students transferring to Rowan University or NJIT must take the Calculus I, II track and Physics III, IV track.

5. The Fruits of Our Labor

By the middle of July 2006, the RPI was full to capacity and we had to direct many applicants to our evening program. Because of the size of our labs we could only accept 24 students in the first RPI cohort group. The group consisted of 22 men and two women. The age distribution ranges from 18 to 55 years old, with 19 of the students being under 26 years old and five between 30 and 55 years old. The cohort arrangement brought the students close to each other, and a strong feeling of camaraderie is evident in the classroom. They all help each other towards their common goal which is graduation and landing of a good paying job. The students form their own study groups and assist each other, not only with college activities, but give each other private personal assistance.

In our departmental website used for instructional purposes, we have added general information about the robotics and photonics industry, how to transfer to a bachelor's degree program at the University of Central Florida, and we also keep an active bulletin board posting part and full-time jobs. All these synergistic activities generate a productive spirit of care and cooperation between the students and the faculty of our department. Camden County College experienced similar success in past years with like endeavors in its full AAS Photonics programs. However, as environments change both at the high schools and four year colleges and universities as well as industry, modifications are almost constantly required for maintaining enrollment.

6. Future Plans and OP-TEC

We are planning to add a third course in the photonics option that will consist of several modules of laser technology applications. These modules are under development by OP-TEC with the support of the National Science Foundation. We are also developing a series of videos of the experiments for the first course of OP-TEC, "Fundamentals of Light and Lasers". We will make these videos available to colleges that are interested in infusing photonics in their curricula. The location of IRCC on the Atlantic coast of Florida, and its proximity to three world class ocean research institutions, prompted the exploration of a cutting-edge application of photonics in bioluminescence. We are in discussions with all of our research partners with the purpose of creating educational materials for these technologies, training technicians for their special needs, and assisting them in their mission of exploring and protecting our oceans. IRCC as a principal partner with OP-TEC, is chartered to produce educational modules in the areas of homeland security. CCC is chartered to produce educational modules in applications of lasers in medical electronics.

7. Conclusion

Electronics engineering technology education is a moving target. One cannot rest after a successful implementation of a program. We always need to be vigilant and continually scan the horizon for the new technologies that are appearing and taking root. Curriculum must be revisited, updated, and modernized to not only satisfy the needs of today's industry, but anticipate the new needs created by the emerging technologies. Engineering departments need to be visionary, forward looking, risk taking, and flexible in the creation and delivery of new knowledge. Industry cannot wait for the slow bureaucratic wheels to turn. Community colleges have to deliver at the speed of industrial changes and not the speed of intra-college mechanisms. The presentation and marketing of our educational programs is as important as the technical content of our degrees. Full AAS Photonic Technology programs need to reassess their course offerings and develop career pathways to make sure curriculum offerings meet the needs of their industrial employers and to honor articulation agreements for transfer to four year colleges and universities. Efforts should also be made to infuse photonics into other technical areas as suggested in this paper.

References

[1] Florida Community Colleges 2006 Fact Book, available at: http://www.firn.edu/doe/arm/cctcmis/pubs/factbook/factbook_main.htm
[2] Science and Engineering Indicators 2006, National Science Board http://www.nsf.gov/statistics/seind06/
[3] OP-TEC, http://www.op-tec.org/
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V.

Evolution of a Photonics Education Program

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Abstract
The Photonics Technology program at Niagara College was first launched in 2001. Since that time, in an attempt to meet the joint needs of industry and students, Niagara has developed the technology program into a cluster of four programs related to photonic technology. Niagara is also building relationships with universities to deliver photonic course material to physics undergrad students using Niagara College Photonics facilities and faculty to create an undergraduate specialization in lasers.
This paper will review the development of the photonics cluster at Niagara College and present the current state of its evolution.

1. INTRODUCTION
As a result of the proliferation of photonic technology in virtually every sector of industry, many companies find themselves without the necessary optical and electro-optical expertise. In 2001 the Ontario Photonics Education and Training project (PET) established completely new Photonics Engineering Technician (2 years) and Photonics Engineering Technologist (3 years) programs at Niagara and Algonquin Colleges. With the conclusion of the 2007 winter term, Niagara College will have educated 3 cohorts of Photonic Engineering Technologists, and 4 cohorts of Photonics Engineering Technicians. Since the initial launch of these two programs both colleges have expanded their offerings in photonic education. This growing demand for photonic professionals is what fueled the creation of the original two Photonic programs. With the initial graduating class has come acceptance of Photonic Technicians and Technologists by industry. With acceptance has come greater demand for more professionals trained in the discipline of photonics. To this end Algonquin and Niagara Colleges have introduced a 4-year Bachelor of Applied Technology or BAT in Photonics, and Niagara College a 1-year Advanced Lasers Graduate Certificate. Although graduates are being readily hired by industry, recruitment of students into these new and often misunderstood programs has proven to be a substantial challenge.

2. PHOTONICS PROGRAMS

2.1 Introduction
In this section the individual photonic programs at Niagara will be reviewed. Changes in the program curriculum since inception will be described, and the reasons for those changes discussed.

2.2 Photonics Engineering Technology

The Photonics Engineering Technology program as launched in 2001 ran for 3 consecutive intakes from Fall 2001 until Fall 2003. In Fall 2004, Niagara College suspended intake of the Technology program in an attempt to bolster numbers for the new 4-year Bachelor of Applied Technology (Photonics) program. The removal of the 3-year program created a gap in the college's ability to retain students within the Photonics cluster. Students who had difficulty coping with the rigor of the BAT (Photonics) had only the option to transfer to the 2-year technician program if they were to remain in Photonics despite being better suited to a 3-year technology program. The lack of a 3-year program could be a contributing factor in poor retention rates in keeping BAT students within the Photonics cluster.

In 2006 changes were proposed and accepted to modify the curriculum of the Photonics Technology program. The Photonics Technology program is currently accepting an intake for the Fall 2007 term under the new model and is expected to run.

The adopted program model provides laddering of the Technician curriculum directly into that of the Technology program. Under the new model both the Technology and Technician programs share a common first year. Second year is also common with the exception of math courses. The new program model is shown in Table 1. This model provides students with several opportunities for movement within the photonics cluster. For struggling technologists it provides an exit point after two years which will provide the student with a Technician diploma. It also provides easy lateral movement for Technicians who after one or two years in the system decide to complete the third year and graduate with a Technologist diploma. When combined with courses designed to provide bridging from Technology to BAT, this model provides a complete pathway from Technician to BAT and in an attempt to maximize retention it provides a reverse pathway from BAT to Technician.

Some of the changes in curriculum address the recommendation made in the paper **Technician and technologist photonics teaching: An Ontario success story Jay Yatulis et. all.** In order to improve the students electronics manufacturing skill set a new course has been introduced. Manufacturing Technology for Photonics is a 3-hour per week course delivered in term 2. As an introductory course in manufacturing technology it exposes students to through–hole and surface mount soldering, epoxies, and printed circuit board fabrication. This will allow more advanced manufacturing technologies to be explored in the preexisting Manufacturing Photonics Components, and Photonics Manufacturing Systems courses.

When combining the Technology and Technician streams it was necessary to replace the Technologist version of Light and Lasers Principles with the Technician version. In order to improve the rigor of the Technologist's light and laser theory, the addition of the Advanced Laser Theory (3 credits) course in term 5 was made.

Another improvement made to the curriculum was to modify the Photonics Research Project so that it spans terms 5 and 6 (originally term 6 only). This will allow an improved treatment of the project, enable students to generate more reasonable timelines, and hopefully provide longer more meaningful contacts with industry partners. The first term will be used to develop the project and finalize details on what is to be accomplished. Any materials for fabricated parts of a design would be ordered at this time. The second term will be used to perform and complete any testing. A comprehensive paper will be prepared for the conclusion of this course

2.3 Photonics Engineering Technician

The Photonics Engineering Technician program has gone through several iterations since its initial launch in Fall 2001. Students of the first cohort were enrolled into the same core courses as Technologist students. In many cases the difficulty of the technologist courses was above the ability of students enrolled at the Technician level. This resulted in the creation of modified courses to provide an improved academic fit within the Technician program. The introductory manufacturing course described in 2.2 was introduced into the program for the Fall 2006 cohort. As discussed in 2.2 the current version of the Technician program is once again common with the Technologist program. In the new model Technician level courses are delivered to both streams, and additional theory is introduced in year 3 of the Technologist program to maintain the academic rigor of that program.

Photonic Engineering Technician

Crs. No.	Course Name	Hrs.
LEVEL 1		
CTEC1544	Computer Programming & Applications	60
ENGL1133	College English	45
MATH1131	Mathematics I for Technology	60
PHYS1108	Optics & Waves	105
TECH1244	Health & Safety for Technology	45
TECH1271	Future Trends in Advanced Technology	45
LEVEL 2		
ELNC1220	Electrical Principles for Photonics	75
MATH1231	Mathematics II for Technology	60
MMFG1279	Manufacturing Technology for Photonics	45
PHTN1220	Optic/Optical Fibre Principles	90
PHYS1220	Kinematics & Dynamics	75
LEVEL 3		
CTEC1330	Data & Telecommunications	60
ELNC1320	Electronic Principles for Photonics	90
MATH1299	Statistics for Technicians	30
PHTN1300	Principles of Light Sources and Lasers	75
PHTN1334	Fibre Optics Communication	75
GenEd	General Education Elective	45
LEVEL 4		
ELNC1430	Digital Technology	60
PHTN1400	Principles of Laser Systems	75
PHTN1431	Manufacturing Photonics Components	75
PHTN1432	Vacuum & Thin Film Coating Applications	60
GenEd	General Education Elective	45

Photonic Engineering Technology

Crs. No.	Course Name	Hrs.
LEVEL 1		
CTEC1544	Computer Programming & Applications	60
ENGL1133	College English	45
MATH1131	Mathematics I for Technology	60
PHYS1108	Optics & Waves	105
TECH1244	Health & Safety for Technology	45
TECH1271	Future Trends in Advanced Technology	45
LEVEL 2		
ELNC1220	Electrical Principles for Photonics	75
MATH1231	Mathematics II for Technology	60
MMFG1279	Manufacturing Technology for Photonics	45
PHTN1220	Optic/Optical Fibre Principles	90
PHYS1220	Kinematics & Dynamics	75
LEVEL 3		
CTEC1330	Data & Telecommunications	60
ELNC1320	Electronic Principles for Photonics	90
MATH1331	Mathematics III for Technology	45
PHTN1300	Principles of Light Sources and Lasers	75
PHTN1334	Fibre Optics Communication	75
GenEd	General Education Elective	45
LEVEL 4		
ELNC1430	Digital Technology	60
PHTN1400	Principles of Laser Systems	75
PHTN1431	Manufacturing Photonics Components	75
PHTN1432	Vacuum & Thin Film Coating Applications	60
GenEd	General Education Elective	45
MATH1431	Mathematics IV for Technology	45
LEVEL 5		
ENGL1430	Technical Communications	45
MATH1637	Statistics	45
PHTN1500	Advanced Laser Theory	45
PHTN1530	Advanced Optical Systems	75
PHTN1531	Opto-Electronic Devices	60
PHTN1533	Photonics Research Project I	30
PHYS1630	Heat Transfer	60
LEVEL 6		
ELEC1532	Industrial Controls - PLC	75
PHTN1630	Photonics Manufacturing Systems	75
PHTN1631	Imaging/Image Processing	60
PHTN1632	Laser/Matter Interaction	75
PHTN1633	Photonics Research Project II	45

Table 1 Photonics Technician and Technology Programs of Instruction

2.4 Bachelor of Applied Technology (Photonics)

The Bachelor of Applied Technology (Photonics) or BAT was launched in Fall 2004. The 4-year BAT program is designed to provide industry with photonic undergraduates who possess the theoretical background comparable to that of a university undergraduate science degree and also to provide an individual with hands-on technical skills comparable to that of a Technologist. The graduate of this program is industry ready, requiring minimal on-the-job training.

The curriculum of the BAT program is unique in that it is modeled after a top down approach to learning. As shown in Table 2, students of the BAT program are exposed to applications of photonics immediately in term one. Unlike a traditional university degree which begins with minimal exposure to the discipline of choice, instead focusing solely on the fundamentals, the BAT degree immerses the students in lab based activities exposing them to advanced applications and concepts immediately. Initially these concepts are treated from a perspective not requiring an understanding of the underlying principles. As the program progresses more of these principles behind the concepts are revealed until the student is left with a complete understanding of both fundamentals and advanced concept. The advantage of this model is that it engages the student into the material from day one. Attrition is often the result of students losing interest in the material, or failing to understand how the fundamentals being studied relate to the applications that may have drawn the student into the program in the first place.

The BAT program received a second intake of students in Fall 2005, but the intakes for Fall 2006 and 2007 have been suspended due to recruitment difficulties. Although the college's industry partners have expressed interest in the graduates of this program, the challenges of recruiting university level students to take a degree at a college has proven problematic. Science and technology teachers at the secondary school level have proven to be invaluable allies in correcting the misconception that a college BAT degree is somehow less valuable than a university Bachelor's degree.

LEVEL 1		
Crs. No.	Course Name	Hrs.
BATP9101	Occupational Health and Safety and Ethics	45
BATP9102	Optics and Waves	75
BATP9103	Trends in Photonics	45
BMAT9104	Calculus I	60
BPRO9105	Programming I	45
BSCI9106	General Chemistry	45
LEVEL 2		
BATP9201	Optics/Optical Fibre Principles	75
BELN9202	Electro-technology	75
BMAT9203	Calculus II	60
BPRO9204	Programming II	45
BSCI9205	Kinematics and Dynamics	60
LEVEL 3		
BATP9301	Fundamentals of Light Sources	75
BATP9302	Interfacing	60
BATP9303	Optics/Optical Fibre Devices	60
BELN9304	Semiconductors and Logic	60
BMAT9305	Linear Algebra	45
CPLN9061	Career Planning and Development	
	Liberal Studies Elective	45
LEVEL 4		
BATP9401	Laser Systems	75
BATP9402	Manufacturing Photonics Components	60
BATP9404	Telecommunications	60
BCOM9403	Technical Communications	45
BMAT9405	Differential Equations	45
BMAT9406	Statistics	45
LEVEL 5	**Co-op**	
COOP9402	Co-op Work Placement I	

LEVEL 6		
Course Name	Course Name	Hrs.
BATP9501	Advanced Optical Systems	75
BATP9502	Control Systems	60
BATP9503	Photonics Manufacturing Systems	75
BATP9504	Thin Film and Vacuum Systems	75
	Liberal Studies Elective	45
LEVEL 7	**Co-op**	
COOP	Co-op Work Placement II	
LEVEL 8		
BATP9601	Image/Signal Processing	60
BATP9602	Opto-Electronic Devices	75
BMAT9603	Advanced Calculus	45
BMGT9604	Business Principles	60
BSCI9605	Electro-Magnetic Theory	45
	Liberal Studies Elective	45
LEVEL 9	**Co-op**	
COOP	Co-op Work Placement III	
LEVEL 10		
BATP9701	Advanced Optical Theory	45
BATP9702	Photonics Research Project	60
BATP9703	Thermodynamics and Heat Transfer	45
BSCI9704	Materials Science	60
BSCI9705	Quantum Physics	45
	Liberal Studies Elective	45
LEVEL 11		
BATP9801	Advanced Research Project	60
BATP9802	Bio/Medical Photonics	60
BOPS9803	Operations Management	60
BSCI9804	Solid State Physics	45
	Liberal Studies Elective	45

Table 2 Bachelor of Applied Technology (Photonics) Program of Instruction

2.5 Advanced Lasers Graduate Certificate

The Advanced Lasers Graduate Certificate is a one year program providing an amalgam of courses running in the BAT and Technology programs. The program received approval from Niagara College to run its first intake for Fall 2007. This intake was later suspended as a result of low application numbers (public marketing for the program did not receive approval until February 2007). The college will be marketing for a Fall 2008 intake.

The Advanced Lasers program was designed to accomplish two tasks;

1. Provide skilled and theoretical laser training to those with a technical or engineering background
2. To economize the BAT (Photonics) program.

The program provides students with the expertise to work at an advanced operator or design level and is open to any student with a science or technology diploma and/or degree, including electronics, mechanical and electrical engineering technology graduates. The applied & practical skills acquired in this program are required for direct entry into industry which should be of particular interest to students of university physics programs which are classical in nature. The program provides hands-on experience in the areas of laser operation, maintenance, reprocessing and design. With the exception of business principles, every course in this program features a major laboratory component.

The Advanced Lasers program was originally designed to leverage off of preexisting courses from the BAT and Technology programs, using students of the Advanced Lasers program to help offset the effect of attrition of students. This was seen to provide improved economy of the BAT program and year 3 of the Technologists program, while at the same time providing a useful service to industry, and engineering professionals. Since the design phase of the program much has changed. The program has necessarily morphed into one that can be delivered independent of the other photonics programs. In order to recruit the additional students required to allow the Advanced Lasers program to run independently Niagara has created a partnership with Brock University.

An articulation agreement between the Brock University Bachelor of Science Honours Degree in Physics and the Niagara College Advanced Lasers Graduate Certificate program has been created. The Senate of Brock University has approved the establishment of a concentration in Applied Optics and Laser Technology within its current honours Bachelor of Science program. This agreement is designed to enable students to complete concurrently an honours degree in Physics from Brock University and a graduate certificate in Advanced Lasers from Niagara College. The current structure of the Advanced Lasers Graduate Certificate as accepted by both Niagara College and Brock is provided in Table 3.

LEVEL 1		
Crs. No.	**Course Name**	**Hrs.**
BATP9301	Fundamentals of Light Sources	75
BATP9303	Optics/Optical Fibre Devices	60
PHTN1530	Advanced Optical Systems	75
PHTN1531	Opto-Electronic Devices	60

LEVEL 2		
Crs. No.	**Course Name**	**Cr.**
BATP9401	Laser Systems	75
BMGT9604	Business Principles	60
MMFG9101	Laser Maintenance and Manufacturing Technology	60
PHTN1432	Vacuum and Thin Film Coating Applications	60
PHTN1632	Laser Matter Interaction	75

Table 3 Advanced Lasers Graduate Certificate Program of Instruction

2.6 Additional Academic Options

Niagara College currently offers additional academic options to students of the Photonics programs. Given the similarities in program curriculum between photonics and other technology programs, select Photonics graduates have been provided with a one year advanced standing in Niagara College's Electronics, and Electrical Technician programs. The completed dual diploma has proven to be extremely popular with employers looking for employees with a broad base of experience.

In partnership with the Hoseo University of Korea, Niagara College is piloting a hybrid English as a Second Language (ESL) and Photonics Technology program. This project will bring select students who have completed their second year in the Bachelor of Science at Hoseo University to Niagara College for eight weeks of training. The first six weeks provides traditional ESL training to be followed by two weeks of hands-on training to develop skills in the field of display technology. Niagara College expects to host the first 20 students of this program in July of 2007.

3. RECRUITMENT

The challenges and successes of recruiting for the photonics programs at Niagara College have been explored[1].

In a move to improve recruitment of students the Technology Division has hired an individual with a science background to work part time as a Program Liaison Officer. This individual is responsible for recruiting activities within the division, with special focus on the photonics program cluster. Internally the Program Liaison Officer organizes events, tours, and provides support to Niagara College's recruitment department. The most effective recruitment technique at Niagara College's disposal continues[1] to be on site tours of the lab facilities by high school students. New recruitment activities have included attendance at popular cultures events such as science fiction exhibitions. The success of recruiting at these events has been mixed, but has resulted in exposure of the program not just at the event, but also by television, print, and Internet media present at the event.

4. FACILITIES

The photonic facilities at Niagara College have previously been described in great detail[1]. Since that time numerous upgrades and improvements have been realized, the most notable as described below;

a. New laser machining lab:
    i. Laser Marker
    ii. Laser Welder
    iii. Laser (Micro)Machining Centre

b. New Class 4 laser lab
c. Dedicated research lab space
    i. 100W CO_2 laser
    ii. Pyrocam (10.6um laser profilometer)
    iii. Infrared camera system
d. Scanning Electron Microscope
e. Lesker 3 target sputtering thin-film deposition system
f. Two new aerospace grade laser projectors

Additional equipment to be donated to Niagara College, but as yet unrealized includes a computer controlled polisher capable of polishing high-end aspheric lens.

Improvements to facilities and equipment are primarily the result of excellent relations with industry. Employed graduates frequently donate equipment and materials to the college. This shows the good will of our partners, but also demonstrates industries realization that the college is training the next generation of photonic professionals. By training students with equipment donated by industry the college is providing industry with employees who require significantly less on the job training, saving time and money.

5. RESEARCH

The introduction of photonics curriculum at the college level occurred at approximately the same time that the province of Ontario began to encourage applied research at College institutions. Given Niagara College's unique collection of photonic facilities and faculty it has become involved in several applied research projects.

Current projects funded by the Ontario InnovationTrust;

a. Laser Applications in the Greenhouse Industry
b. Use of Photonic Technologies to Control Disease Spread in Greenhouse Production

Niagara College is in the process of submitting other proposals that would include research into the areas of display technology and laser induced breakdown spectroscopy.

The applied research projects are designed to help local industry and garner attention for the college and the program. Funded research has resulted in dedicated lab space and new equipment that can be used for both the intended research and as learning tools during scheduled classes. The most important aim of the projects is to involve students in collaborative relationships with industry. Past projects have resulted in employment opportunities for students who have worked with industry on these projects. The research crosses disciplines, and helps to demonstrate to students the importance of breadth of knowledge.

6. RECOMMENDATIONS

6.1 Co-Operative Learning

Providing Co-operative learning opportunities for BAT students was initially challenging. This was deemed to be primarily a result of industry's inexperience with a photonics undergraduate degree program, and as a secondary concern most members of industry are seeking eight month placements, where as the BAT program only offers 4 month placement opportunities. As of the end of March 2007, BAT co-op placements are progressing slowly although at an improved rate over the same time in 2006.

Co-ops have been an immensely successful and important component of other Technology programs at Niagara College. They provide on the job training, and industrial experience of the kind that is not reproducible in a class environment. It also provides employers the opportunity to try out students at little risk or cost to themselves and many times results in permanent full-time employment of the student upon graduation.

Co-operative learning is currently missing from the curriculum of the Photonics Technology program. Given the success of co-operative learning in other programs and consultation with members of industry, it is recommended that the Photonics Technology program be aligned with the other existing Technologist programs to include one four month co-op, and one eight month co-op.

6.2 Facilities

Optical lens and mirror manufacturers in Ontario have begun to employ graduates of the Photonics programs. Unfortunately the college facilities do not currently include any optical lens manufacturing or polishing equipment on which to train students. One industrial partner has made motions to provide Niagara College with a donation of a lens polisher, and proposed the loan of two others. This will still leave the college with a requirement for equipment for the generation and grinding of lenses and mirrors.

6.3 Articulations

Unofficial articulation agreements between Photonics, Electronics, and Electrical programs need to be formalized and expanded. This agreement will allow a student who has completed Photonics at the Technician or Technologist level direct entrance into year 2 of the Electronics or Electrical program. This agreement already exists in principle, and has been used by several students successfully. Formalizing the agreements will allow them to be used as recruitment tools, and hopefully make the Photonics program more appealing to those with interests outside of the Photonics discipline. Other possible articulations into Computer Technology and from Mechanical Technology are being considered.

7. SUMMARY

Photonics curriculum at the college level is still a relatively new introduction and is in a continual state of self-improvement. With the assistance of industry partners, graduates, and the students currently in the system, Niagara College is endeavouring to create curriculum that will meet the needs of all parties. Given the continued demand for photonic professionals that has been communicated to the college by industry it is assured that the college photonic programs will enjoy long life in one form or another. As the general populace better understands the term "photonics", and photonic professionals become more ingrained within the fabric of local industry, recruiting pressures will begin to ease. With continual interest by partners to collaborate on applied photonics research, Niagara College is assured exposure not only locally, but internationally. Continual research and donations by members of industry also ensure that students will be training in modern facilities for many years to come.

ACKNOWLEDGEMENTS

The author(s) wish to acknowledge the continued support of our industry collaborators, college staff, our partners at Brock and Hoseo universities and the graduates and students of the Niagara College Photonic programs.

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Post-secondary Photonics Lab: Simplified Portrait Holography

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Teaching photonics is greatly enlivened by demonstrations of practical holography. One of the more impressive varieties of display holography is the portrait hologram. However, the large number of complicated, time-consuming steps required to produce traditional portrait holograms makes it an unlikely process for demonstration and practice in a classroom laboratory environment. This paper presents a process for producing simple portrait holograms using the Denisyuk single-beam (Deep Hologram) method and a single stereoptic pair of images, which can be performed, start-to-finish, in a standard 3-hour lab period. Possibilities for expansion of the technique to larger numbers of images, potentially approaching the quality of multiple-image, master hologram-transfer hologram traditional portrait holography, as well as strategies for multiple and single beam illumination are discussed.

1. Introduction

A post-secondary degree program in Photonics will contain courses dealing with optics and lasers. A natural approach which combines these subjects is found in holography, usually implemented in a one-period laboratory. At TRCC (Three Rivers Community College, Norwich, CT), holography is introduced through two hands-on experiments in which a single beam Denisyuk hologram and a transmission hologram are produced. This approach is not limited to colleges, since the major producers of holography kits provide fixtures and/or directions to produce Denisyuk holograms as a first step. The addition of laser pointers to the battery of available coherent sources has decreased the cost of entry, to the point where many students entering college may have already completed a number of successful Denisyuk holograms and may be ready for something more advanced.[1,2,3]

One of the more impressive varieties of holography is the portrait hologram or holographic stereogram. In the canonical Benton approach[4], a series of black-and-white images are shot using standard photographic techniques, but in a sequence of positions along a line tangent to a circle whose radius is the nearest approach to the subject. The film is processed directly to transparencies and multiplexed into a hologram in stripes using one of various transmission hologram processes, so that each successive image in the sequence is encoded into a subsequent stripe. Care must be taken in photography to avoid keystoning, and, when striping the transmission hologram, to ensure that the stripes do not overlap and that spaces do not form between them. Mechanisms to ensure this have been developed and reported in the literature which range from simple to expensive, automated complexity[5]. Once processed, this hologram is used as a master in a transfer to a reflection hologram. This last step distributes each point in the master hologram across every point in the reflection hologram, eliminating the appearance of stripes. Because of the angle of view which is associated with each stripe, the resulting reflection hologram delivers a stereoptic pair of images to each eye, appropriately registered and located to give a sense of three-dimensionality. These image pairs are essentially identical to paired images used in the 19th century stereoscope (still extent today in the commercial "View Master"). However, when a sufficiently large number of views (varying in the literature from five or six to hundreds), each giving a view from a slightly different angle, are provided, the viewer gets a sense of occlusion, which is normally missing from stereoscopes.

Unfortunately, the optical setups required for making portrait stereograms and the time required for the three recording and three processing steps generally precludes their use in post-secondary class labs. In addition, the set-up for striping successive images into the master hologram requires accuracy and repeatability, in order to line the edges of each strip up exactly without overlapping or leaking light between the edges of the stripes.

This paper describes a process for creating a variety of single-beam hologram which makes use of the angular selectivity of single-beam (Denisyuk) volume holograms to register a pair of two- dimensional images forming a stereoptic pair, overlapping, in the emulsion. The result admits reconstruction of both images using two sources of reconstruction illumination, with each of the images forming on one side of the normal to the emulsion center. Additionally, suggestions are given towards establishing a single-period laboratory exercise in which the principles of three-dimensional perception, volume holograms, and angular selectivity are introduced. Finally, some discussions of the shortcomings of current understanding of volume holograms with regards to successful geometries is given, and a wish list of future topics of exploration which might grow from the subject are introduced.

2. The Denisyuk Hologram

An in-depth description of the Denisyuk hologram (as a reflection, deep or volume hologram) is beyond the scope of this paper, as it is already very well covered in the literature.[5,6,7,8] A simplistic overview will be provided which highlights the characteristics of volume holograms (of which type the Denisyuk is most elegant), emphasizing angular selectivity.

The single-beam volume hologram is a simple affair, illustrated in Figure 1. In recording (1a), a glass plate or a piece of film, constrained to avoid motion during exposure, is placed directly in front of an object and a suitably spatially-filtered, spread laser beam is shined through the emulsion to illuminate the object beyond. The illumination beam forms the reference beam as it passes through the emulsion and the object beam as it returns (Figure 1a). This creates standing waves in the emulsion, angled and spaced according to the angle formed between the reference and object beams. The bisector of this angle (**AB**) is, according to Gabor and Strokes, the angle bisector between two face-edges of a cone of greatest reconstruction, one of which face-edges forms along the axis of the reference beam. This infers that a certain amount of control is possible over the location of brightest area of reconstruction if the conditions of recording and reconstruction are controlled.

Unfortunately, simple calculations to predict the location of these areas of visibility from the geometries used in recording and reconstruction are not to be found, and this is not surprising, since most of the equations used to explain the subject are extremely complicated and are based on varying or difficult-to-discern parameters (such as emulsion thickness and wavelength). In addition, for an object of more complexity than a single point or short line segment, equations quickly climb into advanced calculus. Perhaps the best approach is to follow Gabor and Strokes' conclusions: the greatest brightness of reconstruction can be expected in a cone as described above, with two axially-concentric cones (Fig1b, **e**), which enclose the cone of greatest brightness (**C**) and define the edges of extinction. If the problem is reduced, for instance, to the plane perpendicular to the plate's horizontal centerline and intersecting the viewer's eyes, it should be possible by experiment to find a geometry for recording an image which, when reconstructed by a single white-light illumination source, produces one image that is visible on the opposite side of plate normal(**N**). Using two such images, recorded and illuminated from opposing sides, will produce one image visible to each eye without the other eye's view being polluted by the wrong image. Further constraint, namely, reducing the recorded images (**O**) to 2-dimensional images printed on paper, is expected to reduce experimental complexity further, although in fact this may further complicate the math.

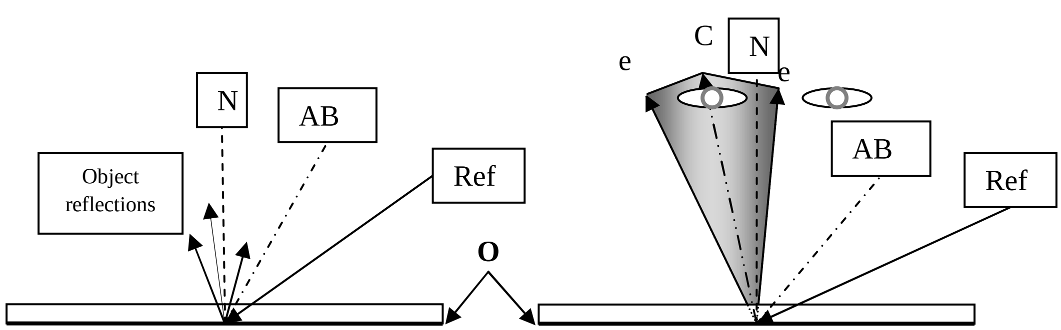

Figure 1. Schematic showing Image **O** pressed against the emulsion side of the plate, illustrating recording and reconstruction of one image.

Experimentation proved to be the only way to determine a working geometry.

3. Experiments to Establish a Geometry for the Denisyuk Stereogram

The first step was to prove that a plane image pressed against the emulsion of a glass plate (Slavitch PFG-03M) could produce a reconstructable image, viewable in white-light. Further, these tests looked for a clear extinction point where the image would cease to be viewed, based on angle to plate-center normal in the x axis. The first image was made of a slide rule, because the object was of high contrast, had fine markings, and was solid. The results were very satisfactory.

Subsequent tests used images printed on various grades of printer paper by a laser printer. The early results were disappointing, until the "bad spots" were recognized as interferometry. Using a second glass plate to back the image paper and butterfly clips to hold the plates together helped to stabilize the paper with the image. Additionally, long (10 minute) rest periods after placing the plate on the table allowed the plates to equalize in temperature eliminating movement caused by the minute changes in size of the glass. This eliminated most signs of interference.

Finally, an experiment using paper images which indicated the angle of recording illumination to the table (later translated to angle-to-normal) was made, processed, and tested with illumination at various angles and from various viewing angles.

The plate marked for an angle of +60º to plate normal (i.e., with the illumination source to the right of the plate and at the same 60º angle that was used for recording) was found to produce a left-side-of-normal image which abruptly disappeared about 13º to the right of the normal when a single-point viewer (one eye) was brought across the plate from the left. This plate was rotated around the normal by 180º, and when illuminated with the same reconstruction beam angle, but also rotated around normal by 180º, produced an image to the right of center, which also extinguished for a single-point of observation moved from right to left. When viewed from the other side of plate normal, in both cases, the image did not reconstruct. In reconstruction, the reconstruction area (between the extinction cones) can be shifted away from the angle bisector by increasing the angle-to-normal of the reconstruction beam. Placing the illumination source at approximately 70º to plate normal shifted the extinction point to within 2-3º of plate normal.

This indicated that, for conditions in the author's home lab, using Slavitch PFG-03M plates and JD4 processing chemicals, a proper Denisyuk stereogram could be recorded using 60º as the illumination angle to normal, illuminating from the right side to record the left image and the left side to record the right image, and the result, when viewed straight down the plate centerline normal and illuminated from near to 70º from both sides should produce a viewable stereoptic pair with minimal crosstalk between the two images.

4. Using Denisyuk Portrait Stereograms for a Post-Secondary Laboratory Experiment

The exact geometry to be used must be determined beforehand, since the angle of illumination given in this paper was specific to the laser, emulsion and chemistry used in the author’s lab. This might be an excellent extra-credit lab for an advanced student or student group.

For a completely new installation using different emulsions (or film instead of plates) or different chemistry, a recommended approach is to record a set of Denisyuk holograms with the reference beam at varying angles of illumination from normal. The angles could be established by a mirror on a pivoting, lockable extension, which can be rotated around the hologram to redirect light from a fixed laser to the plate. In such a case, a horizontal slit placed just after the spatial filter can be used to make a line of light on a piece of vertical cardstock aligned along the x axis of the plate-position midpoint, which can be marked beforehand with the angles intended. Likewise, with a laser pointer, it is feasible to mount the pointer on the pivoting arm itself. In this case, the laser can be fixed to the arm and the arm's angle-to-normal (with a slight adjustment for elevation of the pivot point) can be used directly. The author is blessed with a laser diode pigtailed to single-mode fiber at the diode's wavelength (658.6nm), and has mounted the fiber connector to his pivoting rod, using a small, clean, negative lens to increase the spread of the beam over the NA of the fiber. With only the weight of the connector and fiber on the rod itself, very little is required to lock illumination in place.

Once a desirable angle is determined, a Denisyuk stereogram can be made using a geometric stereoptic pair (such as a wire-frame cube) to record right and left images. This can be used to determine if the resulting right and left images have sufficient brightness at the position of the viewer’s eyes, and ensure that image overlap is acceptable. It is not necessary that the image extinction edges are precisely aligned, it is sufficient that balanced views of each image are presented to the appropriate eye without crosstalk.

The following is an example of a possible lab scenario. It should be mentioned that, even with the simplifications, this lab can be lengthy. It is desirable to distribute the lab sheets before the lab starts and encourage the students to have familiarized themselves with the particulars before beginning the lab period. However, since many of the steps can be performed in parallel, or *en masse* (such as development and bleaching), it is quite possible for each member of a lab group to make their own Denisyuk Stereogram within the given lab period. The laboratory manual produced by Project PHOTON2 (NSF/ATE #0302528) included a procedure to produce a Denisyuk hologram using materials included in the PHOTON2 lab kit. The procedure that follows is an adaptation of the PHOTON2 experiment, which assumes students have already completed the basic Denisyuk hologram experiment.

<<Beginning of example lab>>

Denisyuk ("single-beam") Portrait Stereogram

Safety Notes
Do not look directly into the laser cavity, or at any reflections of the laser caused by shiny surfaces. In this experiment, the beam will be aimed at the optical table: so spread the beam first, then angle it towards the table, to avoid powerful specular reflections! Limit personnel in the lab to the minimum number required to perform the lab.

Preliminary notes
Have all developing chemicals mixed and arranged in the order that they will be used before beginning. Be sure to follow directions on the packages. NOTE: Bleach, rinse water and photo-flo solution do not degrade, so they can be mixed well beforehand and left standing in covered trays. Part A and B can be made beforehand if they are refrigerated, but should be mixed when the lab begins.

Check alignment of the optical system before exposure - then check it again.

The safelight for red sensitive holography film is green. A green nightlight, placed away from the film developing process, will work well.

During exposure, the entire optical set-up must remain vibration free. Ensure the set-up has had plenty of time to settle and equalize to room temperature from handling. Do not move around, make noise, or touch the table during exposure.

Be sure to dispose of spent chemicals safely, following all state and local regulations.

Objective

- To create and view a Denisyuk (single-beam) holographic stereogram.

Equipment and supplies

- Developing chemicals, mixed per instructions on the package

- Trays or bowls for developing chemicals
- Source of running water (or large pail of tap water)
- Holography emulsion plates
- Breadboard with magnets to hold holography emulsion plates
- Masking tape (black is preferable)
- Pointer laser without lens, or fiber-delivery laser system with spreading negative lens, 630-660nm (or a HeNe laser beam which is spread by a spatial filter, negative lens or reflection from a concave mirror)
- Laser mount or connector adapter with appropriate posts, swivels and post holders
- Digital camera
- Computer with digital camera interface (or card reader) and appropriate software (the Gimp or Photoshop)
- Rare-earth magnets to secure the edges of the plate during recording (voice-coil magnets from an old hard disk drive are ideal! Cover them with rubber tape to reduce the stress on the plate edges.)
- Opaque cardboard for shutter and light-stops
- Matte black spray-paint
- Two illumination sources, White light point sources with adjustable supports

Theoretical background

Photography captures a 2-dimensional image of a scene, focused through a lens and aperture to place the image plane on the film or sensor. Grey-scale pictures (black and white) with acceptable representation of skin tones are easily produced by weighting the film or sensor's response to different colors or by computer post-processing. If two images of a scene are captured by photography from slightly-different locations (similar to the position of a human's eyes) the resulting pictures can be superimposed by presenting the appropriate picture to each eye. These images are called a *stereoptic pair*. The mind of the viewer will knit the two images into one, perceiving three-dimensionality from slight offsets in recognizably identical objects between the two pictures. This three-dimensional presentation lacks two important features of depth-vision, occlusion (further things disappearing behind nearer things as you move your head) and accommodation (focus-changing which provides another clue to depth), and yet it has been a popular method of providing 3D views for over a century. (The primary steroptic viewer, the traditional Stereoscope was designed by author Oliver Wendell Holmes in the late 19th century!)

Holography captures the entire scene in the emulsion, complete with dimensionality, by interference between the reflected object light and the mutually-coherent reference beam. However, the monochromatic characteristic of laser light (which cannot capture skin tones), coupled with its capacity for large amounts of energy, make it ill-suited for taking holograms of living subjects. Further, the small movements of air currents or relaxing textiles make many objects unsuitable for hologram subjects.

The solution to the problems of direct-laser-illumination of portrait subjects has been solved by holographic stereograms. This process uses multiple pictures of the subject, each taken from a slightly different position, and encodes them into a hologram in stripes. Each stripe acts like a vertical window into the subject space, presenting a slightly different perspective. Taken together, these images provide a sense of smoothness (like the still frames of a movie, when viewed above the “flicker rate”), allowing a sense of perspective, parallax, occlusion and, because each stripe reconstructs the object wave, requiring the eye to focus differently to resolve objects at different virtual depths, accommodation. The process is also lengthy, requiring special photographic processing, complex optical setups, and recording of two holograms.

The Denisyuk Stereogram which you will produce in today’s lab is a simplification of this process, but retains the significant features of a holographic stereogram: two images, taken with a digital camera, will be encoded into a Denisyuk hologram so that each image reconstructs for one eye of the observer.

In the **Single-Beam Reflection Hologram** lab, you have already created a Denisyuk (single-beam) hologram. This type of hologram is viewable in white light, but you may have noticed that there are angles of illumination which do not recreate the hologram image. Likewise, you may have noticed that there are angles of viewing, from which the image is not visible, and that the change from bright reconstruction to no reconstruction at all is quite abrupt. This is the result of angular selectivity, which is a characteristic of reflection holograms. By changing the recording illumination angle, multiple images can be stored in one hologram and selectively reconstructed by changing the angle of the reconstruction reference.

Angular selectivity in reflection holograms comes from the similarity of the fringes which form in the emulsion to volume gratings. In general, the angle formed between the object beam (extended through the emulsion) and the reference beam establishes an angle bisector. When the image is reconstructed, the brightest image will form an angle with the illumination reference beam which has the same bisector. Additionally, the image of reconstruction is brightest here, but falls off on either side.

If the illumination for recording is angled approximately 60º from plate normal, for an object which comprises a two-dimensional image pressed against the emulsion of a PG-03M holographic plate (Slavitch), the resulting image (with a white-light illumination source near 80º to normal) will reconstruct near the opposite side of the plate normal. This is shown in figure L-1.

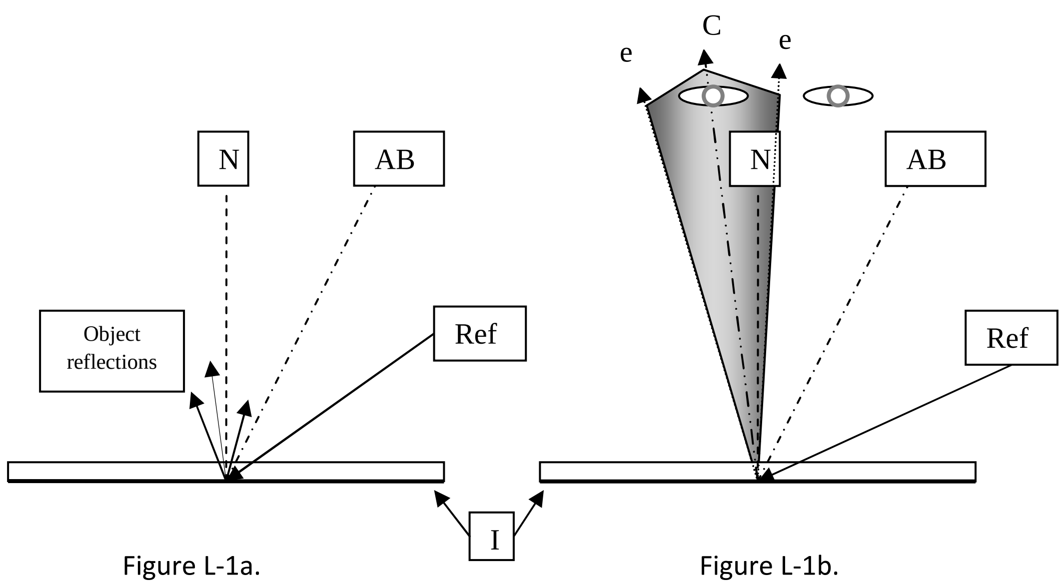

Figure L-1. In recording, the reference illumination **Ref** passes through the plate and emulsion, strikes the image **I** and returns almost immediately. Because of the close proximity of the image to the emulsion, the predominant reflection acts near-to-parallel to the normal **N**. The resulting interference pattern, a complex volume grating, develops an encoded angle bisector (roughly 60º in this case). When the hologram is illuminated (at a slightly different reference angle) by white light, the reconstruction forms in a cone around the angle bisector (only the left cross-section of which is shown, for clarity). The bounding curve of this cone **C** identifies points of maximum reconstruction brightness, with two concentric cones **e** marking the boundaries on either side where extinction takes place. By increasing the angle of the reconstruction illumination, the cone of maximum brightness is skewed in the opposite direction from normal, to the left side. The left eye in Fig. L-1b sees the image, while the right eye does not.

The two images which will each be encoded into the single holographic plate will be recorded with reference illumination from opposing sides of the plate normal, so that their reconstruction cones will form on either side of the plate normal. Since the reconstruction forms to the left for right-side recording illumination, and to the right for left-side illumination when illuminated from one side with white light, we will be using the geometry shown in figure L-2. For simplicity, inverting the second image and rotating the plate 180º about its Normal will allow using a fixed recording reference beam.

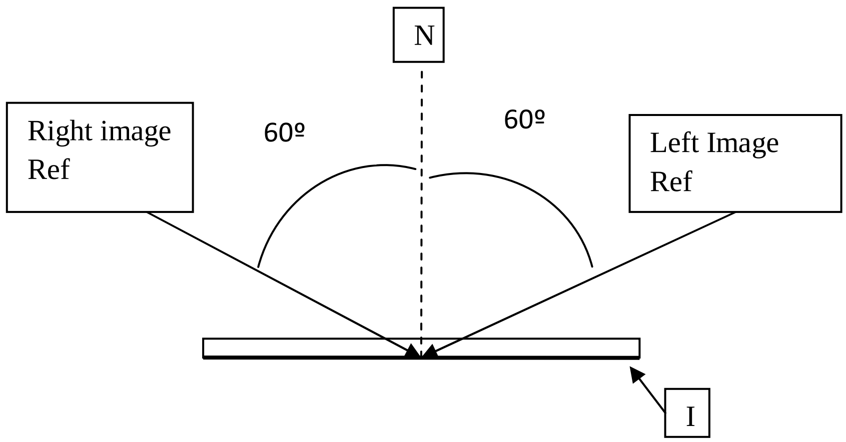

Figure L-2. Each image is recorded with a reference beam coming from the opposite side of plate normal. In practice, rotating the plate and second image allows using a fixed reference illumination. Reference rays represent spread, filtered beams.

This geometry will yield a hologram in which two images are recorded. The two images will be reconstructed with a pair of illumination beams from opposite sides at whatever angle provides the best image visibility for each of the viewer's eyes, as in figure L-3.

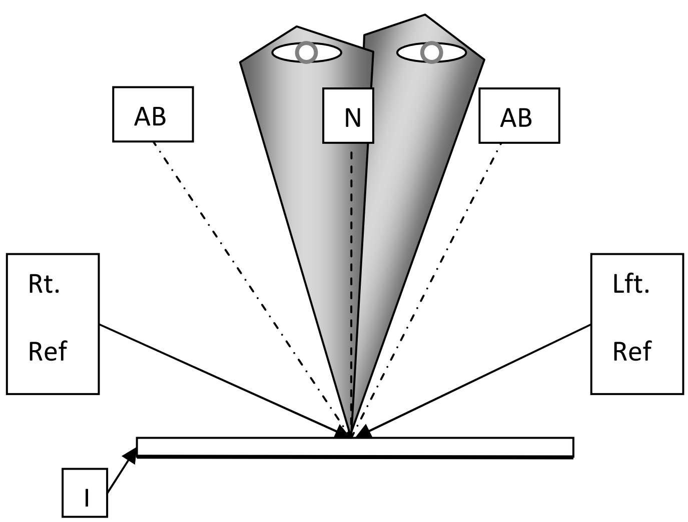

Figure L-3. On reconstruction, the visibility spaces formed will superimpose the proper image on each of the viewer's eyes, the right image for the right eye, and the left image for the left eye. Angling the reconstruction illumination beams further from plate normal deflects the reconstruction away from the angle bisector AB, shifting the extinction point near to the plate normal, and making the left image reconstruct for the left eye but not the right eye, and vice versa.

Procedure

NOTE: This procedure assumes the use of PFG-03M film plates (Slavitch) and JD-4 developer, available from Integraf (http://holokits.com/). If you use different film or developer, consult the manufacturer's instructions.

Set-up

1. Pour enough developer (equal parts A and B) into one developing tray to cover a film plate (around 2 cm deep.) Pour a similar amount of bleach into a second tray. Fill a third tray with water only and add a few drops of Photo-flo. Have a source of running water nearby. (If no running water is available, a large bucket of clean tap water will do.)
2. Arrange the counter so the film plates and developing trays are readily accessible. Clear away any other objects. Remember, you will be developing film in the dark!
3. Set up the laser, any required lenses, mirrors, holders, etc. to provide illumination of a spot on the table slightly larger than the plates. The incoming angle of this spread beam should be 60º to the table normal (i.e., 30º from the table surface). (Placing the illumination 8" above the table and directing it down at a point 14" away from the deflection point will provide an angle of 30º to the table.)
4. Choose a suitable subject: lab partners make good subjects! Take two pictures of them with the digital camera using the "shoot-lean-shoot" procedure. Ensure the camera is level and moves horizontally between the two images by about 4”.
5. Transfer the images to the computer, convert them to grey scale and size them to print out at the dimensions of the plate. Place the images side-by-side for printing and test them by looking past the images (through the screen) until the images superimpose. (If this is difficult, it is possible to arrange the images so the right-eye image is on the left: then cross your eyes to overlap the images.) When the images are superimposed and your eyes grow accustom to them, they should fall into focus and you will see the three-dimensionality.
6. Print the images and cut them out. Trim them to exactly the dimensions of the plates being used. Rotate the right-eye image 180º and tape it to the table so that it is centered in the spot. The right side of the image should be toward the diversion point (or laser if direct illumination is used) and perpendicular to a line between the center of the spot and the deflection point. Tape all four sides so that the paper lies flat. Then, tape the other image over the first (the top of the second image should be in the same direction as the bottom of the first) and tape only one side to the table.
7. Block the beam with the shutter, turn off all lights but the safelight, and close doors and light barriers.
8. Take a plate from the darkbox, and close the box completely. Determine which side of the plate has the emulsion (the emulsion is sticky when touched with a moistened finger.)
9. Place the plate over the upper image so that it aligns with the image edges, with the emulsion side down. Place the magnets so that they grip the edges of the plate from above and compress the plate onto the images.
10. Wait for at least 10 minutes for the plate to equalize temperature from handling. Lift the shutter and hold it so it still blocks the beam, without touching any part of the table or optical set-up for at least 15 seconds to allow the table to settle from any vibrations.
11. Lift the shutter completely to expose the plate for about 15 seconds.
12. Replace the shutter.
13. Remove the magnets and lift the plate. Rotate the plate 180º, and remove the top image, tape-and-all. Place the plate on the lower image and align the edges. Replace the magnets so that the image is compressed under the emulsion side of the plate.
14. Let the table settle and the plate equalize temperature for 10 minutes.
15. Lift the shutter, and as before, continue to block the beam for at least 15 seconds.
16. Lift the shutter completely out of the way and expose the plate for 15 seconds.
17. Replace the shutter.

Development:

1. Put a plastic glove on the hand you will use for developing the plate.
2. Develop for 1 minute in the A+B developer mix. Hold the plates at the edges and agitate by shaking back and forth with the emulsion completely submerged. Rotate the plate from time to time to expose the edges that were covered by your fingers.
3. Rinse for 1 minute.
4. Bleach for at least 15 seconds after the plate is clear in the safelight.
5. Rinse again, then dip in photo-flo for 5 seconds.
6. Air dry the emulsion. The holograms will not be visible until the plate is entirely dry. The impatient can employ a hair dryer, but be careful not to hold it too close.
7. When the emulsion is completely dry, spray-paint the emulsion side with black, matte paint. Although this coating is not absolutely necessary, it will vastly improve the results.

Viewing:

Use two matched point sources of light (a light bulb will work at sufficient distance) placed at about 70-75º from plate normal on either side of the plate. Viewer position should be with the plate center directly in front of the viewer. Distance from the plate may be dependent on the viewer. Test the two images by closing one eye at a time. There should be an image visible for each eye, without two images appearing to one eye. Adjust the location of the light sources for the best image for each eye which doesn't produce an image for the other eye, turning on one source at a time. Once this viewing point is found, turning on both sources and opening both eyes should reveal a 3-dimensional image!

Conclusion

Describe the differences between the Denisyuk stereoscopic hologram and a "real" hologram. What is missing? Did your two images register properly and superimpose with a minimum of viewer strain? Was the color of each image identical? What might have caused a difference? Can you think of ways to improve this process?

The portrait holograms in the hall display and those which we viewed on our visit to the MIT Holography Museum are made differently from the Denisyuk stereogram. Where our Stereogram has only two images encoded into it, the traditional portrait hologram contains many views. Each of these images is "striped" into a transmission hologram, and the resulting multiplex transmission hologram is transferred to a reflection hologram to create the white-light viewable hologram you saw. What would be necessary to be able to store more images into a Denisyuk Stereogram?

<<End of example laboratory>>

5. The Future

The Denisyuk Stereogram process currently can reliably produce a dual-image stereogram. Further work is necessary to discern a simple geometry, which can be expressed in understandable math, which will predict the width between the extinction cones, allowing control over how many images could be multiplexed into a single Denisyuk hologram. Additional simplified calculations that will predict the required reference beam angle and allowable deviation from spherical or parallel wavefronts required to produce a visible region with desired extinction edges in three dimensions are much to be desired. The more images that can be stored in a holographic stereogram, the more smooth the transitions between views, and the more 'natural' the appearance of the resulting 3D image.

Multiple-beam illumination is required for this kind of Denisyuk stereogram. A single-illumination approach is desirable. None-the-less, there are applications where multiple fixed, selectable illumination sources working on one Denisyuk stereogram with a different stereoptic pair encoded to each angle of illumination might be interesting. One such possibility would be super-imposed images, selected by the presence of illumination from specific angles, causing (for instance) a bottle to appear and disappear in a subject's hand. Other combinations of stereoptic pairs, singly or in combination, might be possible.

6. Acknowledgements

The author would like to acknowledge the help he has received from many people, including Dr. Tung Jeong and Mark Kahan, who suggested and provided papers which had significant impact on the development of the theoretical background for this project, Denis Leonard of IPG, who provided a red pointer-laser which was used as the laser illumination for all experiments, my wife Deborah Brohinsky, for proofreading and continuity (and the patience of a saint) and of course, my advisor, Judy Donnelly, without whose encouragement this process would never have been developed.

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Using a Mach-Zehnder interferometer to measure the phase retardations of wave plates

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Abstract: A wave plate is a commonly used optical element in optical experiments. In this report, we have achieved measuring the phase retardations of a half-wave plate and a quarter-wave plate using a Mach-Zehnder interferometer. Besides, when we rotate the half-wave plate's c-axis form the vertical to the horizontal directions, or vice versa, the phase retardations of the two orthogonally polarized beams are observed to be exchanged between 180° and -180°. In addition, we also predict the expected results by the Jones calculus theory in order to check the experimental results. This system can be applied to explore intuitively the birefringence characteristics of anisotropic materials in an optics teaching laboratory.

OCIS codes: (120.3180) Interferometry; (120.5050) Phase measurement; (260.1440) Birefringence

1. Introduction

A wave plate is a commonly used optical element in optical experiments. The phase retardation of a wave plate is an important value that influences the measurement results significantly. In this report, an interferometric method is presented to measure the phase retardation of a wave plate intuitively. We achieve measuring the phase retardations of a half-wave plate and a quarter-wave plate using a Mach-Zehnder interferometer. When we rotate the half-wave plate's c-axis form the vertical to the horizontal directions, or vice versa, the phase retardations of the two orthogonally polarized beams are observed to be exchanged between 180° and -180°. In addition, we also evaluate the results in theory by Jones calculus in order to check the experimental results.

2. Experimental Setup and Principle of Measurement

The schematic diagram and photograph of the experimental setup are shown in Fig. 1. The output light of a He-Ne laser is linearly polarized with an angle of 45° with respect to the horizontal direction, and is of wavelength at 632.8 nm. The laser beam passes through a beam splitter and is divided into two parts. The reflected light passes through the free space and the transmitted light passes through a test wave plate with c-axis in the x or y direction, and a mirror mounted on a piezoelectric transducer (PZT) which is driven by a triangle-wave alternating voltage of low frequency. In this way the phase of the transmitted light could be modulated linearly. Both of the reflected light and the transmitted light are incident on the second beam splitter and interfere with each other. Then the interfering light is divided into two orthogonally polarized parts by a polarizing beam splitter. The plane-polarized transmitted light passes through an objective lens and arrives at a photodetector. The surface-polarized reflected light passes through another objective lens and then is measured by another photodetector. The two sinusoidally oscillating optical intensities are recorded by an oscilloscope, which reveals the phase retardation produced by the test wave plate.

The theoretical analysis of the principle of measurement is derived as follows. At first, the He-Ne laser beam passes through a beam splitter and is divided into two parts. The electric field of the transmitted beam passing through the test wave plate and the mirror mounted on a PZT is expressed by

$$\vec{E}_w = A'_x \exp[j\beta_x L + j\beta_0(z_0 - L + a\times t)]\,\hat{x} + A'_y \exp[j\beta_y L + j\beta_0(z_0 - L + a\times t)]\,\hat{y} \qquad (1)$$

The β_x and β_y are the propagation constants of the two orthogonally polarized modes in the principal axes of the wave plate. The β_0 is the propagation constant of light in free space. The $\hat{x}$ and $\hat{y}$ are the unit vectors along the two birefringent principal axes. The z_0 is the total distance of the optical path. The L is the thickness of the test wave plate. The coefficient a is the varying rate of the optical path induced by the linear displacement of the vibrating PZT. The electric field of another beam passing through the free-space optical path is

$$\vec{E}_f = A_x \exp[j\beta_0 \times z_0]\,\hat{x} + A_y \exp[j\beta_0 \times z_0]\,\hat{y} \tag{2}$$

Finally, the two optical beams recombine in the second beam splitter and interfere with each other component at the reflection or the transmission ports. One of the two interfering beams will be divided into the plane-polarized and the surface-polarized beams by a polarizing beam splitter, with optical intensities

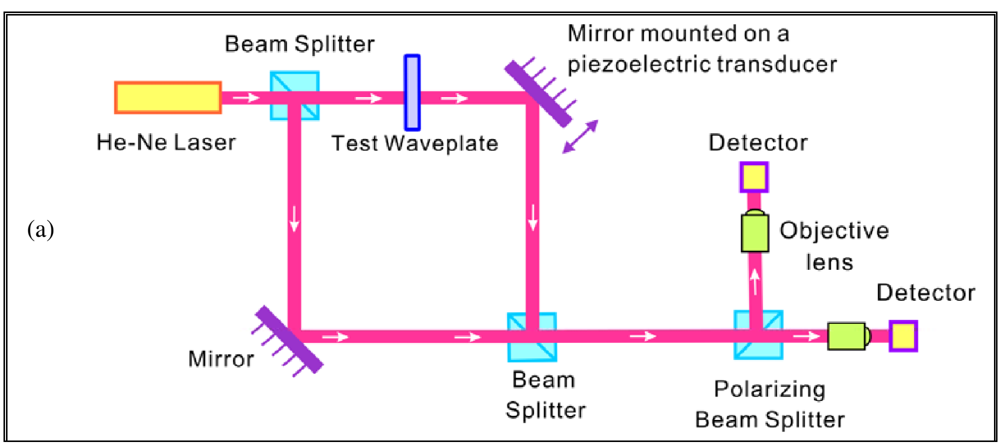
$$\begin{aligned} I_x(t) &= \left|A_x \exp[j\beta_0 \times z_0] + A'_x \exp[j\beta_x L + j\beta_0 (z_0 - L + a\times t)]\right|^2 \\ &= \left|A_x\right|^2 + \left|A'_x\right|^2 + 2A_x A'_x \times \cos[\beta_0 \times z_0 - \beta_x L - \beta_0 (z_0 - L + a\times t)] \\ &= \left|A_x\right|^2 + \left|A'_x\right|^2 + 2A_x A'_x \times \cos[(\beta_0 - \beta_x)L - \beta_0 \times a \times t] \end{aligned} \tag{3}$$

$$\begin{aligned} I_y(t) &= \left|A_y \exp[j\beta_0 \times z_0] + A'_y \exp[j\beta_y L + j\beta_0 (z_0 - L + a\times t)]\right|^2 \\ &= \left|A_y\right|^2 + \left|A'_y\right|^2 + 2A_y A'_y \times \cos[\beta_0 \times z_0 - \beta_y L - \beta_0 (z_0 - L + a\times t)] \\ &= \left|A_y\right|^2 + \left|A'_y\right|^2 + 2A_y A'_y \times \cos[(\beta_0 - \beta_y)L - \beta_0 \times a \times t] \end{aligned} \tag{4}$$

Thus, the phase delay between the two sinusoidally oscillating optical intensities $I_x(t)$ and $I_y(t)$, which is induced by the optical path vibration due to the PZT driving, is given by

$$\phi = (\beta_0 - \beta_x)L - (\beta_0 - \beta_y)L = (\beta_y - \beta_x)L \tag{5}$$

As a consequence, the phase delay ϕ between $I_x(t)$ and $I_y(t)$ happens to equal the phase retardation of the two orthogonally polarized fields produced by the birefringent wave plate, which is to be determined. As long as the magnitude of the PZT driving voltage is large enough to make $I_x(t)$ and $I_y(t)$ oscillate by a phase change more than 2π in the time of half a period of the PZT alternating signals, we can easily measure the phase delay between the two sinusoidally oscillating scan traces on the oscilloscope, which represent the signals from the two photodetectors.



(b) 

Fig. 1. The (a) schematic diagram and (b) photograph of the experimental setup.

3. Measurement of the phase retardations of various wave plates

Figure 2 shows the measured results of the two sinusoidally oscillating optical intensities on the oscilloscope. The phase retardation of the two orthogonally polarized interfering beams is 0°, when there is no any wave plate placed in the set up. The phase retardation becomes 90° when a quarter-wave plate is inserted, and the phase retardation becomes 180° when a half-wave plate is tested. Hence we have achieved measuring the phase retardations of wave plates using a Mach-Zehnder interferometer in a more intuitive way.

(a) (b) (c)

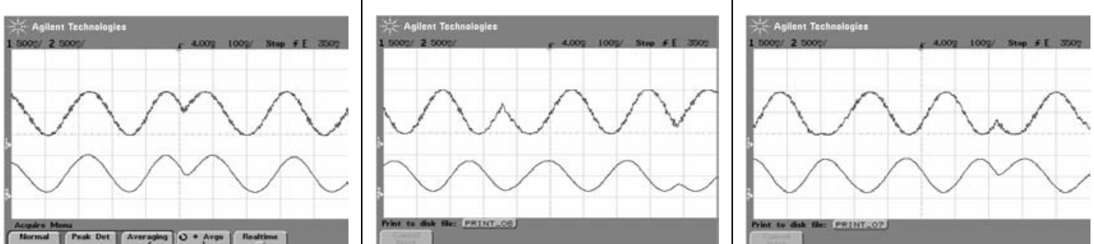
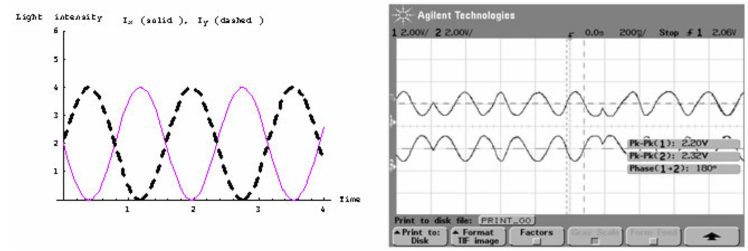


Fig. 2. The oscilloscope scan traces for the two orthogonally polarized interfering beams. (a) Without any wave plates, the phase retardation is 0°. (b) With a quarter-wave plate, the phase retardation is 90°. (c) With a half-wave plate, the phase retardation is 180°.

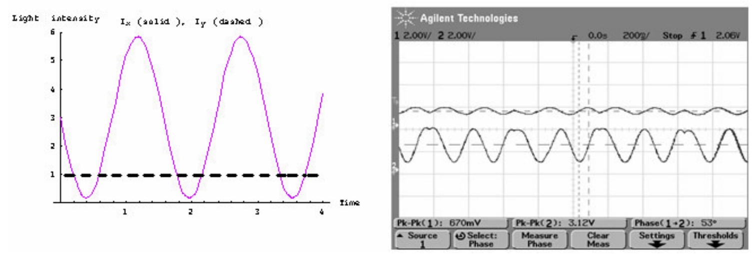
4. Measurement of the phase retardations of a rotated half-wave plate

Figure 3 shows the theoretical and experimental results of the phase retardation of the two orthogonally polarized beams when we rotate the half-wave plate by an angle of 22.5° successively. We can see that the phase retardations of the two orthogonally polarized beams are exchanged between 180° and -180° when we rotate the half-wave plate’s c-axis form the vertical to the horizontal directions, or vice versa. The experimental results agree quite well with the theoretical analysis performed by the MATHEMATICA software, as shown in the Appendixes.

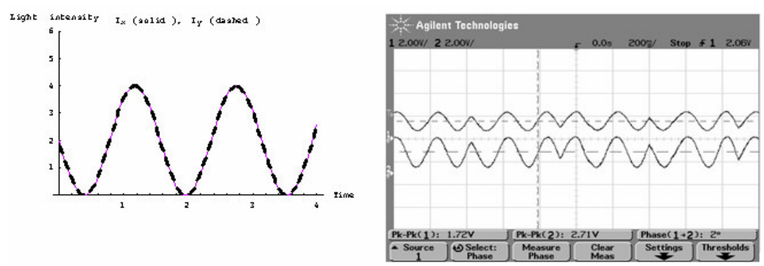
(a) the angle of half-wave plate = 0°, the phase retardation = 180°



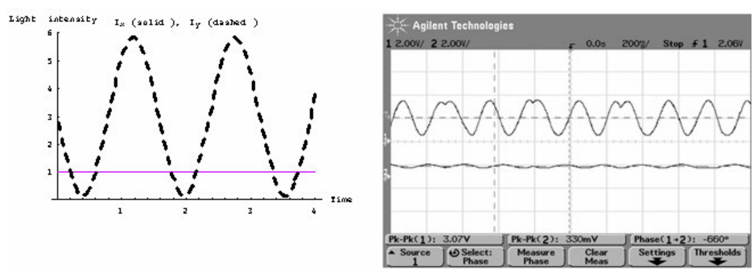
(b) the angle of half-wave plate = 22.5°, the phase retardation is undefined



(c) the angle of half-wave plate = 45°, the phase retardation = 0°



(d) the angle of half-wave plate = 67.5°, the phase retardation is undefined



(e) the angle of half-wave plate = 90°, the phase retardation = −180°

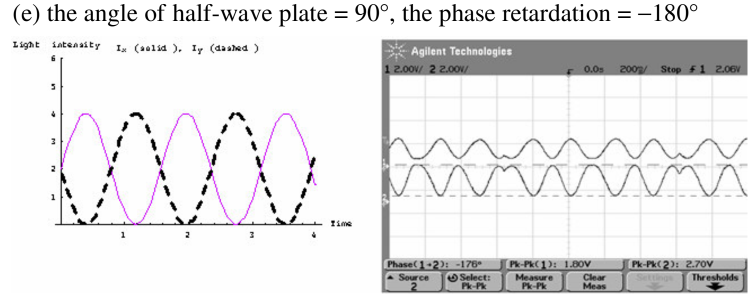


Fig. 3. The theoretical and experimental results for the two orthogonally polarized interfering beams, when we rotate the half-wave plate by (a) 0°, (b) 22.5°, (c) 45°, (d) 67.5°, and (e) 90°. In the simulation parts, the surface-polarized light signal is shown as the dashed line and the plane-polarized light signal is shown as the solid line.

5. Conclusion

The experimental results and theoretical analysis show good agreement and prove that using a Mach-Zehnder interferometer is a good technique to measure the phase retardations of wave plates easily and quickly. This system can be applied in an optics teaching laboratory to explore the birefringence characteristics of anisotropic materials in a more intuitive manner.

Acknowledgements

We acknowledge the financial support from the National Science Council, Taiwan, through project NSC-95-2112-M-415-004.

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Appendixes

The MATHEMATICA code of the theoretical analysis of the phase retardations of a rotated half-wave plate:

```
(* ---------------------------------Half Waveplate---- ----------------------------- *)
Γ = π;
  For[ψ = 0, ψ ≤ π / 2, ψ = ψ + π / 8,
   W = {{Cos[ψ], -Sin[ψ]}, {Sin[ψ], Cos[ψ]}}.{{Exp[-ⅈ Γ / 2], 0}, {0, Exp[ⅈ Γ / 2]}}.{{Cos[ψ], Sin[ψ]}, {-Sin[ψ], Cos[ψ]}};
   β0 = 2; a = 10; b = 2; zW = a + b × t; z0 = 10;
   EW = {{Exp[-ⅈ β0 × zW], 0}, {0, Exp[-ⅈ β0 × zW]}}.W.{{1}, {1}};
   Ef = {{Exp[-ⅈ β0 × z0], 0}, {0, Exp[-ⅈ β0 × z0]}}.{{1}, {1}};
   ETotal = EW + Ef;
   Ex = {1  0}.ETotal;  Ey = {0  1}.ETotal;
   Ix = Norm[Ex]^2;  Iy = Norm[Ey]^2;
   T = 2 π / (β0 × b);
   Pdcx = N[∫_0^T Ix ⅆt] / T; Print["Idcx=", Pdcx];
   Qdcy = N[∫_0^T Iy ⅆt] / T; Print["Idcy=", Qdcy];
   xsol = FindRoot[Ix == Pdcx, {t, 1}]; Print["xsol=", xsol];
   ysol = FindRoot[Iy == Qdcy, {t, 1}]; Print["ysol=", ysol];
   phase = 360 × ((t /. xsol) - (t /. ysol)) / T; Print["phase=", N[phase]];
   Print["Waveplate: angle ψ = ", ψ, "  , phase retardation Γ = ", Γ];
   Plot[{Ix, Iy}, {t, 0, 4}, PlotRange → {0, 6}, AxesLabel → {"Time", "Light intensity"},
    PlotLabel → "Ix (solid), Iy (dashed)",
    PlotStyle → {{Hue[0.8]}, {Thickness[0.015], Dashing[{0.03, 0.03}]}}];
   Print["-----------------------------------------------------------"]
  ];
(* ---------------------------------Half Waveplate---- ----------------------------- *)
```

II.

A laboratory of image processing and holography for physics students

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Abstract: In the Physics degree in Spain the students have a mandatory course in Fundamentals of Optics as well as an Optics Laboratory course. With these two courses the students receive a general background of optics. There are also some optional courses on Optics in the last years of the degree. One of them is a course on Optical Image Processing and Holography. This course has 60 hours (equivalent to 6 credits of a total number of 300 credits in the Physics degree). Fifteen hours of the course correspond to the laboratory experiments. In this contribution we will describe the contents of this laboratory experiments and we will also discuss the influence of this laboratory in the background of a physicist. The laboratory works consist of three lab experiments about the following topics: Diffraction, Coherent Spatial Frequency Optical Filtering and Holography. Optical Image Processing and Holography course survey of students' opinion is presented to analyze different pedagogical aspects.
Keywords: Diffraction, Image Processing, Spatial Frequency Optical Filtering, Holography.

1. Introduction

The Physics degree in Spain lasts in general 5 years. There is a course of Fundamental of Optics in the second or third year. The topics studied in this course include: geometrical optics, wave optics, interferometry, diffraction, polarization, etc. The students have the chance to follow several optional courses related to Optics. One of them is a course on Optical Image Processing and Holography (OIPH).

The OIPH course not only provides them a theoretical knowledge, but also an experimental one, since 15 hours (the course lasts 60 hours) correspond to the laboratory experiments. This way, an experimental understanding reinforces the theoretical knowledge learned at the classroom, let us say in the theoretical lectures. The laboratory practices are made in groups of a maximum of three people. Therefore, the teacher can focus his effort in a small number of students, becoming a more individual training and promoting a teacher-student interaction that leads to a better level of understanding. Furthermore, by means of the delivery of a questionnaire about the experiment, the teacher sets a guideline that allows students to know the fundamental points of the experiment. In addition, these questionnaires help students to do a constant work and consolidate the knowledge they have learned. These questionnaires and a mandatory report (about one of these three experiments) are evaluated and have a specific weight in the final course mark. All this, plus a final theoretical exam gives the final mark, and one of the questions of the final exam refers to the work done in the laboratory. Therefore, it is especially important to pay attention in the three lab sessions in order to achieve a good mark.

The theoretical course has mainly three key lines, giving a solid mathematical base in Diffraction, Optical Filtering and Holography. In the lab, three experiments are made, showing a new vision of mathematical concepts through real phenomena and students are initiated into the laboratory process complexity. These experiments, in addition to the theoretical fundamentals taught in the course, allow the study of particular phenomena in both quantitative and qualitative ways.

Before the students go to the lab, the topics have been studied in the theoretical lectures. An explanatory text for each experiment is also given in advance to the students. It contains the guidelines to make the lab work. Besides a lab teacher is with the students to help them along the experiment. After the experimental works, the students present four lab reports: 3 short questionnaires, one for each experiment and one more detailed report about one of them. We have surveyed all students of the (OIPH) course (2006-2007) to obtain a feed-back of information.

The survey analyzes several pedagogical aspects: importance of the theoretical and experimental classes, quality of the guidelines, importance of the lab teacher, etc.
The introduction of the course in the Physics studies permits to train the students in the fundamentals of the general theory of Signal Processing. Although the dimension (two dimensions / one dimension) and the magnitude (spatial / temporal) of the signal are different, the mathematical fundamentals are analogous.

In sections 2, 3 and 4 we show the aim of the three experiments and describe their usefulness in students training. In section 5 we show the statistical results of (OIPH) course survey of students' opinion. Finally, in section 6 we summarize the work.

2. Fraunhofer's diffraction

In this experiment, the Fraunhofer's diffraction is studied [1-3]. The students observe, capture with a CCD camera and a frame-grabber and measure the diffraction made by several apertures. The set-up used (fig. 1) allows not only a qualitative and quantitative study of the diffractive phenomena, but also lets us know properties of several typical laboratories elements, as spatial filter, lens, laser, CCD camera and so on. Moreover, this experience shows clearly the relationship between the object space and the Fourier plane in a visual way. In fact, regarding to diffraction patterns, in this experiment the student watch the Fourier transform for slits with different shapes, double slits, one-dimensional and two-dimensional arrays, and in each case, the teacher gives a detailed mathematical formulation. Some experimental results obtained by the students are shown in fig. 2.

Furthermore, this experiment is also useful to introduce students to metrology relations. Measures are made upon the images captured by means of the CCD camera placed on the detector plane (fig. 1), and students have to seek out the relationship between distances in millimeters in the focal plane and the pixels in the digital image. To perform the calibration a grating is used in the aperture plane. Then, in the detector plane several bright spots corresponding to the different diffraction orders of the grating are obtained (fig. 2d). The distance between several spots is measured firstly with a calibrated ruler to determine the distance in millimeters. Then, this pattern is captured with the CCD camera and the distance in pixels is measured with the software written for this experiment. This software permits the capture of images and its analysis, distance measures, intensity graphs, etc. Moreover, the theoretical diffraction image can also be calculated and a comparison between experiments and theory can be performed.

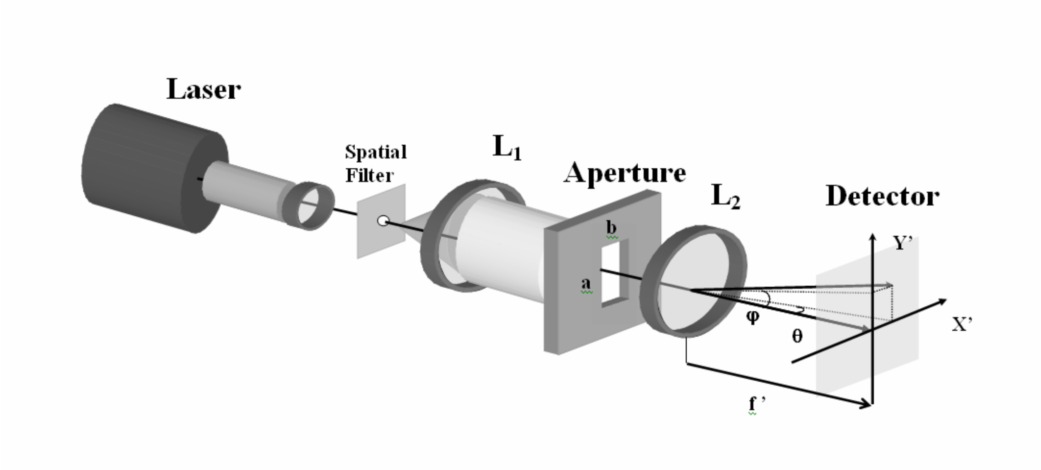
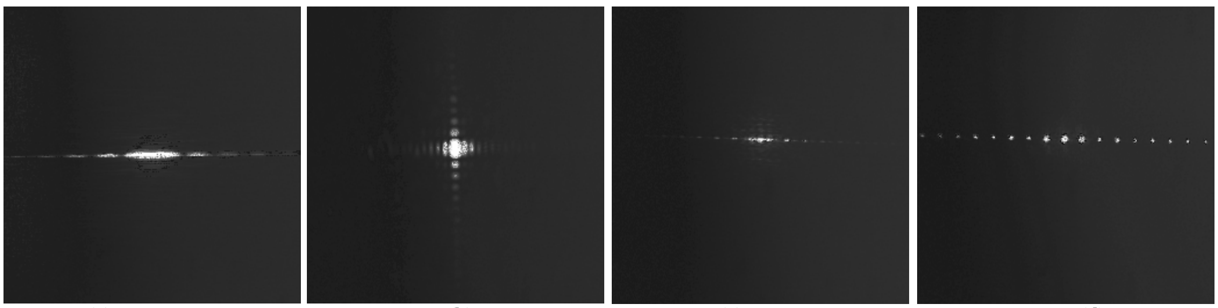


Fig. 1. Fraunhofer's diffraction experimental set-up.

The diffraction patterns studied in this experiment are produced by the following apertures:

- Slit aperture. The distance between the minima is measured (see fig. 2-a) and the width of the slit is evaluated. The diffraction produced by a complementary aperture is also studied.
- Rectangular aperture. The distance between the minima in two axis is measured (see fig. 2-b), and the width and height of the aperture is evaluated.
- Circular aperture. The radius of the central disk of the diffraction pattern is measured. The radius of the circular aperture is evaluated.
- Double aperture (two rectangles). The distance between the interference minima is measured (see fig. 2-c). The distance between the two apertures is evaluated.
- One-dimensional array. Diffraction patterns of gratings with different numbers of slits from 3 to 6 are studied. The diffraction produced by a grating is also studied (see fig. 2-d). The distance between the principal maximum is measured, to obtain the distance between the slits.
- Different types of two-dimensional arrays: a rectangular array of circular apertures contained within a circular aperture, hexagonal array of circular apertures, etc.



(a) (b) (c) (d)

Fig. 2. Experimental Fraunhofer's diffraction patterns captured by the students.
a) slit aperture, b) rectangular aperture, c) double slit aperture, d) one-dimensional array.

3. Coherent spatial frequency optical filtering

This experiment has mainly two aims. On one hand, we look for a visualization of the spatial frequencies contents in several images and on the other hand, we want to produce modifications in the spectral content (coherent optical filtering) [4-6]. In this last case, we want to see its effect in the final image. For that reason, we use a correlator that allows us to obtain and see the Fraunhofer's diffraction of a scene, as well as its filtering process and the final image.

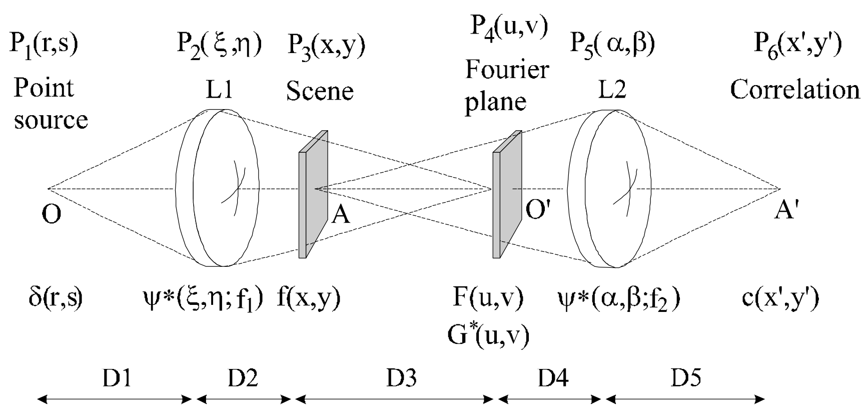


Fig. 3. Geometry of the optical convergent correlator. L_1 and L_2 are convergent lenses.
O´ is the image of O given by L_1, and A´ is the image of A given by L_2.

Fig. 3 shows a convergent correlator [6,7]. The lens L_1 generates a convergent wave and makes in O' the image of the point source O. By inserting a transparence with a transmission f(x,y) just after the lens L_1, we obtain a complex amplitude F(u,v) in the Fourier plane. F(u,v) is the Fourier Transform of f(x,y) multiplied by some constant values and an exponential term. The second lens L_2 produces an image of the scene in the correlation plane A'.
In order to lead students into a better understanding, we have made several improvements [7] to the typical convergent correlator as we show in figure 4. In fact, we have introduced a spatial filter and a perpendicular arm that projects, through the lens L3, the Fourier plane image, let us say F(u,v), in the screen.

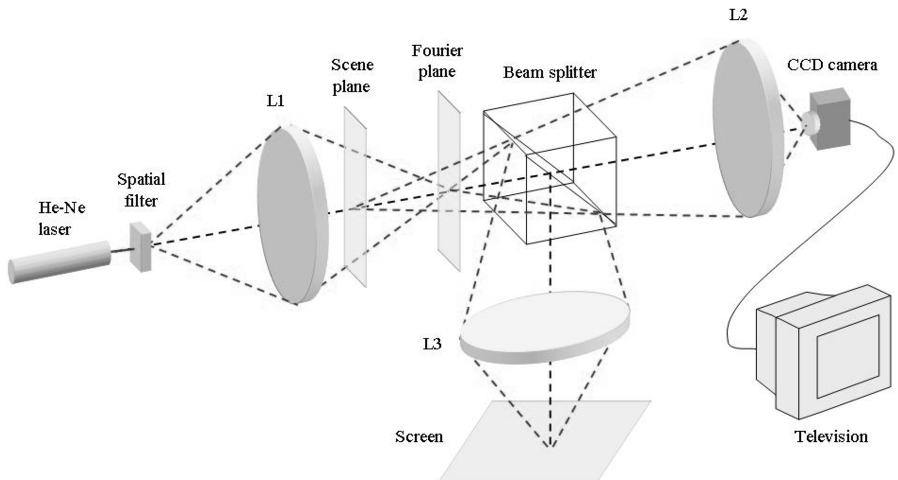
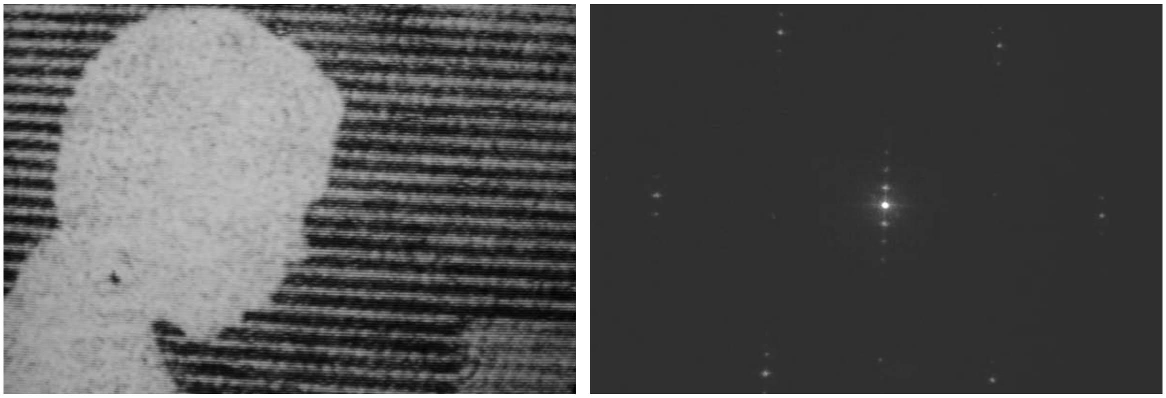


Fig. 4. Experimental set-up: convergent optical correlator with two arms.

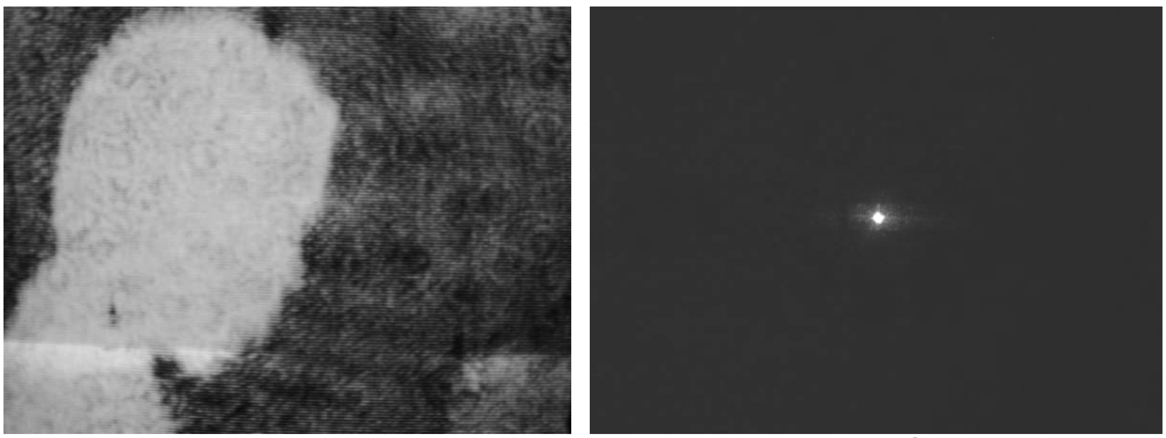
By means of this device, the students can see at the same time the Fourier plane in a screen and the final image, captured by a CCD camera, displayed in a television set. Therefore, it is very interesting the point that students, by making some changes on the Fourier plane, can see the modifications on the Fourier plane and on the final image. Moreover, by changing the distance D3 they are able to observe directly the variations in the scale of the Fourier transformation of a scene, and by using filters in the Fourier's plane, they can directly realize that the final image only contains the frequencies which the filters let pass through. We also think that using a digital camera connected with a television, students notice the important role that technology plays in Optical Signal Processing.

We show some images captured by the students in the following figures. Each group of graphs shows the original image and its Fourier Transform (FT), and the filtered image alongside with the manipulated Fourier Transform. Fig.5-a shows a scene with a face and a blind (parallel bars) background. This photograph has been taken from a computer monitor. Fig. 5-b shows its Fourier Transform. The hexagonal periodicity in the diffraction orders is due to the hexagonal distribution of the pixels in the monitor we used. The filtered image is showed in fig. 6-a. In this case a horizontal slit has been used to filter the image, removing the bar background (fig. 6-b). Another example is shown in fig. 7. In this case, the scene is a two dimensional rectangular array of circles (fig. 7-a). The Fourier Transform of this scene is shown in fig. 7-b. We will show two different manipulations of the image. First, we can see in fig. 8 that the scene is transformed in a set of horizontal bars when the FT is filtered with a vertical slit. Secondly, we can see in figure 9 that the scene is transformed in a set of vertical bars when the FT is filtered with a horizontal slit.



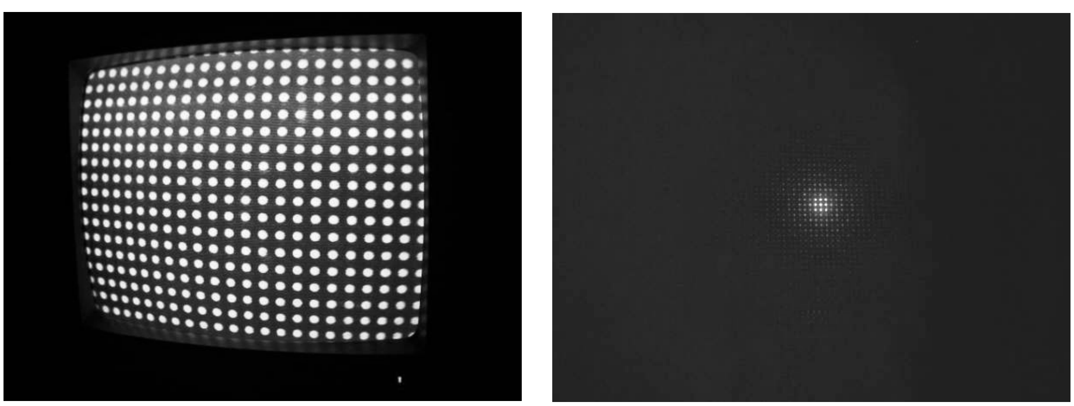
(a) (b)

Fig. 5. a) original scene, b) diffraction pattern (Fourier Transform).



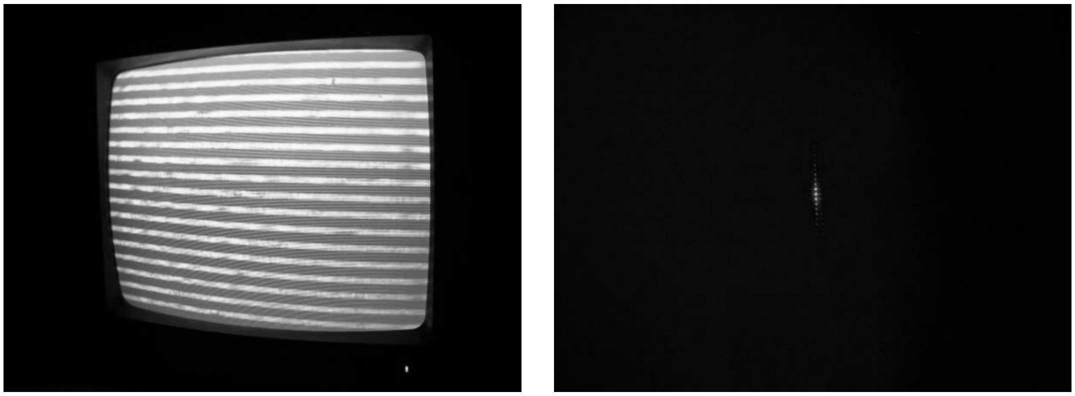
(a) (b)

Fig. 6. a) filtered image, b) diffraction pattern (Fourier Transform) filtered with an horizontal slit.



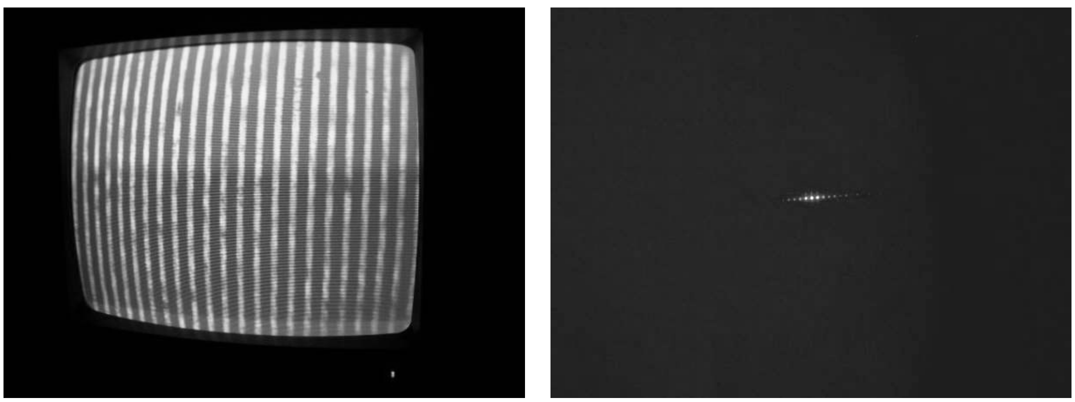
(a) (b)

Fig. 7. a) scene, b) diffraction pattern (Fourier Transform).



(a) (b)

Fig. 8. a) filtered image, b) diffraction pattern (Fourier Transform) filtered with a vertical slit.



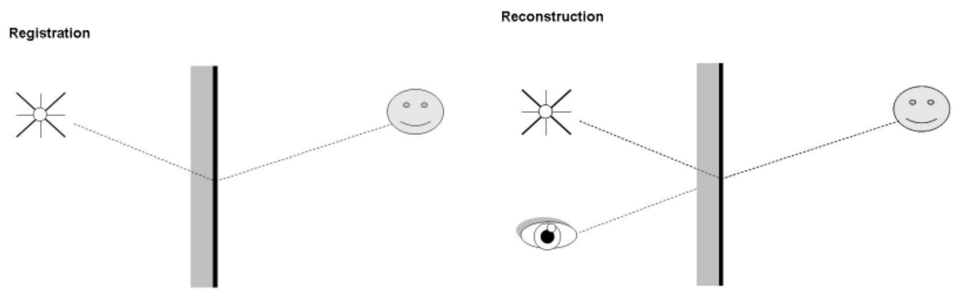
(a) (b)

Fig. 9. a) filtered image, b) diffraction pattern (Fourier Transform) filtered with an horizontal slit.

4. – Holography

In this experiment, students approach the holography as a particular case of interferential phenomena. In the theoretical lessons, students learn different holographic methods and in the lab the students work with different type of holograms to reconstruct the image [8-12] . With transmission holograms they observe the virtual and real image. They can observe that each point of the hologram keep information of the entire scene. This property can be observed if we obtain the reconstruction of the real image by illuminating directly with the laser in a very small area. Different types of rainbow holograms are also observed in the lab, for instance, as security method in credit cards, currency, bank notes, etc.

Each group of students makes several Denisyuk's reflection holograms. Now, we will describe the whole process with a little more of detail. In a reflection hologram, the light diffused by the object and the light of the reference wave arrive to the two opposite faces of the holographic plate. In order to visualize the object image, the observer has to locate himself at the opposite place of the object, and therefore at the same place where the reference wave source is set. The object image is made by the light reflected by the hologram.



(a) (b)

Fig. 10. Reflexion hologram. a) Registration, b) Reconstruction.

Next, in figure 11 we show the experimental set-up. With this set-up for reflexion holograms the students could make amplitude holograms or phase holograms but the techniques used for the developing in laboratory correspond to a phase hologram. Therefore in this experiment a phase hologram is made by students. The set-up is on a vibration isolating optical table and a He-Ne (633nm) laser is used. The laser beam is expanded by means of a spatial filter and reflected by two mirrors. Finally the beam passes through the holography plate (Agfa-Gevaert 8E75HD) and reaches the object, where the light is diffused. The interference is produced between the wave diffused by the object and the wave which comes directly from the laser. In darkness conditions, the holographic plate is set in its set-up place with the emulsion at the object side. By means of the use of an electronic shutter we adjust the exposition time.

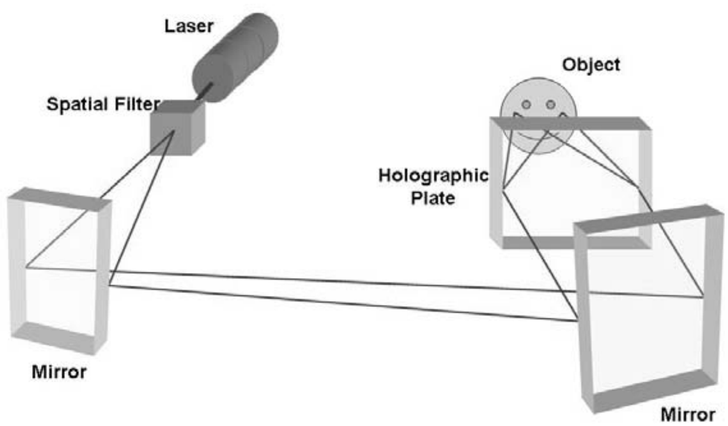


Fig. 11. Holographic experimental set-up. Denisyuk's configuration.

In addition, this experiment allows students to make acquainted with developing material for the first time in the physics degree. In fact, they have to use a developer, stop liquid (water) and bleaching liquid, and do the different steps required to obtain a hologram. Beside, this experiment also stimulates the teamwork because the students have to help themselves in the registration of the hologram and in the developing process.

Specifically, the developing is made with the next materials and steps:

- Developer D-19 4 minutes (1 minute shaking the container where the plate is immersed in the liquid and later the shaking is in intervals of 30 seconds).

- Stop liquid (water) 1 minutes shaking.

- Bleaching liquid — until the holographic plate turns transparent plus one minute more.
- Washing in water — 10 minutes without shaking.
- Drying — 1 day in ambient temperature and in darkness conditions.

5. OIPH course survey of students' opinion

In this section we show the results of a survey of students' opinion that we have done with the students of the Optical Image Processing and Holography (OIPH) course. The questionnaire has been answered anonymously by all of the 15 students of the course at the end of the final exam (Feb. 2007). The questionnaire we have given to the students in order to make the survey is as follows:

Evaluate from 1 to 5 the following questions:

1) Mark the influence in your degree of knowledge satisfaction made by theoretical and experimental classes:

	Theoretical classes	Experimental classes
Diffraction	☐	☐
Optical Filtering	☐	☐
Holography	☐	☐

2) Do you think lab experiments have helped you to be aware of the mathematical fundamentals taught in the theory lectures?
3) Do you think OIPH has assisted you to consolidate concepts previously studied in the mandatory General Optics course?
4) Are the questionnaires given in the lab experiments useful to do the lab experiments and become conscious of their theoretical base?
5) Do you find helpful the assistance of the laboratory teacher to do the experiments?
6) Do you think OIPH has provided you a higher knowledge about how the research is made in the research laboratories?
7) Has OIPH helped you to make acquainted yourself with optical laboratory typical elements?
8) Have the experiments done in the lab been useful to obtain better marks in the final exam?
9) Do you assume questionnaires and reports value in the final mark (12,5%) are suppose to be enough?

In figures 12 and 13 the results of the survey are shown.

Fig. 12 shows that the students value positively (more than 3 over 5) the theoretical lectures as a source of knowledge for the three topics (Diffraction, Optical Filtering and Holography). Nevertheless, they are even more satisfied with the experimental classes (more than 4 over 5).

Fig. 13 shows an average of the students answers to the items 2 to 9. We observe that all the items except item 9 receive very positive scores. Item 2 receives a very high score (4.6 over 5) that shows that the experimental classes have been very helpful to fully understand the mathematical fundamentals of the topics studied. Item 3 obtains a good score (3.9 over 5) showing that the lab experiments help them to consolidate concepts studied in the General Optics course. Probably, the score would be higher if the lab classes would cover more topics of Optics, but this aspect was not studied in the survey. Item 4 is scored positively (3.4 over 5) but less than other items. This suggests that the guidelines to the experiments are useful but maybe they are not enough to properly make the experiments. This is probably the reason why the students value very positively the help from the lab teacher in item 5 (4.3 over 5). Items 6 (3.7 over 5) and 7 (3.7 over

5) show that students feel that their knowledge about lab research and optical devices has improved. Interestingly, the students think that their final mark has been better because of the experimental classes (item 8: 4.1 over 5). Probably there are two reasons. Firstly, one third of their final exam includes questions about the lab experiments. This good score suggests that the concepts studied in the lab were well learned and consequently it improved the result on the final exam. Secondly, the lab questionnaires and reports that they present have a weight of 12.5% on the final mark. Item 9 clearly states that the students feel that the lab reports should have a higher weight on their final mark.

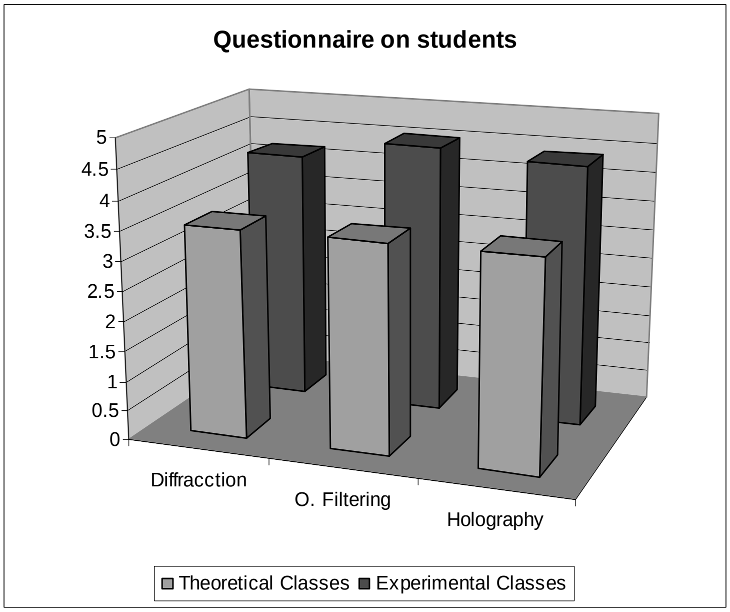


Fig. 12. Students' satisfaction degree (0 to 5) on the knowledge of the three topics related to the theoretical and experimental classes (item 1).

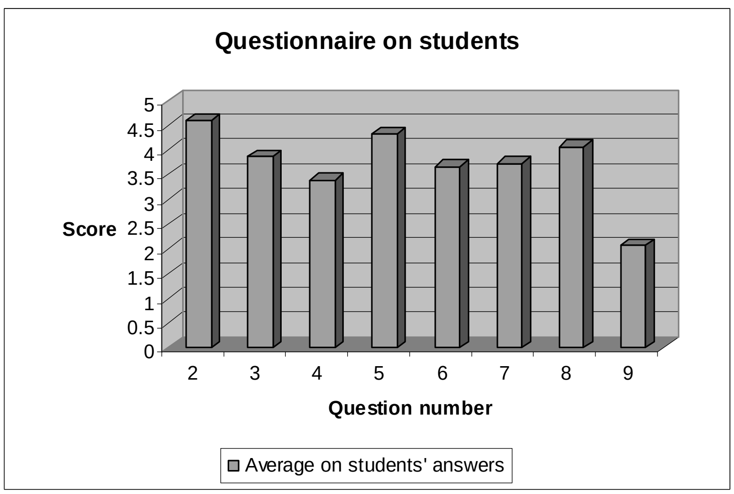


Fig. 13. Student's satisfaction degree (0 to 5) on the items 2 to 9 of the survey.

6. Summary

We describe the three experiments that the students make in the lab during the course of Optical Image Processing and Holography in the Physics degree. The experiments are: Diffraction, Coherent Spatial Frequency Optical Filtering and Holography. We also describe the way the students make the experiments and how they are evaluated. The students of the course have fulfilled a questionnaire about pedagogical aspects of the subject just after the final exam. We have used this survey to discuss the influence of the laboratory in the background of a physicist.

Acknowledgments

The authors acknowledge financial support from the Spanish Ministerio de Educación y Ciencia (grant FIS2006-13037-C02-01). The authors thank the students (OIPH, 2006-07) for filling in the questionnaires and especially to M. J. González, C. Belver and J. Serra for the photographs presented in this paper.

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III

Using a wavelength tunable diode laser to measure the beat length of a birefringent fiber

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Abstract: In this report we demonstrated a method for measuring the beat length of a birefringent fiber. In this method the beat length is determined from the wavelength dependence of the phase difference between two orthogonally polarized modes at the output end of a sample fiber. In addition to the mode hopping of the laser diode's optical wavelength due to the temperature variation, we have also observed the phase hopping of the output light polarization at the end face of the birefringent fiber. It is a simple and precise method to determine the birefringence magnitude of anisotropic materials in an optics laboratory course.

OCIS codes: (140.2020) Diode lasers; (260.1440) Birefringence; (060.2420) Fibers, polarization-maintaining

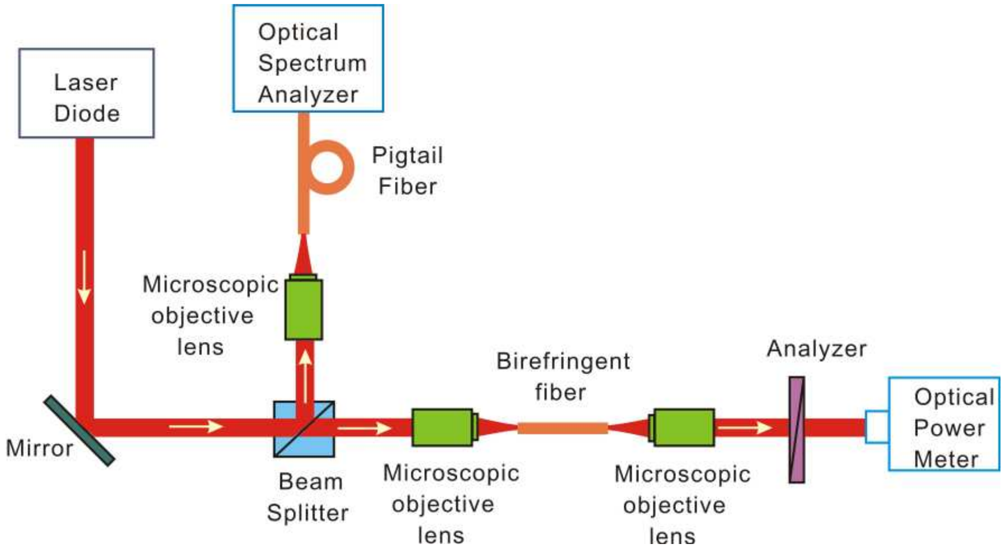
1. Introduction

In heterodyne-type optical communications or some kinds of fiber-optic measurement, the polarization state of the received signal must be kept constant. To meet this requirement, various birefringent fibers have been developed in which the propagation constants of two orthogonally polarized modes (HE_x and HE_y) are different. The degree of such modal birefringence is often expressed by the beat length between these two modes. There are many methods to measure the beat length. In this report, the beat length is determined from the wavelength dependence of the phase difference between the two modes at the output end of a sample fiber [1].

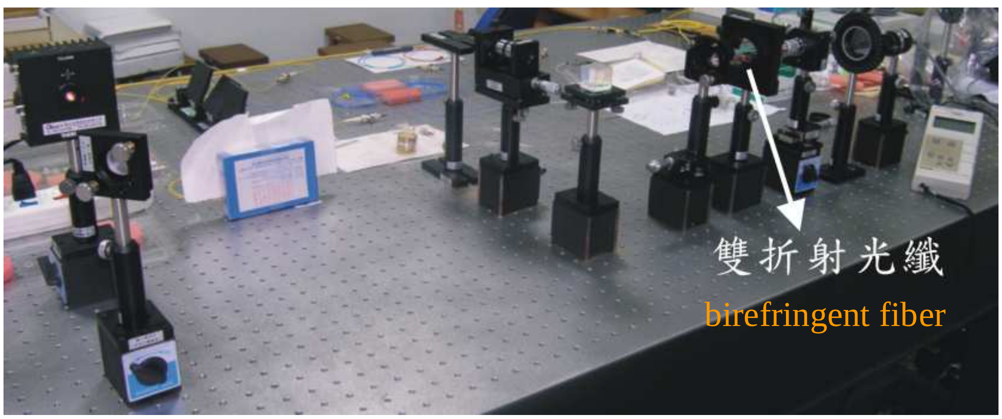
2. Experimental Setup and Principle of Measurement

Figs. 1(a) and 1(b) show the schematic diagram and photograph of the experiment setup. An AlGaInP diode laser (THORLABS DL3147-060 Sanyo) is used as the light source. As shown in Fig. 2, the optical wavelength is tunable by controlling the laser diode's temperature, and the laser spectrum is measured by an optical spectrum analyzer (ADVANTEST Q8384). The linearly polarized laser light, having a polarization angle of 45° with respect to the principal axes of the birefringent sample fiber [Figs. 1(c) and 1(d), 3M FS-PM-7811, $\Delta n = 7.718 \times 10^{-4}$], is launched at the fiber input end via a microscopic objective lens [2]. The phase difference between the HE_x and HE_y modes at the fiber output end is given as $\phi = \ell\, \Delta\beta$, where $\Delta\beta = \frac{2\pi}{\lambda} \cdot \Delta n$ denotes the difference in the propagation constants of the two modes and ℓ is the fiber length. The phase difference ϕ can be determined from the maximum and minimum transmitted light intensities I_a and I_b, respectively, of the elliptical polarization as $\sin\phi = \pm \frac{2\sqrt{I_a I_b}}{I_a + I_b}$, when we rotate an analyzer behind the fiber and measure the transmitted optical power. Because of the variation of the device temperature, the optical wavelength λ of the laser light source is swept by a small amount of $\Delta\lambda$, where $|\Delta\lambda| << \lambda$. Then the change in ϕ induced by $\Delta\lambda$ is given as $\Delta\phi = \ell\, \Delta\lambda \frac{d(\Delta\beta)}{d\lambda} = \ell\, \Delta\lambda (-\frac{2\pi}{\lambda^2} \Delta n) = \ell\, \Delta\lambda (-\frac{\Delta\beta}{\lambda}) = -\frac{\Delta\lambda}{\lambda} \ell \Delta\beta$. Using the definition of beat length $L_B = \frac{2\pi}{\Delta\beta}$, it can be rewritten as $\frac{\Delta\phi}{\Delta\lambda} = -\frac{1}{\lambda}\frac{2\pi\ell}{L_B}$. Thus, by measuring the phase difference ϕ as a function of the wavelength λ, we can calculate the $\phi - \lambda$ relationship and hence obtain the value of beat length L_B.

(a)



(b)



(c)

(d)

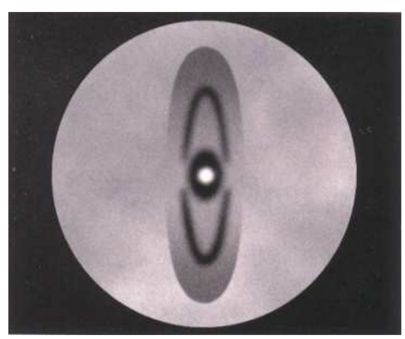


Fig. 1. The (a) schematic diagram amd (b) photograph of the experimental setup. (c) The birefringent fiber under test in a rotary mount. (d) The cross-section picture of the birefringent fiber (3M Single Mode Polarization Maintaining Fiber, FS-PM-7811, THORLABS INC. Catalog 2004).

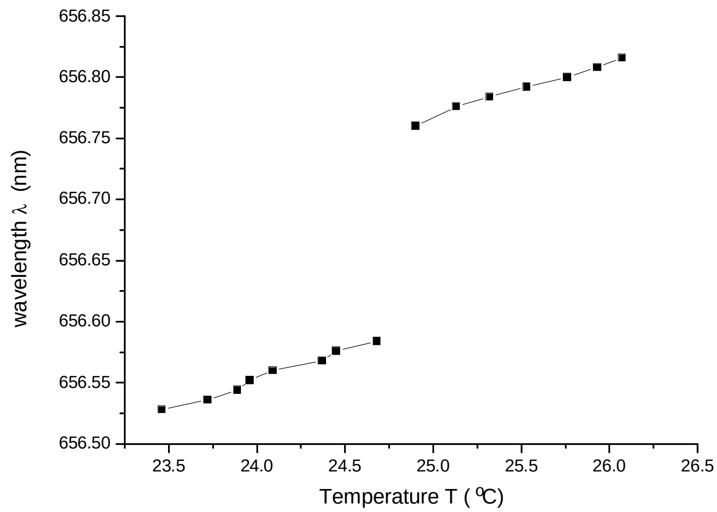
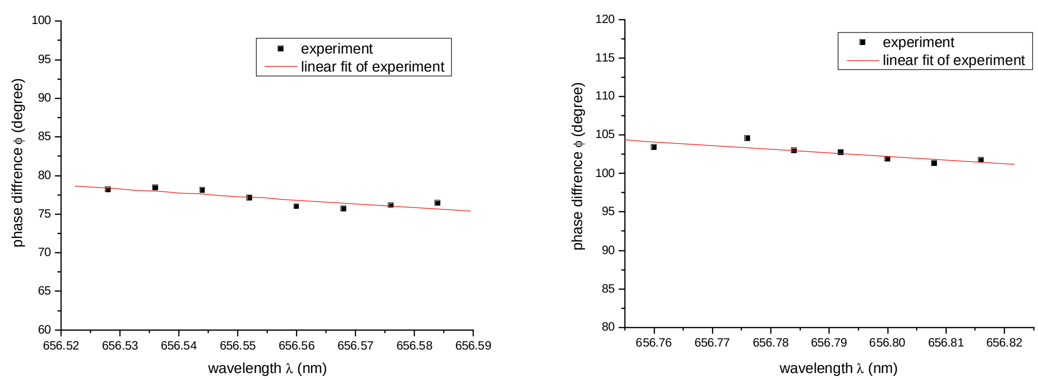


Fig. 2. The laser optical wavelength versus the laser diode's temperature.

3. Experimental Results

The wavelength dependence on the device temperature reveals a discontinuous change because of the mode hopping of the laser diode. As shown in Fig. 2, there are two kinds of longitudinal modes, one of which has a center wavelength λ_c = 656.556 nm and the other has λ_c = 656.79 nm. The corresponding measured $\phi - \lambda$ diagrams also exhibit a hopping phenomenon and are shown in Figs. 3(a) and 3(b). The slopes of their linear fitting curves are $\frac{\Delta\phi}{\Delta\lambda} = -47.19^\circ$/nm and $\frac{\Delta\phi}{\Delta\lambda} = -47.71^\circ$/nm, respectively. The predicted beat lengths $L_B = \lambda_c / \Delta n$ are 0.8507 mm and 0.8509 mm, respectively. The sample fiber has a length ℓ = 7.2 cm. Using the relationship $\frac{\Delta\phi}{\Delta\lambda} = -\frac{1}{\lambda_c}\frac{2\pi\ell}{L_B}$, we can calculate the measured beat length L_B to be 0.8366 mm and 0.8272 mm for the two kinds of longitudinal modes, and the error percents are 1.657 % and 2.785 %, respectively. The errors may be due to the device thermal fluctuation in tuning the temperature of the laser diode.



(a) (b)

Fig. 3. The measured results and linear fits of the phase difference ϕ as a function of the wavelength λ for (a) the longitudinal mode with center wavelength λ_c = 656.556 nm, and (b) another longitudinal mode with center wavelength λ_c = 656.79 nm.

4. Conclusion

We have successfully achieved measuring the beat length of a birefringent fiber by a wavelength tunable diode laser. In this method the beat length is determined from the wavelength dependence of the phase difference between two orthogonally polarized modes at the output end of a sample fiber. In addition to the mode hopping of the laser diode's optical wavelength due to the temperature variation, we have also observed the phase hopping of the output light polarization at the end face of the birefringent fiber, because the fiber length is far larger than that of the birefringent retardation wave plates. In an optics laboratory course, this simple method can be used to determine the value of beat length, or the magnitude of birefringence, of any anisotropic materials precisely.

Acknowledgements

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IV

Laser Diode and Photodiode Modules and Analogue Circuits Training for the Optical Fiber Transmission Practice System

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Abstract: In this paper, the technical training for fabricating the laser diode and photodiode modules and also assembling the electronic drives for the both modules is described from a view point of student technical training to study fundamental technology of optical fiber telecommunications. First, the students assembled the both modules using small parts and adjusted the optic axis of laser light from a source with an accuracy of a few micrometers so that the laser light efficiently enters the core of an optical fiber cable. The characteristics of the modules such as the spatial intensity distribution of emitted laser light, the relationship between the input laser power and the output current of a photodiode were measured to evaluate the fabricated modules. Second, two electronic analogue circuits of the drives used for the modules were assembled to study about typical optronics devices such as laser diode and photodiode, the functions of the circuits in the drives and how they are used in combination with the optical fiber telecommunications technology. Lastly, the fabricated modules and the assembled drives were tested by transmitting the test image using an optical fiber cable.

1. Introduction

Optical fiber technology [1] is becoming the key technology of advanced telecommunications, optical measurements and sensing and so on in a variety of fields. In order to study the optical fiber telecommunications system the students have to learn about the theory of transmitting laser light in fiber and some optical properties related with laser light. Recently, we have introduced the new technical training about the basics of optical transmitting system for the students of Department of Information Systems Engineering at our university [2], [3]. The system mainly consists of two basic optical modules and two electronic drives for them. One of the two is the laser diode module which converts electronic signal into optical intensity signal and mainly uses a laser diode (LD) as a light source. The other is the photodiode module which converts the transmitted light signal into the electronic signal again and mainly uses a photodiode (PD). In these modules, the main important and essential technologies to be trained are fabrication technique with an accuracy of few micrometers according to the size of fiber core and also assembling technique for electronic analogue drive circuits .Through the training, students fabricated the laser diode and photodiode modules at the starting stage and then measured the characteristics of both modules. After that they assembled the LD and PD drive circuits and measured some characteristics of both drives. Lastly, they tested the fabricated modules and the assembled drives by checking the transmitted image using an optical fiber cable.

In the present paper, the contents of the training are described from a view point of student technical training from which they can learn about not only the basics of optical transmission technology, but also some practical assembling techniques with an accuracy of only a few micrometers and how the optical telecommunication technology is supported by precision machinery and electronic technologies.

2. Training schedule

The training is planed for one semester for junior students at the Department of Information Systems Engineering. It has 6 steps which consists of the module fabrications of LD and PD modules, the measurements of the characteristics of both modules, the basic training of an operational amplifier (op amp), the assembling of LD and PD drive circuits, the measurements of characteristics of LD and PD drive circuits, the rough estimation of signal and noise ratio in transmitted image signal using the LD and PD modules and optical fiber cable, and so on. The schedule of the training is shown in Fig. 1. In each step the training times are denoted and one unit of time is 6 hours including the times for explanation to students about training subjects.

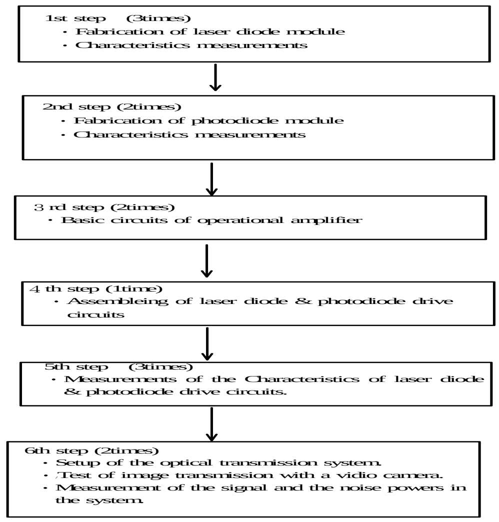


Fig. 1 Training schedule of the optical fiber transmission practice system for students. One time in each block means 6 hours.

3. Optical Fiber Transmission Practice System

The whole optical fiber transmission practice system is shown in Fig. 2 which consists of a video camera, LD(λ =1.5 μ m),PD modules and their drives, optical fiber cable and some electronic instruments.

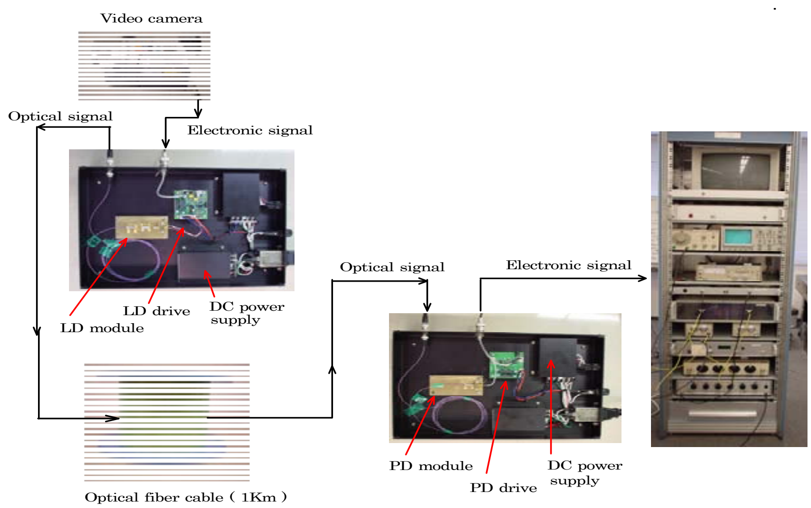


Fig. 2. Outlined figure of the optical fiber transmission practice system.

To understand the electronic circuit of drives in the modules, students have to study and understand about the fundamental functions and workings of op amp through the practices of the circuits, such as an inverting amplifier, a noninverting amplifier, a differential amplifier, an integrator circuit and so on. Then they assemble the circuits of the drives . The technical training has been done as described in the following sections.

4. Laser Diode and Photo Diode Modules

4-1 Laser diode module

The assembled LD module was shown in Fig. 3 and was connected to the LD drive circuit as shown in Fig.4 to send the modified signal of laser light to the PD module which is placed 1Km away from the LD module.

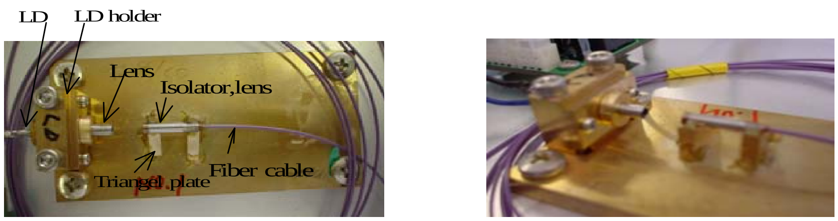


Fig. 3. A photograph of the assembled laser diode module.

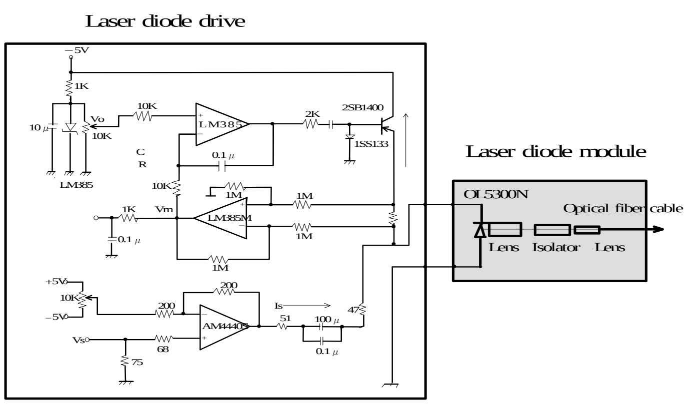


Fig. 4. Laser diode (LD) module and its drive circuit.

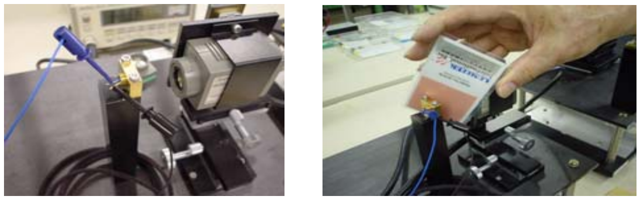
The assembling components of the modules shown in Fig. 5 consists of these parts; (a) a brass base plate of 40mm× 80mm square, (b) a laser diode, (c) a holder plate, (d) the attached laser diode to the holder plate, and (e) a lens holder, the first lens attaching to the laser diode and a plate with screws.

(a) (b) (c) (d) (e)

Fig. 5. Components of the laser diode module. (a) a brass base plate(40mm×80mm) , (b) a laser diode, (c)a holder plate, (d) the attached laser diode to the holder plate and (e) a lens holder, the first lens attaching to the laser diode and a plate with screws

The laser diode used here is OL5300N (Oki Electronics) which emits the wavelength of 1.5 μm and 10mW. The diode is fixed to the plate of which the size is 40 mm and 80mm and 5mm in thickness with a screw. The first lens of which the diameter is 5mm and 10 mm in length and is used to convergence the laser light into the core of a fiber cable of which the diameter is 10 μ m.

The diode was fixed to the plate temporally and the electric lead wires were connected to the electrodes of the diode as shown in Fig 6(a) to check the emitted laser light using a constant current power supply (Oyokouken YN54AD), a light



(a) (b)

Fig. 6. (a) the laser diode attached to the plate and a power meter, (b) an infrared sensor plate for detecting the light from the laser diode.

power meter (Anritsu ML9001A) , and an infrared sensor plate(Q32R, International Inc) for detecting and seeing the laser light by eye shown in Fig. 6(b). Here, the spatial distributions of the light intensity emitted from the laser diode were measured in the horizontal and vertical directions as shown in Fig. 7 at the distance of 75mm between the laser diode and the photodiode for measuring the intensity of laser light at the injection current of 20mA. The emitted laser light shows almost same spatial intensity distribution in both directions.

After checking the laser emission from the diode, the base plate and the LD were placed on a assembling jig as shown in Fig. 8(a).

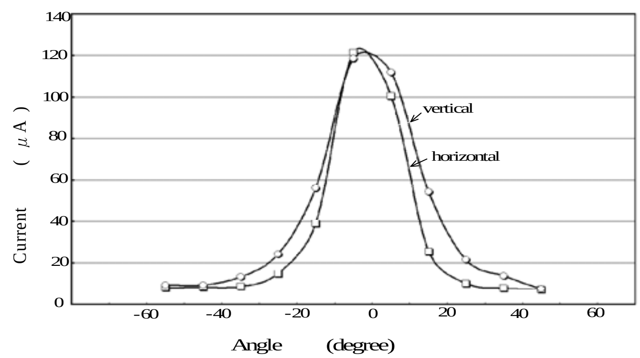
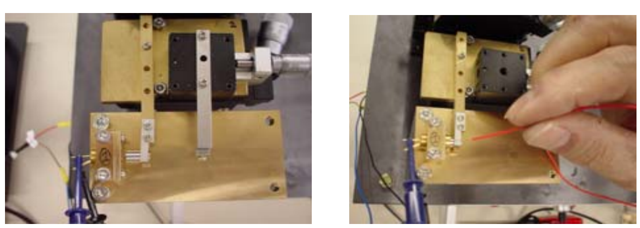


Fig. 7. Measurement result of spatial distribution of the light intensity emitted from the laser light.



(a) (b)

Fig. 8. (a) the first lens connected to the laser diode is adjusted, (b) fixing the first lens by an instant adhesive agent.

Next, an isolator ,of which size is 5mm in diameter and 10.5mm in length as shown in Fig.9(a), was also fixed at 5mm a way from the diode holder as shown in Fig.9(c). In a fixing procedure, the special attention was needed to set the isolator in correct direction of it. In the case of its right direction, the output laser beam becomes one, but it becomes two beams in the case of wrong direction. The isolator was adjusted and fixed as to the output beam is coincident with the optical axis of the laser diode by using a manipulator and two wedge plates of which the size is 8mm×12mm and 3mm in thickness as shown in Fig.9(b). The second lens was also attached at 6mm from the end of the first lens and connected to an end of the fiber cable. The lens holder was wiped up with ethanol and then the lens and the fiber were set on an attachment of the manipulator. Then, the laser light,0.63 μm in wavelength, of He-Ne entered into the fiber cable at the other end of the cable having a FC connector to adjust coarsely the optical axis of the second lens by using a corner cube. The FC connector was taken off from the He-Ne laser and connected to the power meter. The current power supply was switched on and the current of 20mA was injected to the laser diode, then adjustment of the optical axis of the second lens was carried out prudently with spending much time moving the x and y axes of the manipulator, thus inclining the assembling stage and reading the output of the power meter and lastly the lens was fixed at the most appropriate position.

(a) (b) (c)

Fig. 9. (a) an isolator of which the diameter is 5mm and 10.5mm in length, (b) wedge plates to fix the isolator as shown in (c).

The laser light passed through the LD holder, the isolator, the second lens and then the fiber cable. After adjusting the position of the second lens, the two wedge plates were arrayed to fix the lens. At this moment special attention must be paid to array the two plates to be put in the same direction to keep the adjusted optical axis.

The two wedge plates were fixed temporarily by using the instant adhesive agent as checking no change of the readings of the power meter. A final fixing was done by using another adhesive agent (Semedaine Hi-super 5A and 5B) as shown in Fig. 10.

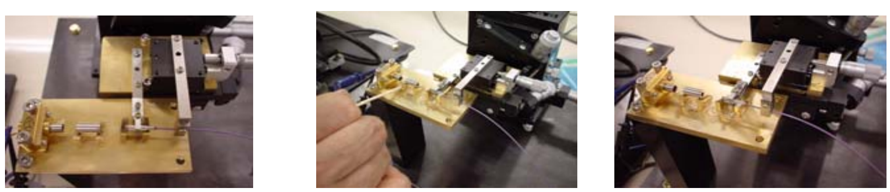


Fig. 10. Fixing the isolator, the second lens and the two wedge plates.

The characteristic of the injection current and the output laser power in the assembled LD module was measured as shown in Fig. 11. The power was about 1.1mW at the current of 20mA.

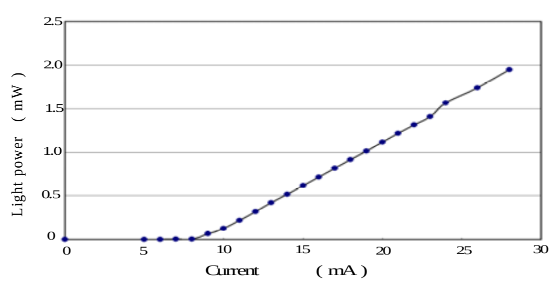
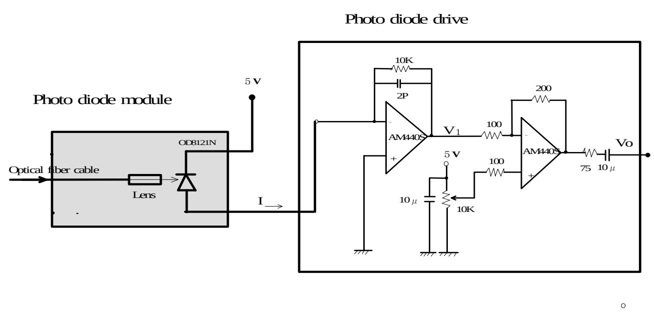


Fig. 11. Measurement result of the injection current of the laser diode and the output power of the laser light.

4-2. Photodiode Module

The PD module was also assembled as shown in Fig.12(a) and (b) in this training which is used in the system. In a similar way of the LD module, the PD module was assembled using some components such as a photodiode (OD8121N), a holder and a base plate. First the photodiode was fixed on its holder and placed on the base plate. Then a lens was connected to a ferrule of the fiber and fixed in front of a photodiode window. A He-Ne laser was used to set the position of the lens appropriately. The laser beam of the He-Ne entering from the FC connector of the fiber cable passed through the lens and entered the photodiode. The output current of the photodiode was measured to check the detection for the incident laser light by an electronic multi meter. After checking the current, the fiber was connected to another laser light source of 1.5 μm in wavelength, which is the same wavelength used in the module and then the lens was adjusted accurately by using the light power meter and a light attenuator shown in Fig. 13. After doing the final adjustment, the two wedge plates were also used here to fix the lens on the plate by using the same adhesive agent which is used for the LD module.



(a) (b)

Fig12. (a) a photodiode module and its drive, (b) a photograph of the assembled module.

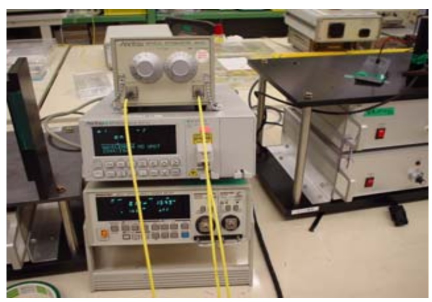


Fig. 13 A light attenuator, a power meter and laser light source used for lens adjustment.

Some of the characteristics of the PD module were measured in the training. The relationship between the input light power of laser light and the output current of the photodiode was obtained as shown in Fig. 14. The output current is almost linearly proportional to the input power.

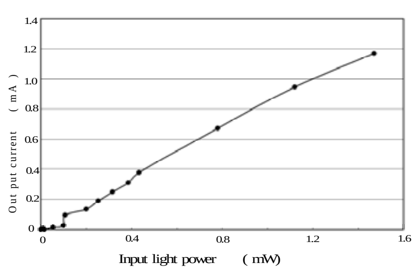


Fig. 14. Measurement result of input light power of the laser and the output current of the photodiode.

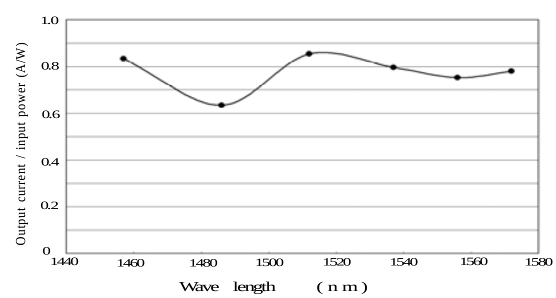


Fig. 15 Measurement result of the wavelength and the ratio of output current and the input laser power.

The ratio of the output current and the input laser power at the wave length rage from 1460nm to 1570nm were obtained as shown in Fig. 15. The ratio, which shows the conversion efficiency of input power of the laser light into the current (A/W) ranged from 0.6 to 0.8 that is approximately close to an ordinal value of 1.0. That means that the assembled PD module was considerably good quality.

5. Laser Diode Drive Circuit

The LD drive circuit assembled in this training is shown in Fig. 16 and also the photographs of electronic components, a board for assembling and the assembled circuit are shown in Fig. 17. The circuit was assembled on the board which is prepared for this circuit and the symbols of electronic components used in the circuit are printed on it so that students could put each device on the board correctly by doing the check of the values of it and the polarity of capacitors and by watching the position in the circuit. It is seemed to easy to assemble the electronic devices on the board, however soldering the electrodes of IC chips of op amps or wires in small space with sure electric contact and fully electric isolation with neighbor ones are sometimes difficult. Students felt difficulties because the space gap between the electrodes to be soldered is about 0.7mm. Through the work for soldering them, they could notice its importance.

After assembling the circuit, the circuit was divided into two parts, 1) the constant current supply circuit to the laser diode, 2) the modulation circuit of electronic voltage signal to the intensity signal of the laser light. In each circuit the characteristics were measured as described below.

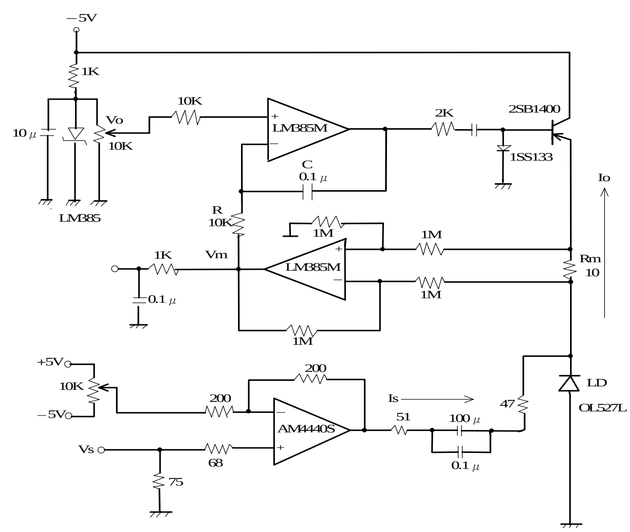
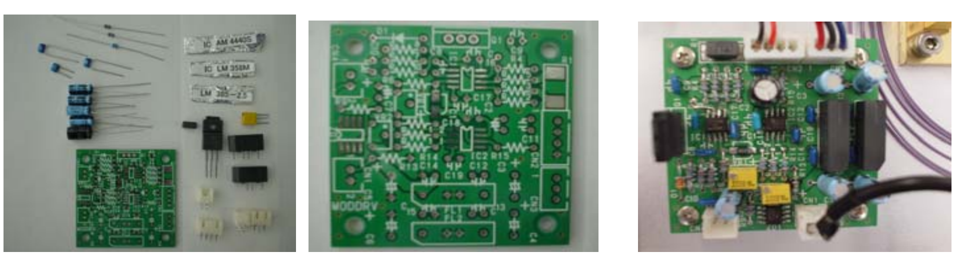


Fig. 16. Laser diode (LD) drive circuit.



(a) (b) (c)

Fig. 17. Photographs of (a) electronic components, (b) assembling board of 50mm×50mm square and (c) assembled LD drive circuit.

The constant current drive circuit of laser diode is taken out as shown in Fig. 18 to measure the main characteristics of the circuit.

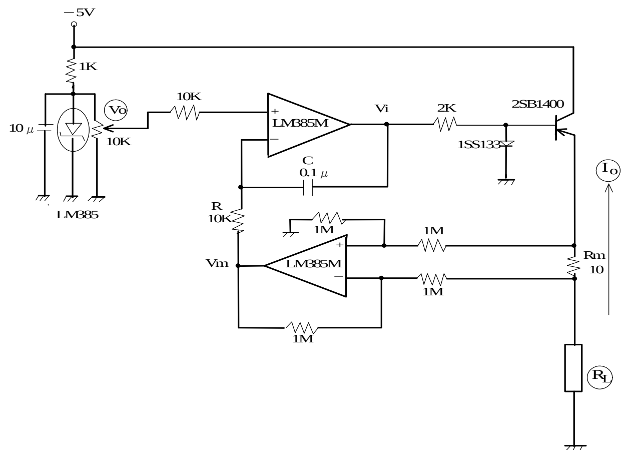


Fig. 18. Constant current drive circuit. The relationships between the voltage Vo and the current Io, and also between the load resistance RL and Io were measured.

5.1 The characteristic of zener diode.

A zener diode is used in this circuit to generate constant voltage which make any level of voltage with a variable resistant to flow the current to the laser diode. In order to test the constant voltage of the zener diode, the current against the applied voltage was measured and obtained as shown in Fig. 19. The constant voltage of –2.5V was obtained as the zener voltage and any voltage between 0V and –2.5V could be set with the variable resistance.

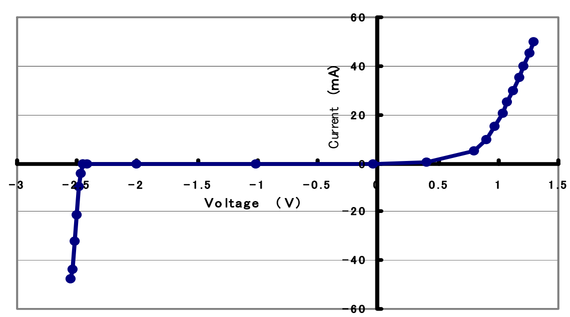


Fig. 19. Measurement result of the zener voltage.

5.2 The characteristic of the set voltage Vo and the current Io of the laser diode.

The current to the laser diode is set at any level with the variable resistance in Fig. 18 which is connected parallel to the zener diode and the set voltage determines the controlling constant current Io to the laser diode. To control the current constant, the integrator circuit was used here in the usual way. Here, the explanation how to control the current if the load resistance of the laser diode changes with some reasons such as temperature changes. It is important to let the students understand the combination operation of the monitor voltage Vm of the current Io using a differential amplifier and integrator circuit. One example of the explanation was done using the figure 18 in which the current Io, the set voltage Vo, the monitor voltage Vm, which is the potential difference at the electric resistance Rm for monitoring the flowing currents and becomes the input voltage of the integrator, and the output voltage Vi of the integrator are drawn graphically against time. When the switch turns on at the time to, the output voltage Vi of the integrator is zero and immediately begins to decrease linearly with $(\Delta V/RC)\cdot t$, where $\Delta V = (-Vm + Vo)$ and Vo, Vm are negative voltage and also Vm=0 at to, t is time, R and C are the resistance and the capacitance of the integrator. It causes an increase in the current Io of the order of milli-ampere through the transistor. The increase in the current also causes an increase of Vm so that the input voltage ΔV of the integrator decreases and brings the rising speed of the current Io more slowly. When the time reaches at any time t1 and then Vm equals to Vo, the current Io becomes constant and can keep its value. Next, if the current changes slightly, say such as $Io+\Delta I$, in that case Vm will immediately increase by ΔVm which is caused by increased ΔI and the output voltage Vi of the integrator will begin to increase with $(\Delta Vm/RC)\cdot t$ from the constant voltage. This slight increase of ΔVm causes a small decrease in the current and when the current goes down to Io, ΔV becomes zero again that means that the current Io goes back to the initial set values. In the case of opposite change, the similar movement is done to keep always Io constant.

The characteristic of the set voltage Vo and the current Io was measured as shown in Fig. 20. The current is linearly proportional to the set voltage and the rate of current and voltage was 105 mA / V.

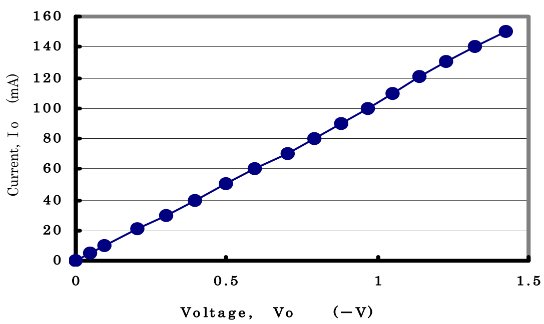


Fig. 20. Measurement result of the relationship between the set voltage Vo and the current lo of the laser diode.

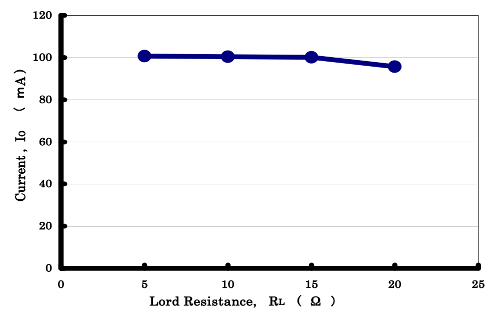


Fig. 21. Measurement result of the relationship between the electric Resistance RL and the current Io to the laser diode.

5.3 The stability of the current Io for electric resistance loads

As described previously the current Io is influenced remarkably by a change in the electric resistance load. Here, the stability for load changes was tested under some values of the electric resistance replaced in the circuit instead of load changes of the laser diode used. The current Io was measured at the values of 5Ω、10Ω、15Ω and 20Ω as shown in Fig. 21. In the figure it is clearly seen that the current Io keeps constant values against the load and the changes of the current in this range was about 5% which shows that the circuit will work well as a constant current supply.

5.4 The modulation characteristics of the electronic voltage signal to the current signal.

Next, the modulation characteristics were measured. The signal modulation is a very important function that converts the electronic voltage signal into the current signal that means the intensity of laser light to be transmitted in optical fiber cable. The modulation circuit is shown in Fig. 22 and consists of a differential amplifier added to the constant current supply circuit. The electric resistance of 10Ω was put in the circuit instead of the laser diode. The electronic voltage signal to be converted into the current is input into the positive input terminal of the amplifier. On the other hand any polarity voltage can be input into the negative input terminal in order to add the biased voltage to the modulation signal. The biased voltage Vb was set at zero. Here, the modulation currents of Im and Id, which is the net current flowing into the laser diode, and the current Io were measured against the input modulation voltage Vm as shown in Fig. 23. It is easily understood that the current Id is inversely proportional to the modulation voltage Vm in the range between 0 and 2.5 volt which shows us that the intensity of laser light emitted from the laser diode will be inversely proportional to the input signal voltage that is equal to the phase difference of π between them as shown in the figure by the sine waves. This was checked on the display of an oscilloscope in which the input voltage signal of modulation and the monitor voltage of the current Id were compared. Also, the biased modulation characteristics was measured when the biased voltage, Vb was set, for example, at 0.5V. Then Im was shifted to a lower level by 4mA which means higher intensity of laser light compared to Vb=0V.

In these ways, three characteristics were measured clearly with more deep understanding of the functions of the circuit using the op amplifiers and the zener diode.

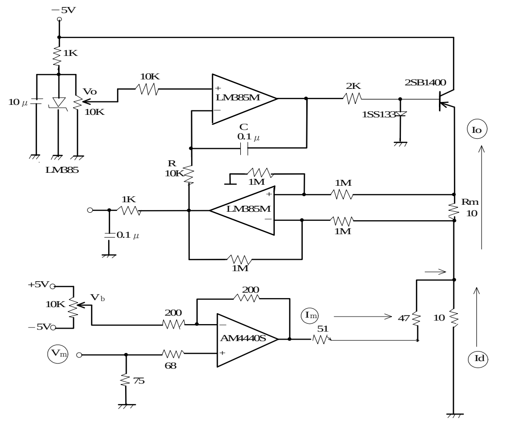


Fig. 22. Modulation circuit. The relationships between the modulation voltage signal Vm and the currents of modulation Im, laser diode Id and the total current Io were measured.

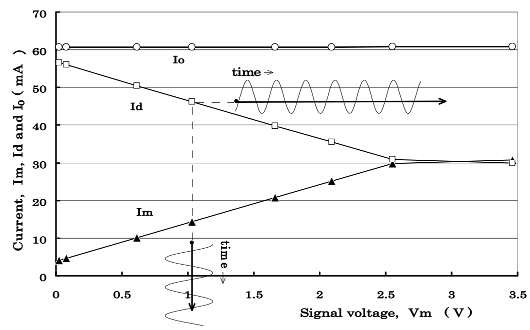


Fig. 23. Measurement result of output voltages of V1 and Vo against the direct input current I.

6. Photodiode Drive Circuit

The characteristic of the photodiode drive circuit whose function is to convert the intensity of the laser light transmitted by an optical fiber cable of 1Km in length with 0.3dB loss per 1Km into the electronic voltage. The photodiode drive circuit is shown in Fig. 24 which is composed of the voltage follower, in which the incoming current from the photodiode is converted into the electronic voltage signal, and then it is amplified in the double at the next differential amplifier. In the training, the two main characteristics of the circuit were measured.

6.1 The characteristics of the input current and the output voltage of the circuit

Before testing the total characteristics of the circuit, the capacitor of 10 μ F at the output of the differential amplifier was removed to measure the dc signal which was simply input by using a dc power supply and an electric resistance.

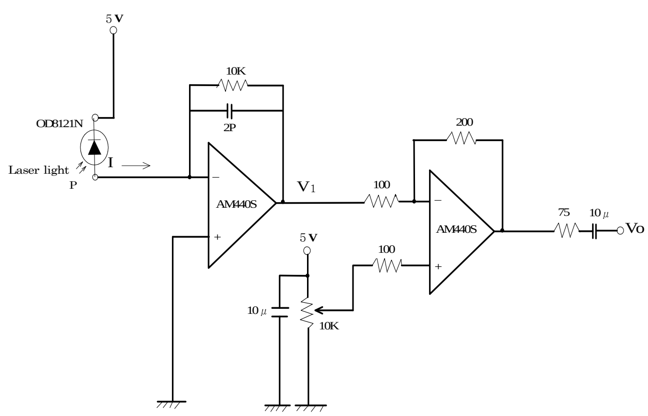


Fig. 24. Photodiode drive circuit.

The out put voltage V1 of the voltage follower and the amplified output voltage Vo were measured as shown in Fig. 25. In the figure the output voltage V1 is almost inversely proportional to the input current I and the ratio of converted voltage and current was −10.7mV per 1 μ A, as expected. The output voltage, Vo was twice of the inverse voltage of V1. Here, the voltage at the noninverting terminal was set at zero in advance.

6. 2　The characteristics of the input power of the laser light and the output voltage.

The characteristics of the intensity of input laser power P from the optical fiber cable and the output voltage Vo was measured and obtained as shown in Fig. 26. The output voltage Vo is almost linearly proportional to the laser power in a range of zero to 140 μ W, and the ratio of the output voltage and the laser power was 21 mV per 1 μ W.

As described up to now, the main characteristics measurements were carried out and good results were obtained which led students to a better understanding of the drive circuits.

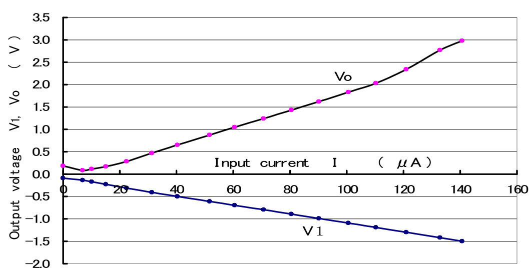


Fig. 25. Measurement results of output voltages of V1 and Vo against the direct input current I.

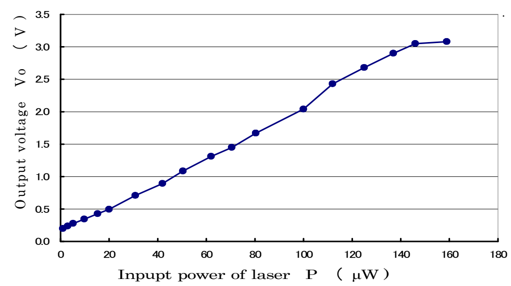


Fig. 26. Relationship between the input laser power P and the output voltage Vo.

7.　Transmission result of the test image by using the fabricated modules and drives

After checking the two drive circuits assembled and also the LD and PD modules fabricated in the training, the image transmission was tested by using them. The image was taken with a video camera and transmitted through the LD module, a fiber cable of 1Km in length with 0.3 dB/Km loss and the PD module, and was displayed on a monitor as shown in Fig. 27.

Fig. 27. Transmitted image of a video camera using the present system.

The image quality was quite good when it expected. The image on the display made students delighted and they really understood that the image signals were sent using laser light when they intercepted the transmission light between the laser diode and the collimator lens to enter the light into the fiber cable in the LD module.

Further training subjects will be considered to make the training more useful from the standpoint of optical fiber telecommunications technology, for example,

1) Accurate measurement of signal and noise ratio,
2) Evaluation of transmitted image quality,
3) Characteristics measurement of light amplifier,
4) Multiwavelength transmission,
5) Environment influence to transmission signal such as temperature, mechanical strength, electric noise and so on.

8. Conclusion

The technical training for fabricating the laser diode and photodiode modules and also assembling the electronic drives for the both modules have been carried out in the student practice to study the basics of optical fiber telecommunications. In the fabricating procedures of the modules, there were a lot of assembly operations needed to adjust the position of the elements of each module with an accuracy of a few micrometers. Manipulators and some special equipment were made and introduced in the practice to do the precise adjustments correctly even by students. The students could experience some precise operations. They also measured the characteristics of the modules which were assembled by themselves and were able to understand the quality of these characteristics and how the optical telecommunication technology is supported by precision machinery and optronics devices. Also, analogue circuits used for the laser diode and photodiode drives were assembled using operational amplifiers and electronic components. They studied about the function of each part of the circuits and the total function of the drives from the measurements of main characteristics of them. Finally, test image with a video camera was transmitted by using the fabricated modules and the assembled drives, and an optical fiber cable of 1 Km in length. The transmitted image was better than expected so that many of the students stared in wonder and were impressed by it when they could see it on a display after some adjustments in the drive circuits. It may be supposed that the transmitted image was vivid for them and was very different from ordinary electronic signals on an oscilloscope that they have been trained on until now. We could say that this training was useful for students and has been successfully carried out. The technical training could be made more efficient by adding some evaluation measurements to the system from a view point of optic telecommunications technology.

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V

WebLab for Measuring the Attenuation Coefficient of an Optical Fiber

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Abstract : The association of web technology with instrument automation and control has made possible the development of the so called Remote Laboratories or WebLabs – distributed environments that allow to access and control experiments remotely through the Internet – extending the interactivity in virtual learning environments to higher levels. In this work we describe the main characteristics of a WebLab developed for the remote measurement of an optical fiber's attenuation coefficient, which is part of an ongoing project whose goal is to implement a photonics remote laboratory aimed to support activities in face-to-face and online courses on optical communications. Preliminary tests on the overall performance of the system have shown very promising results, strongly indicating its potential as a sound and reliable tool for photonics education.

Index Terms - Attenuation Coefficient, Optical Fibers, Remote Laboratory, Virtual Learning Environment.

1. Introduction

The advent of the Internet generated new spaces for communication and collaboration between groups of people in geographically distributed areas. A wide variety of systems based on the web technology has been developed, integrating groupware tools and resources for synchronous and asynchronous communication.

In the educational scenario, these resources have been more and more used to implement on-line learning activities. The web incorporated the so called *Learning Networks* [1], allowing the creation of collaborative virtual learning environments where intense interaction occurs between teachers and students in the process of knowledge acquisition and construction.

The association of web technology with instrument automation and control has made possible the development of the so called Remote Laboratories or WebLabs – distributed environments that allow to access and control experiments remotely through the Internet – extending the interactivity in virtual learning environments to higher levels [2]. Several projects related to the automation and control of real experiments through the Internet have been developed, many focused on educational applications [3].

In this work we describe the main characteristics of a WebLab developed for the remote measurement of an optical fiber attenuation coefficient. This WebLab is part of an ongoing project, developed at the Mackenzie Photonics Laboratory, whose goal is to implement a photonics remote laboratory integrated to a virtual learning environment, aimed to support and complement activities in face-to-face and online courses on optical communications.

2. Structure of the WebLab

The general structure of our WebLab is shown in Figure 1.

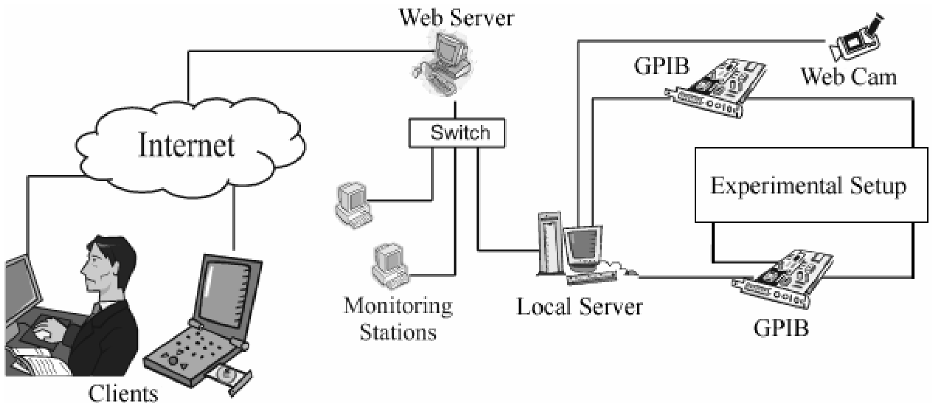

Fig. 1. General structure of the WebLab.

The automation of the experiment is implemented by connecting the instruments to a computer called *Local Server* via GPIB interfaces. A *Switch* is used to connect the *Local Server* to a computer called *Web Server*, responsible for the *Clients* access to the experiment through the Internet, and to local *Monitoring Stations*. Completing the system, a webcam is connected to the *Local Server* for real time instrument visualization and communication between users through videoconference, enhancing interactivity and the sensation of presence during the remote execution of the experiment.

In the system described above, instrument control and data acquisition from a computer called Local Server is performed through GPIB interfaces by using LabView Virtual Instruments (VI). Remote access and control of the experiment is implemented by employing a double client/server architecture [4], as shown in Figure 2.

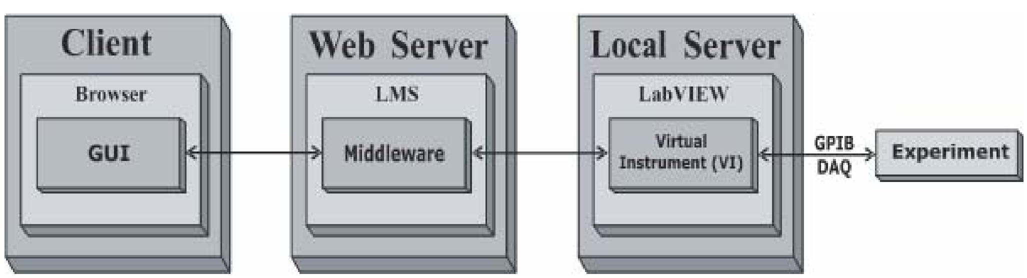

Fig. 2. Double client/server interface architecture.

In such architecture, the communication between the *Client* computers and the *Local Server* is mediated by computer called *Web Server* through a set of interface software applications, denoted by *Middleware*, embedded in a virtual learning environment.

The virtual learning environment is typically a set of integrated tools for user management, instructional content creation and management, on-line communication, assessment and activity tracking. The users access the virtual learning environment via the web browser and remotely control the experiment through a *Graphic User Interface* (GUI) which reproduces and executes the VI in the *Client* computers.

3. Experimental Setup

The experiment chosen to implement the WebLab is the measurement of an optical fiber attenuation coefficient as a function of the injected laser signal wavelength, given by:

$$\Gamma = -\frac{10}{z}\left[\log\left(\frac{P_{out}}{P_{in}}\right)\right] , \quad (1)$$

where z is the fiber's length and P_{in} and P_{out} are respectively the input power and output power measured in Watts.

Our experimental setup, shown in Figure 3, is an adaptation of the traditional *Cutback Method*, which allows the measurement automation and remote control.

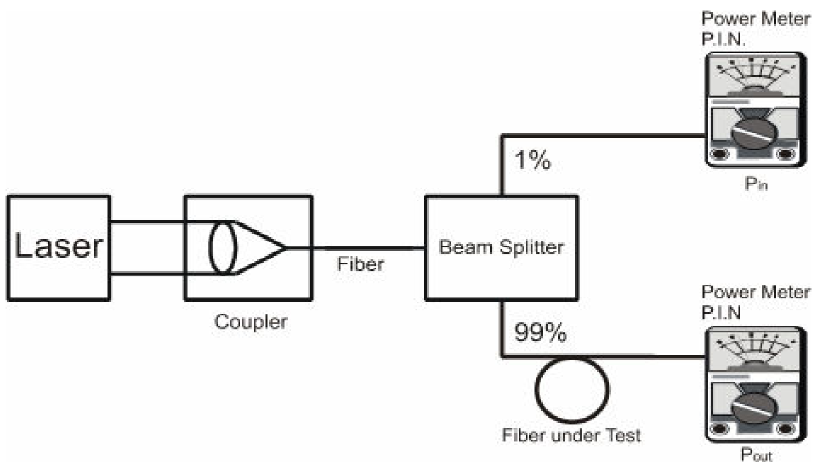

Fig. 3. Experimental setup for the remote measurement of an optical fiber attenuation coefficient.

Instead of cutting the fiber in order to measure the signal input power at each wavelength, as in the traditional Cutback Method, a beam-splitter is used to divide the signal in two parts, such that the input and output power can be simultaneously measured.

4. Virtual Instruments

In Figure 4 we show the Virtual Instrument Front Panel developed to control the experiment.

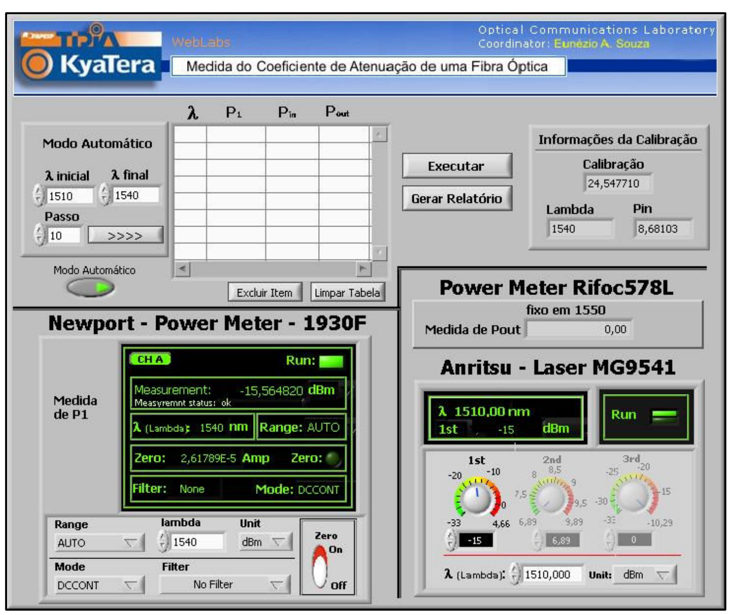

Fig. 4. VI Front Panel used to control the experiment.

The panel on the bottom right allows the user to control the tunable laser:

- Select one of the three channels;
- Control the output power;
- Tune the wavelength;
- Choose the units to be displayed.

Just above, is a panel that allows the user only to monitor the power meter used to measure the output power.
The panel on the bottom left allows the user to control the power meter used to measure the input power:

- Select the channel, range, mode and filter to be used;
- Tune the wavelength;
- Choose the units to be displayed;
- Set the zero power reference.

The panel on the top is used to perform the experiment. The user can select the wavelengths and measure the corresponding input and output powers on the fiber under test one by one or run the experiment automatically, by pre-selecting a number of wavelengths within a given interval.

When the measurements are completed, the user can generate a report that shows the plot of the attenuation coefficient as a function of the wavelength, as shown in Figure 5.

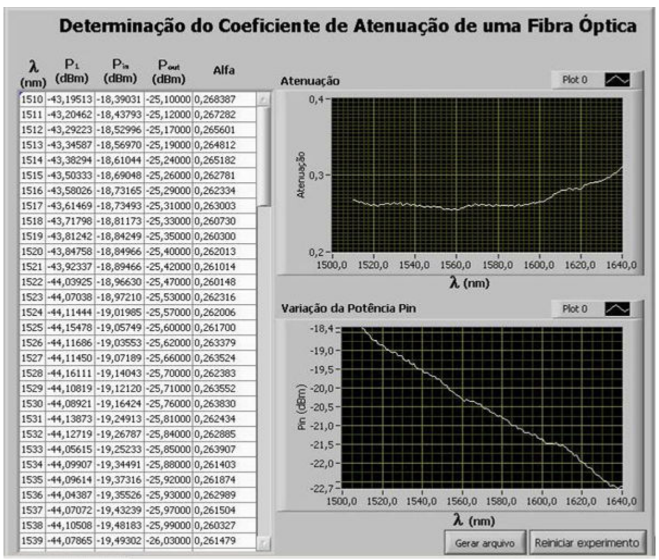

Fig. 5. VI Front Panel presenting the experiment results.

In Figure 6 we show the WebLab video interface, developed using a generic *LabView* webcam driver.

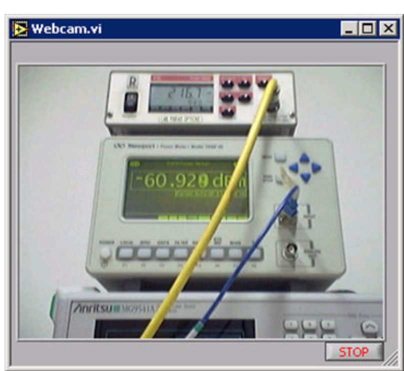

Fig. 6. WebLab video interface.

5. Integration to the virtual learning environment

Our virtual learning environment is implemented with MOODLE (*http://moodle.org*), an open source PHP-based LMS freely distributed under the GNU Public License.

In order to integrate the WebLab to the virtual learning environment we developed a new application, called *WebLab Module*, using PHP scripts and original components from the MOODLE platform [5]. Currently, the *WebLab Module* includes functionalities for user management, registration of remote experiments and configuration of learning activities and assignments.

In Figure 7 we show the *WebLab Module* interface *Description*, which is the first one accessed by the students.

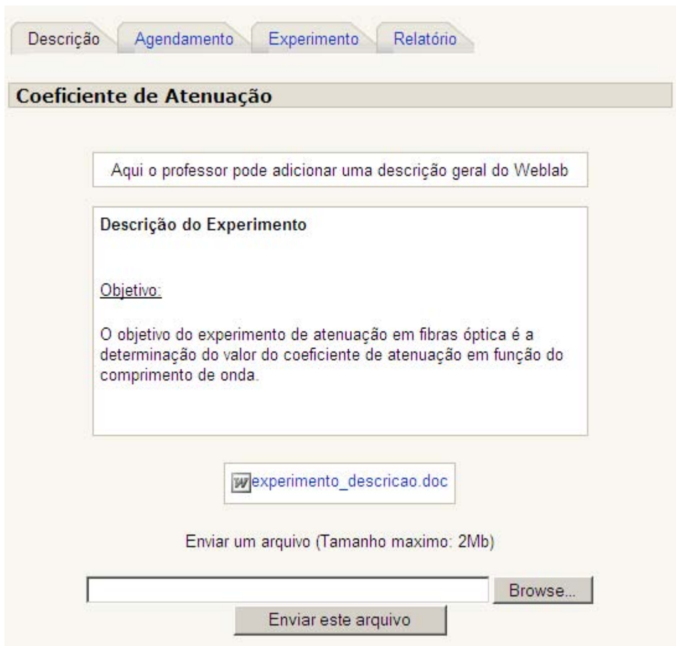

Fig. 7. Interface with the remote experiment description.

In Figure 8 we show the *WebLab Module* interface called *Scheduling,* used by the teacher to create the experiment's execution time slots when configuring a learning activity.

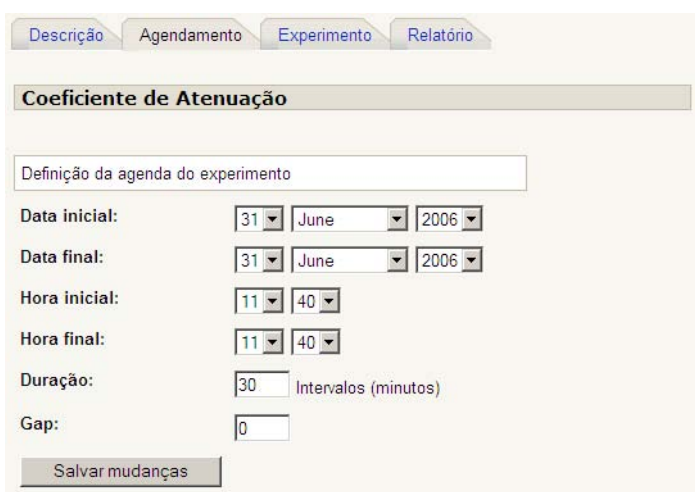

Fig. 8. Interface used to schedule execution time slots.

In Figure 9 we show the *WebLab Module* interface used by the teacher to select a remote experiment.

Fig. 9. Interface used to select a remote experiment.

6. Final Considerations

In this work we described the main characteristics of a WebLab for the remote measurement of an optical fiber's attenuation coefficient. One of the main features of the WebLab is the integration to a virtual learning environment implemented with MOODLE through a component called *WebLab Module.* At the present version, such component allows only for basic functionalities. A deeper integration will be further implemented with the development of *Middleware* components, based on message exchange via SOAP/XML protocol, to mediate communication between the *Clients* and the *Local Server* via the *Web Server*. Such components will allow the WebLab's adaptation within the virtual environment and transparency in remote calls of the experiment's control methods. We also intend to build a more efficient video component based on the framework JMF (Java Media Framework).

Preliminary tests on the overall performance of the system have shown very promising results, strongly indicating its potential as a sound and reliable tool for photonics education.

Acknowledgements

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VI

Temporal coherence characteristics of a superluminescent diode system with an optical feedback mechanism

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Abstract: We explore the temporal coherence characteristics of the output light of a SLD system with different optical feedback ratios by a Michelson interferometer, and we also observe the long-scan-range interference patterns with the one by one wave packets due to the Fabry-Perot modulation of the SLD device. We can obtain the effective cavity length of the SLD active layer and get more information of the temporal coherence length or spectral width from the long-scan-range interference patterns. This tunable light source system can provide more insights into the optical coherence or lasing phenomena often discussed in the optics course.

OCIS codes: (140.2020) Diode lasers; (030.1640) Coherence

1. Introduction

Broadband light sources such as light-emitting diodes (LEDs) and superluminescent diodes (SLDs) have been widely used for the optical measurement [1], and especially the SLD broadband source has been playing an important role in the optical coherence tomography system [2,3]. High output power and large optical bandwidth are key features for the SLD, and the extremely high optical gain in SLD active region may result in very high optical power sensitivity to external optical feedback [4]. Thus, once stimulated emission due to optical feedback occurs, the output light intensity could be increased to achieve optical amplification, and the evident variation of the spectrum shape and temporal coherence length could also be observed.

In this study, we have constructed an experimental system using a non-fiber-coupled SLD device with optical feedback as the light source to observe the output optical spectra by an optical spectrum analyzer, and to investigate the temporal coherence characteristics of the SLD output light by a Michelson interferometer with the short-scan-range and long-scan-range interference patterns.

2. Measurement of the output optical spectra

2.1 Experimental setup

We use a SLD broadband light-emitting device (HAMAMATSU 8414-04) [5] as the light source of the experimental system subjected to an optical feedback mechanism, as described schematically in Fig. 1. The output light of the SLD device is collimated by a focusing lens, and then is divided into the reflection arm (70%) and the output arm (30%) using a cubic beam splitter (BS). A mirror M is used to reflect the light in the reflection arm back into the SLD device, producing external optical feedback to enhance the stimulated emission light. We can control the optical intensity of feedback by placing a neutral density filter (NDF) between the beam splitter BS and the mirror M. The feedback ratio is equal to $(P_r / P_i)^2$, where the P_i is the initial optical power of the output light emitted directly from the SLD device and the P_r is the optical power of the light passing through the NDF in the reflection arm. We measure the output spectra of the SLD system at various optical feedback ratios, and then calculate the spectral widths.

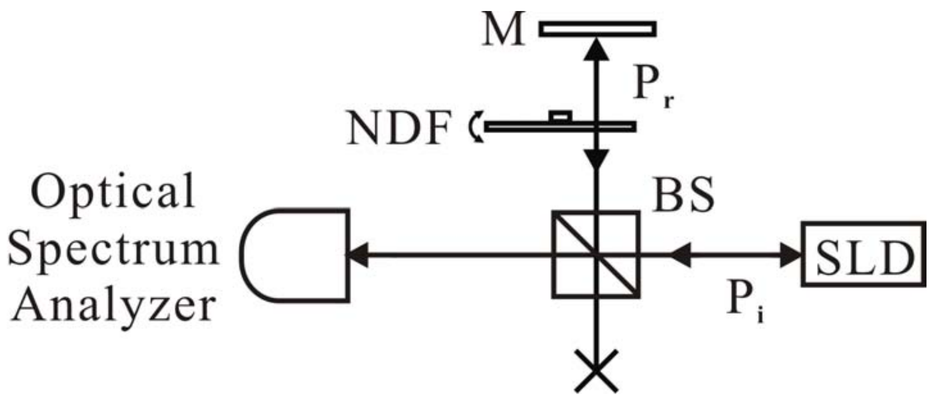

Fig. 1. Experimental setup of the SLD system subjected to a tunable optical feedback mechanism. BS, beam splitter. NDF, neutral density filter. M, mirror.

2.2 The output spectrum characteristics

We measure the SLD output spectra by an optical spectrum analyzer with a resolution limit of 0.01 nm. Fig. 2(a) shows the measured spectrum of the spontaneous emission light from a SLD system without optical feedback, and we get that the center wavelength is at 836 nm and the spectral width is 21.75 nm. The spectrum with the center wavelength at about 838 nm of the stimulated emission light from a SLD system with optical feedback is shown in Fig. 2(b). The mode spacing of the stimulated emission light is measured to be about 0.343 nm, referring to the internal-cavity longitudinal modes of the SLD device. These internal-cavity resonant modes tell us that the laser oscillation in the SLD system with optical feedback is indeed real. Accordingly, the effective cavity length of the SLD active layer is calculated to be 1.038 mm.

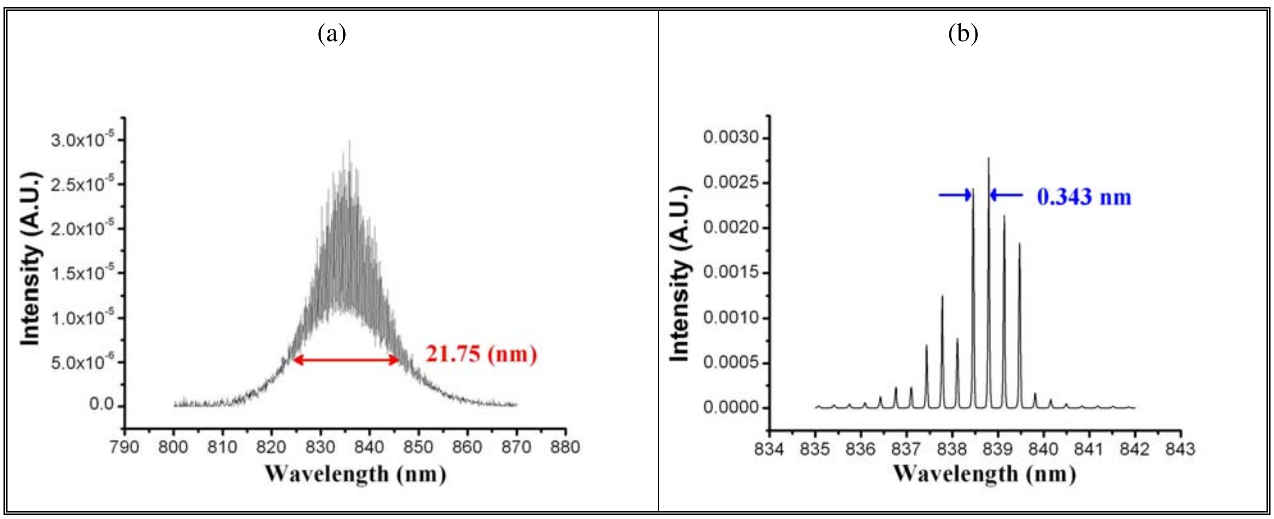

Fig. 2. (a) The spectrum of the spontaneous emission light from a SLD system without optical feedback. (b) The spectrum of the stimulated emission light from a lasing SLD system with optical feedback.

Furthermore, we plot the spectral width (FWHM) of the SLD output spectrum versus different feedback ratios in Fig. 3. As the feedback ratio is raised the spectral width of the SLD output light becomes narrower, because the stimulated emission light due to optical feedback will compete for the gain. However, having excessive optical feedback can cause the spectral width to become broader. From this relationship, we can know that the spectral width of the SLD output spectrum can be tuned via adjusting the feedback ratio. As a result, we deduce that the temporal coherence characteristics of the output light from a SLD system with optical feedback should be also tunable, which will be explored in the next section.

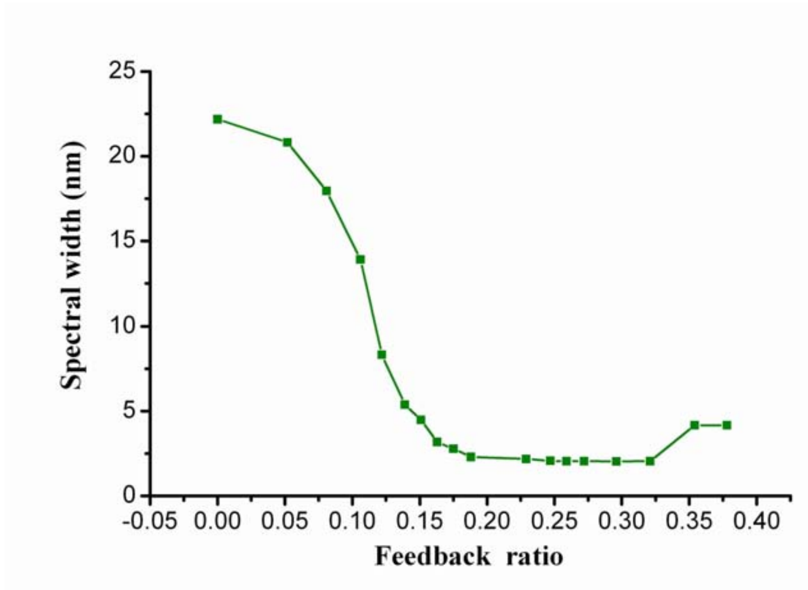

Fig. 3. The spectral width (FWHM) versus the feedback ratio curve.

3. Investigation of the temporal coherence characteristics by a Michelson interferometer

3.1 Experimental setups

We construct a SLD system subjected to an optical feedback mechanism, and then utilize a Michelson interferometer in the output arm to observe interference patterns and measure the temporal coherence length by moving one of the mirrors, as shown in Fig. 4. We monitor the interference signals by an oscilloscope for two cases, namely one is with short-scan-range and another is with long-scan-range. Besides, we also explore the temporal coherence characteristics of the output light of the SLD system at various optical feedback ratios.

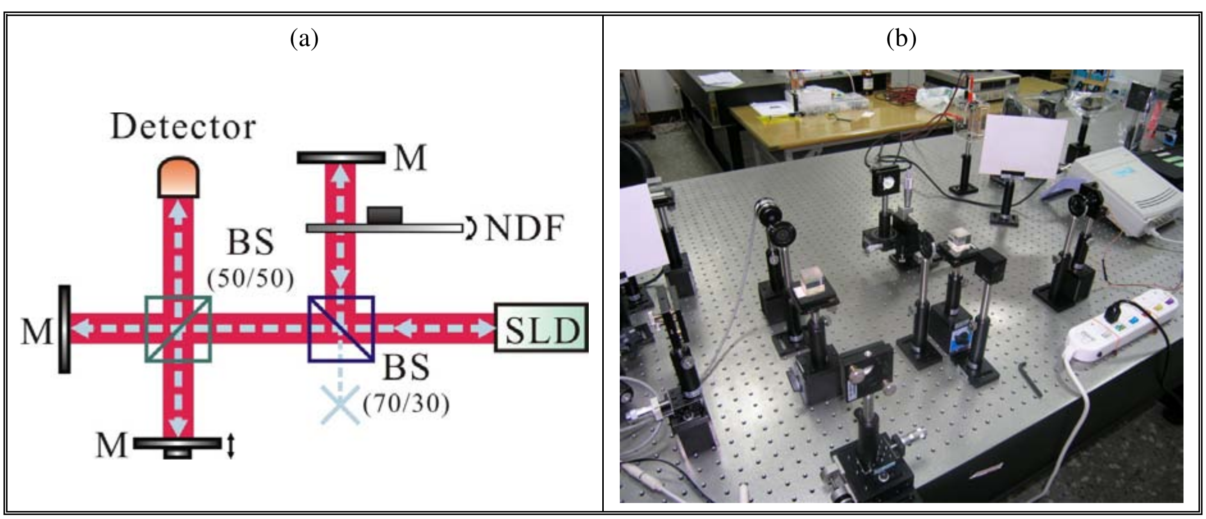

Fig. 4. (a) The schematic diagram of the experimental setup for observing the degree of temporal coherence. BS (70/30), beam splitter with the ratio of separating light of reflection and transmission at 70:30. BS (50/50), beam splitter with the ratio of separating light at 50:50. NDF, neutral density filter. M, mirror. (b) The photograph of the experimental setup.

3.2 The short-scan-range interference results

We first observe the short-scan-range interference patterns of the spontaneous emission light from a SLD system without optical feedback, and those of the stimulated emission light from a SLD system with maximum optical feedback. Figure 5 shows the experimental setups and measurement results. As shown in Fig. 5(a), the measured coherence length of the spontaneous emission light of SLD equals 14.285 μm which is almost identical to the theoretical value $L_c = 0.44\times\lambda_0^2/\Delta\lambda = 14.14$ μm, where $\lambda_0 = 836$ nm and $\Delta\lambda = 21.75$ nm. The error is about 1.025 %, so the measured value by interference is very precise. Another case with maximum optical feedback is shown in Fig. 5(b) with much longer coherence length, and the measured scan distance between two adjacent peaks of interference signal is 425.6 nm, which is just about one half of the center lasing wavelength ($\lambda = 838$ nm), fulfilling the requirement of a Michelson interferometer. The error is about 1.575 %, so the measured value of the lasing wavelength by interference is almost identical with the theoretical value.

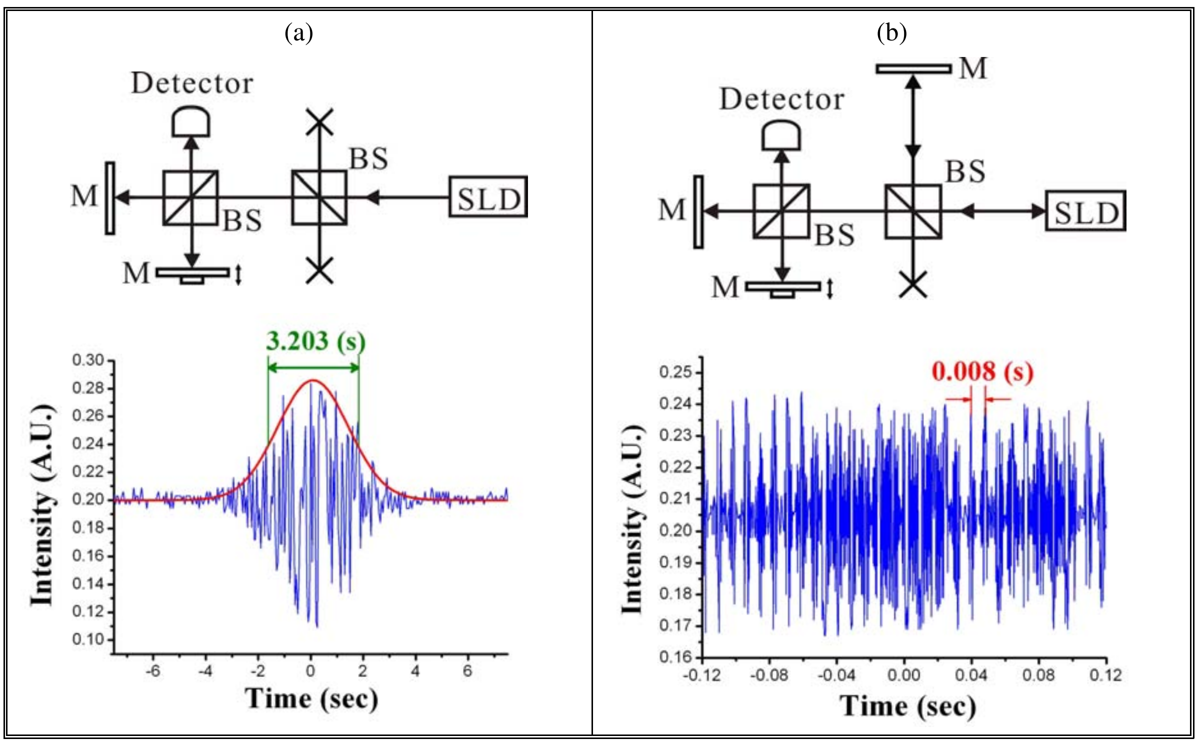

Fig. 5. Experimental setups (top) and measured interference patterns (bottom) for (a) the case without optical feedback at a constant scan speed of 4.46 μm/s, and for (b) another case with maximum optical feedback at a constant scan speed of 53.2 μm/s.

3.3 The long-scan-range interference results

We next observe the long-scan-range interference patterns with one by one wave packets of the SLD system at various optical feedback ratios. The one by one wave packets of interference patterns are caused by the Fabry-Perot modulation of the SLD device, and the schematic diagram of the optical paths due to multiple reflections in the SLD active layer is shown in Fig. 6(a). We assume that the output light of the SLD system can be imagined effectively as multiple wave packets by analogy. For different degrees of temporal coherence of output light, the widths of the effective wave packet and the corresponding interference patterns are different. In Fig. 6(b), there is the long-scan-range interference pattern of the spontaneous emission light of SLD. From the wave packet model, the value of wave packet separation is 1.036 mm, which equals the effective cavity length of the SLD active layer, nL_a, where L_a is the length of the SLD active layer and n is effective refractive index for optical mode. The long-scan-range interference pattern of the stable laser output of a SLD system with an optical feedback ratio at 0.25 has a larger interference wave packet width due to a longer temporal coherence length, as shown in Fig. 6(c). The interference pattern for the case with an optical feedback ratio at 0.37 has a separation of wave packets similar to the case without feedback, but has a broader expansion of multiple wave packets due to the higher optical power output when the SLD system is in lasing resonance, as shown in Fig. 6(d). Hence the temporal coherence length (or the interference wave packet width) of the output light of the SLD system can be tuned by varying the feedback ratio. The relationship of the temporal coherence length of the long-scan-range interference pattern versus different feedback ratios is found to be similar to that of the spectral width of the SLD output spectrum versus different feedback ratios.

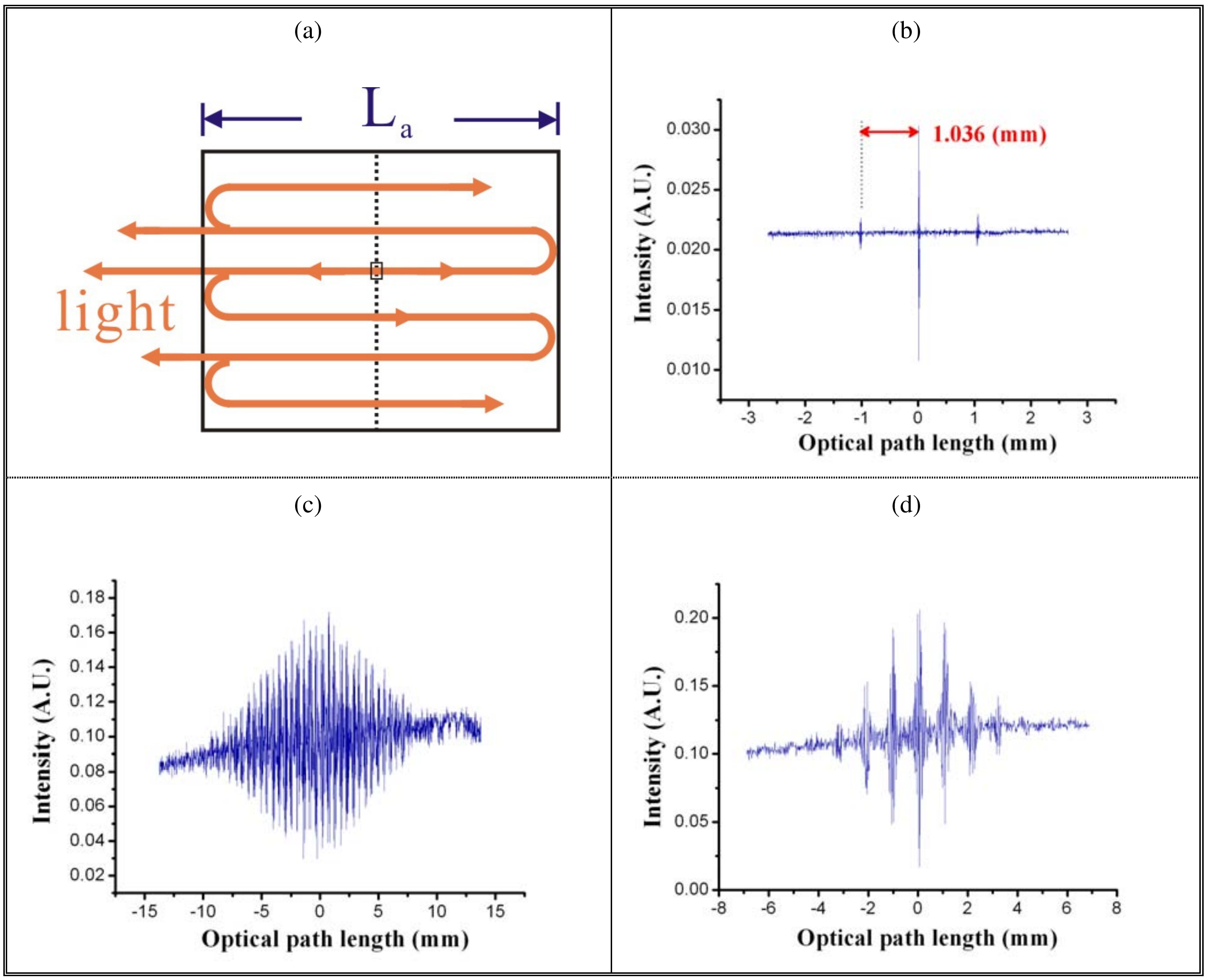

Fig. 6. (a) The schematic diagram of the optical paths due to multiple reflections in the SLD active layer. The long-scan-range interference patterns of the SLD system with different optical feedback ratios: (b) feedback ratio at 0, (c) feedback ratio at 0.25, and (d) feedback ratio at 0.37.

4. Conclusion

The evident variation of the temporal coherence characteristics between the spontaneous emission and the stimulated emission output light of the SLD system could be observed by a Michelson interferometer. By adjusting the feedback ratio, we could obtain different types of long-scan-range interference patterns with variable multiple interference wave packets due to the Fabry-Perot modulation of SLD device. From these interference patterns, we can estimate the effective cavity length of the SLD active layer. This tunable light source system can provide more insights into the optical coherence or lasing phenomena often discussed in the optics course.

Acknowledgements

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VII.

Practical Introduction to Optical WDM Components and Systems in Student Teaching Laboratories

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Abstract

In this paper we describe a new family of teaching packages designed to offer a practical introduction for graduate students of Science and Engineering to the topic of wavelength division multiplexing (WDM) in fibre optics. The teaching packages described here provide students with the background theory before embarking on a series of practical experiments to demonstrate the operation and characterisation of WDM components and systems. The packages are designed in a modular format to allow the user to develop from the fundamentals of fibre optical components through to the concepts of WDM and dense WDM (DWDM) systems and onto advanced topics covering aspects of Bragg gratings. This paper examines the educational objectives, background theory, and typical results for these educational packages.

1. Introduction

Optical fibre communications has proved to be one of the key application areas, which created, and ultimately propelled the global growth of the photonics industry over the last twenty years. Consequently the teaching of the principles of optical fibre communications has become integral to many university courses covering photonics technology. However to reinforce the fundamental principles and key technical issues students examine in their lecture courses and to develop their experimental skills, it is critical that the students also obtain hands-on practical experience of photonics components, instruments and systems in an associated teaching laboratory. In recognition of this need OptoSci Ltd, in collaboration with academics at Strathclyde and Heriot-Watt Universities, has commercially developed a suite of fully self-contained laboratory based photonics teaching packages for use in universities, colleges, and industrial training centres. This range of packages covering topics from the fundamentals of physical optics through to fibre optic communications, optical network analysis and optical amplifiers has been described in detail previously [1,2,3,4].

In the 1990s, the advent of practical wavelength division multiplexing (WDM) systems revolutionised the fibre optic communications industry by enabling unprecedented increases in data rate over optical fibre. The commercial exploitation of WDM required the development of new components to provide certain required functionality such as multiplexing, demultiplexing and wavelength routing. In addition, existing component technologies had to be adapted to operate to the new specifications required by WDM systems such as the fused fibre biconical taper (FBT) couplers and WDMs used in the EDFAs or the high rejection ratio isolators / circulators used to eliminate feedback to the lasers. In light of this OptoSci Ltd. have designed the ED-WDM series of educator kits to provide students and trainees with a good working knowledge and understanding WDM systems, the components used in them and the measurement techniques used to establish the specifications of these components.

The objectives of the ED-WDM series are to enable students

- to develop a practical understanding and knowledge of the components used in optical networks in general and in WDM networks in particular.
- to acquire a knowledge and understanding of the measurement techniques used to establish component specifications and the practical skills to make these measurements and
- to develop a practical appreciation and understanding of the principles and characteristics of WDM systems.

2. Design Philosophy

The overall educational aims of a teaching laboratory are to enable students to consolidate their understanding and knowledge of photonics as presented in an accompanying lecture course and to acquire practical experience of the design, analysis and characteristics of photonics components and systems. To achieve these aims it is essential to take a fully integrated approach to the design of laboratory based photonics teaching packages including the design of dedicated hardware, experimental procedures, exercises and manuals. To ensure that all desirable educational objectives are met and that all of the most important scientific and technical principles, issues and phenomena are addressed, we have developed our suite of fully integrated laboratory based teaching packages in accordance with the following design rules:

- Define the educational objectives in terms of the physical principles, important technical features, design issues and performance characteristics which must be addressed, with particular attention to facilitating student understanding and ability to implement concepts.
- Define the experiments to meet these performance objectives.
- Design the dedicated (custom) hardware to enable the proposed experimental investigation whilst keeping costs within realistic academic teaching budgets.
- Formulate the experimental procedure and manuals to guide the students through the investigation and results analysis (in some cases more open ended investigations may be formulated with minimal guidance to the students).

The primary constraint is cost and the final packages must be affordable within higher education budgets. In general, the packages have been designed as far as possible to be self-contained so that as little ancillary equipment as possible is required. However, where it is advantageous and cost effective to use equipment normally available in student laboratories, the packages have been designed to be compatible with the capabilities of such equipment e.g. a 20MHz or 50MHz oscilloscope.

3. Package Contents

3.1 Hardware

The ED-WDM series is designed in a modular format using the industry standard 19" rack system. The complete version of the kit occupies two 3Ux84HP enclosures, the Optical Components Rack and the Electronics Rack, as shown in Figure 1. Each component part is contained in a standard 3Ux10HP cassette. This modular approach allows the system to be built up from the basics to more advanced levels.

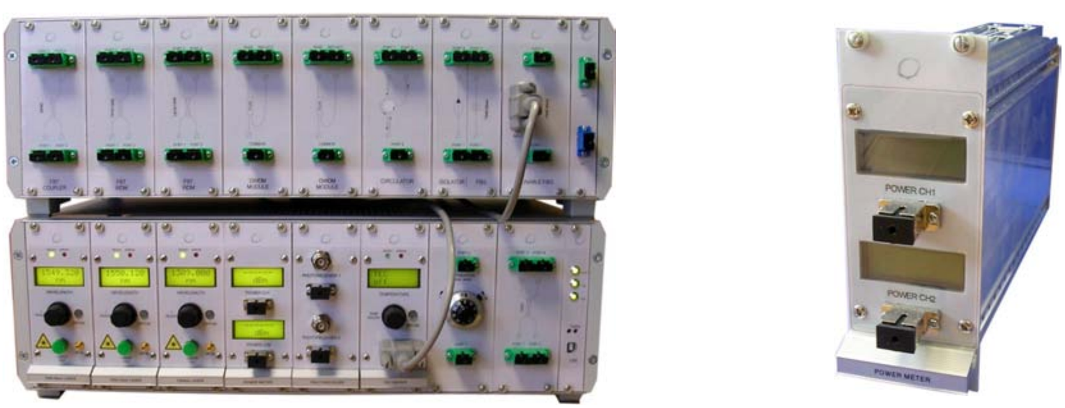


Figure 1: *Complete ED-WDM educator kit and individual power meter module*

The Optical Components rack is intended to house a range of passive components modules such as couplers, WDMs, an isolator, a circulator and fibre Bragg gratings. Patchcords are provided to allow the external connection between the module as required by the experimental procedures. An SC/APC style of connector is used predominately in the kit to allow easy reconfiguring of the optical set-ups and to minimise spurious backreflections.

The Electronics Rack is designed to house the lasers, power meters, photoreceivers and TEC controllers along with a variable optical attenuator and 50:50 coupler. This provides the instrumentation to allow the interrogation and investigation of the WDM components and systems. It is also fitted with a USB interface to allow PC control & monitoring of the instrument by the dedicated driver & display software supplied with the kit

The electronics modules are described below:-

Laser Diode Modules - self contained units housing a DFB laser and drive electronics. The lasers are set to emit a constant power (≈0dBm) output over a 1-2nm range of wavelengths around the specified λ_c. The operating wavelength of the laser can be adjusted by a λ-adjust knob on the front panel or by computer control. The operating wavelength is displayed on a LCD display. RF modulation may be applied to the laser via a panel mounted SMB connector.

Power Meter Module - contains twin optical power meters using SC mounted InGaAs photodiodes. These are calibrated in dBm at 1550nm to display incident powers up to a maximum of +3dBm.

Photoreceiver Module - contains twin wideband (100MHz) photoreceivers using SC mounted InGaAs photodiodes. The maximum recommended peak power to avoid signal distortion is -8dBm. Fixed attenuators are supplied to allow higher powers to be detected where required. The output from the photodiodes is available from panel mounted BNC connectors.

TEC Driver Module - houses the driver for an external Thermo-Electric-Cooler (TEC) which can be connected via a front panel connector. An LCD displays the Setpoint Temperature in the upper line and the Actual Temperature on the lower. The ON/OFF button can used to re-initialise the TEC in the event of an ERROR condition.

3.2 Software

The software provided with the ED-WDM series has three parts:

LVI Plotter - to enable the characterisation of the laser sources by automatically sweeping the drive current of the laser over their operating range and logging the results from the power meter.

λ-Scan - to perform an automated narrowband wavelength scan (~2nm) of the DFB laser, which can be used in conjunction with the power meter modules for spectral characterisation of the DWDM components.

Dispersion_Test - which is used for fibre length and chromatic dispersion measurements

3.3 Literature

As with all OptoSci kits the education objective is to provide a comprehensive package to the educator hence extensive literature support is provided. The literature pack for the ED-WDM series is split into three sections:

Laboratory manuals – introducing students to the underlying concepts and architectures of WDM before looking at detail at the components used within such systems. The different technologies used in the realisation of WDM components are then explained and the key operation parameters and limitations identified. This leads onto the experimental exercises which detail the characterisation techniques and procedures required to measure the component performance.

Instructor supplement - containing full sample results and worked examples along with practical notes to assist the instructor.

General Appendices – which contain information on Laser Safety, additional background of DWDM systems such as the ITU grid structure and, crucially, practical tips on aspects of basic handling and care of fibre optic parts which may be necessary for students new to the topic. (This practical tip section has been included in light of feedback from students and instructors, who perhaps had limited experience of fibre optics, experiencing problems with the optical connectors styles and care of fibres.)

4. Experimentation

The ED-WDM series currently addresses four main areas – WDM components, 1310/1550nm WDM systems, DWDM systems and Fibre Bragg gratings. The ***ED-WDM: WDM Components*** kit is designed as the basic kit to introduce students to the fundamentals of WDM components and establish the basis of WDM systems. The other topics are addressed by extension modules which provide additional hardware to enable the students to investigate the specific aspects of WDM systems or Bragg gratings. Each of the study areas is described below with examples of the experiments and sample results.

4.1 WDM Components

As mentioned above the ***ED-WDM: WDM Components*** kit is intended as the starting point of the suite. The kit contains a ITU grid DFB laser ($\lambda_c \approx 1550$nm), a pair of InGaAs power meters and a variety of standard optical components that are typically present in WDM systems. The components for characterisation include fused fibre couplers, a fuse fibre 1310/1550nm WDM, a micro-optic add-drop multiplexer (OADM) operating at the DFB wavelength, an isolator, a circulator and a fibre Bragg grating.

The kit provides students with the theory and practical ability to study the basics of optical component operation and characterisation. To achieve these objectives the following tasks are carried out:

- Measurement of light, voltage & current (LVI) characteristics of a DFB laser with operating temperature
- Measurement of insertion loss, directivity and backreflection/return loss for a series of fibre optic components (i.e. coupler, WDM, isolator, circulator, DWDM Mux/Demux devices)
- Determination of isolation / extinction ratios in various optical components
- Examination of narrowband wavelength responses of a number of optical components

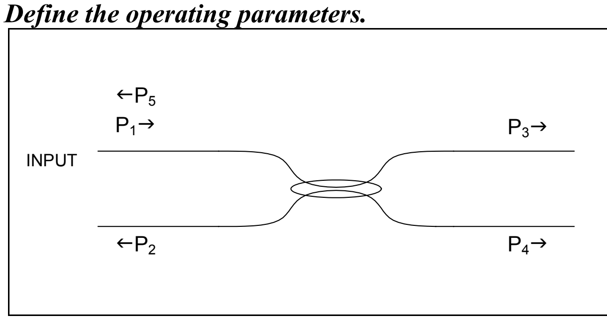
4.1.1 Component Characterisation

From the theory presented to the students they should have gained an understanding of the background and operation of each component supplied in the package. The experimental process now commences to perform the characterisation of the key physical parameters highlighted in the previous discussion. A standardised approach of presenting the relevant information and detailing the characterisation techniques for each individual component is used in the kit. Each component investigation may then be considered a complete task in itself, allowing the instructor to select which component or components he wishes the students to study.

4.1.1.1 Fused Fibre Coupler

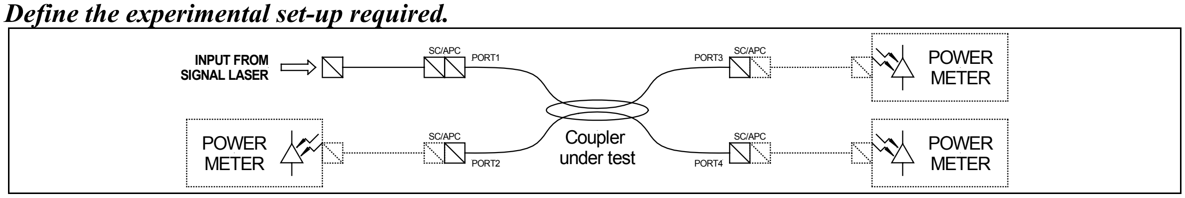
An example of the approach used is presented below for the case of a fused fibre coupler:

A) Define the operating parameters.



Insertion Loss (log measurements)	$[P_1 - P_3]\, dB$ $[P_1 - P_4]\, dB$
Coupling Ratio (linear measurements)	$\left[\dfrac{P_4}{P_3 + P_4}\right] \times 100\%$
Excess Loss (linear measurements)	$-10\, log_{10}\left[\dfrac{P_3 + P_4}{P_1}\right] dB$

B) Define the experimental set-up required.



C) Detail the measurements required and optical connections that should be made.

1. Connect the 1550nm laser directly to the power meter using the hybrid FC/APC to SC/APC patchcord and measure / note the input power to Port 1 of the coupler. Now connect the hybrid patchcord directly to Port 1 of the Coupler being tested as shown in experimental set-up. Measure the powers emitted from Ports 2, 3 and 4 by connecting them in turn to the Power Meter via standard SC/APC patchcords.

2. Now, connect the 1550nm laser to Port 2 and repeat step 1.

D) Analyse the results obtained and comment on the operation of the component being tested.

Note the measured powers in logarithmic (dBm) and linear form (mW – calculated from the measured Log values as in Appendix 2). From these measurements calculate values for insertion loss, coupling ratio, and excess loss as detailed above.

Comment on your results.

E) A sample set of results and worked example of the analysis is presented in the Instructor Supplement.

Measurement	**dBm**	**mW**
TEST OUTPUT (Port 1)	-2.75	0.531
Port 3	-4.20	0.380
Port 4	-10.24	0.0946
Parameter	**Calculation**	**Result**
Insertion loss to Port 3	(-2.75) - (-4.20)dB	1.45 dB
Insertion loss to Port 4	(-2.75) - (-10.24) dB	7.49 dB
Coupling ratio	$\frac{0.0946}{0.380+0.0946}\times 100\%$	19.93%
Excess loss	$-10\log_{10}\left[\frac{0.380+0.0946}{0.531}\right]$	0.48 dB
Discussion		
From these results the student should report that the coupler has a coupling ratio of 20% at 1550nm. When the input is made to Port 2 of the coupler the outputs should switch i.e. Port 3 should now the 20% output.		

4.1.1.2 Other Components

A similar process is then followed for each component to examine the relevant parameters as listed below:

Component	**Parameters Examined**
Fused Fibre WDM	Insertion loss, Wavelength Isolation, Excess Loss
Isolator, Circulator	Insertion Loss, Isolation, Return Loss
DWDM	Insertion Loss, Wavelength Isolation
Fibre Bragg grating	Insertion Loss, Reflectivity

4.1.2 Automated Measurements

If computer control is available the spectral behaviour of the DWDM components can also be examined using the *λ-scan* software program. This is suited to the study of the narrowband components i.e. the OADMs and the Bragg gratings. The set-up shown in Figure 2 allow both arms of the multiplexer to be studied simultaneously using *λ-scan.*

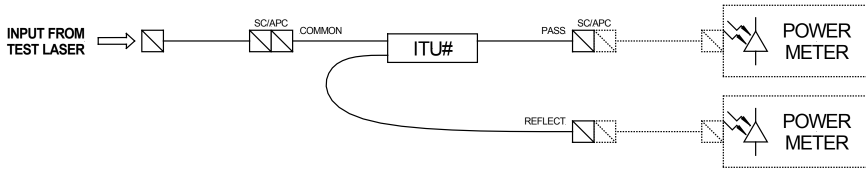
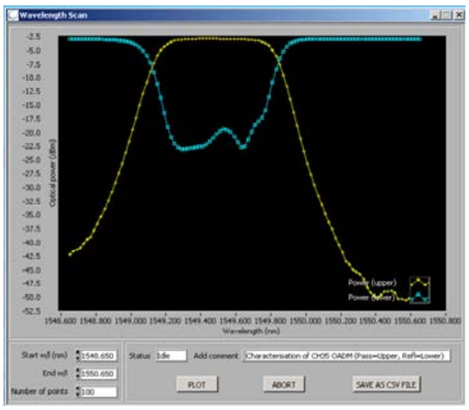
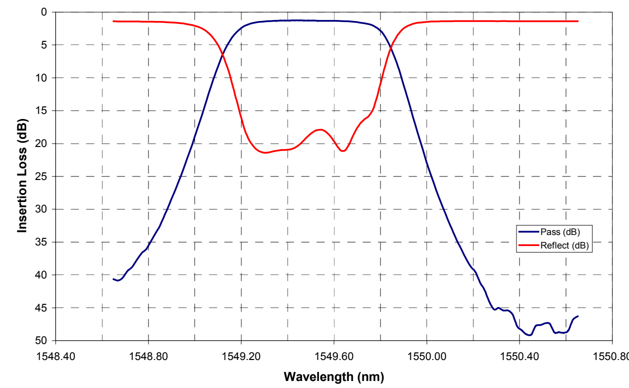


Figure 2: *Experimental set-up for spectral behaviour of the OADM*

A typical results screen is shown in Figure 3(a), the students are directed save the data sets for further processing to normalise the plot and yield the actual insertion losses to each arm, as displayed in Figure 3(b).





(a) *(b)*

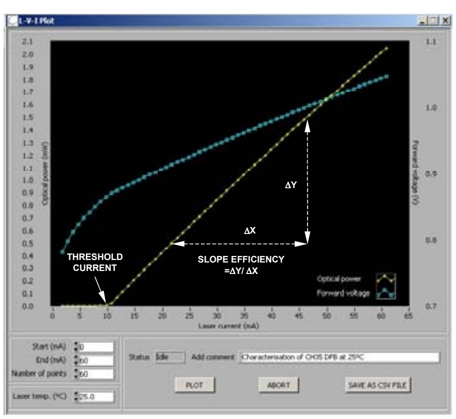
Figure 3: *Spectral characterisation of OADM: (a) Screenshot from λ-scan and (b) Processed data*

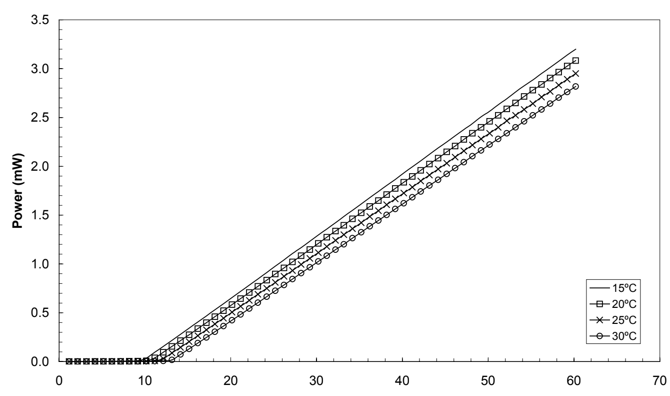
The software thus offers a simple way to acquiring the full spectral characteristic of the components, this is especially beneficial when dealing with the very narrow features associated with the fibre Bragg gratings as will been seen later.

4.1.3 DFB LVI plots

As one of the most important parts if the WDM systems, the students then carry on to investigate the operation of an DFB laser.

The DFB laser characteristics may be obtained using computer control and the LVI plotting software. Figure 4 shows a typical LVI plotter window from the software and the results of a series of L-I plots for a laser with variation of operating temperature.





(a) *(b)*

Figure 4: *DFB laser characteristics: (a) LVI plotter window and (b) L-I plots against temperature.*

As the operating temperature of the 1550nm laser is increased the threshold current is seen to increase and the slope efficiency decrease. Over this limited temperature range the results show the threshold current temperature dependence is 0.25mA/°C.

This should highlight to the students the marked temperature dependence of the laser characteristics thus making it imperative to have close control, not only for wavelength stability, but also to provide stable laser output power levels for DWDM systems.

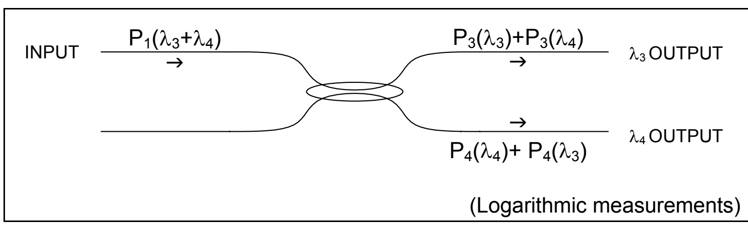
4.2 1310/1550 WDM Systems

The first of the extension kits expands the fundamentals developed in the components characterisation kit to allow the investigation of practical WDM systems working at 1310/1550nm. The extension includes a second laser (λ_c=1310nm), dual photoreceivers and an additional fused fibre 1310/1550nm WDM and a reel of singlemode fibre. To study these WDM systems the students are directed to complete the tasks listed below:

- Measurement of insertion losses and backreflection / return losses for various components supplied with ED-WDM: WDM Components at 1310nm and comparison with 1550nm measurements.
- Assembly, demonstration and characterisation of a two channel 1310nm & 1550nm WDM system
- Fibre attenuation, length and chromatic dispersion measurements at 1310nm & 1550nm.

4.2.1 Component characterisation at 1310nm

By repeating the component characterisation process at 1310nm the students will gain an insight into the broadband spectral behaviour of fibre optic components. In the kit a standard coupler and dual-window coupler are supplied to highlight different types that may be encountered, the dual window should show similar operation at both 1310nm and 1550nm whereas the standard type will operate only as specified at 1550nm. The micro-optic components (i.e. isolator and circulator) are specified at 1550nm hence the students should find operation at 1310nm to be outwith the expected values. Most importantly the availability of the second wavelength laser allows the complete characterisation of the fused fibre WDM as shown in Figure 5.



Insertion Loss (λ_3)	$[P_1(\lambda_3)-P_3(\lambda_3)]\,dB$
Insertion Loss (λ_4)	$[P_1(\lambda_4)-P_4(\lambda_4)]\,dB$
Isolation (λ_3)	$[P_3(\lambda_3)-P_4(\lambda_3)]\,dB$
Isolation (λ_4)	$[P_4(\lambda_4)-P_3(\lambda_4)]\,dB$

Figure 5: *1310/1550nm WDM definitions*

From this series of measurements the students are asked to identify suitable connections to obtain the desired multiplexing and demultiplexing operations required for the WDM systems below.

4.2.2 1310/1550 WDM Systems

The basic characterisation of a simple WDM system shown in Figure 6 is carried out in a similar way to the single component by noting the power levels at either output from each input laser.

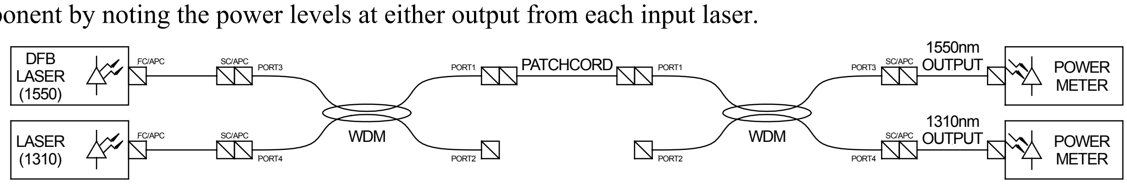


Figure 6: *Basic two-channel WDM system*

In order to demonstrate the effects of multiplexing at each point in the system the lasers are then modulated with different signals. Photoreceivers are used to examine the output waveforms after multiplexing and demultiplexing on a suitable oscilloscope. The system and typical results are shown in Figure 7.

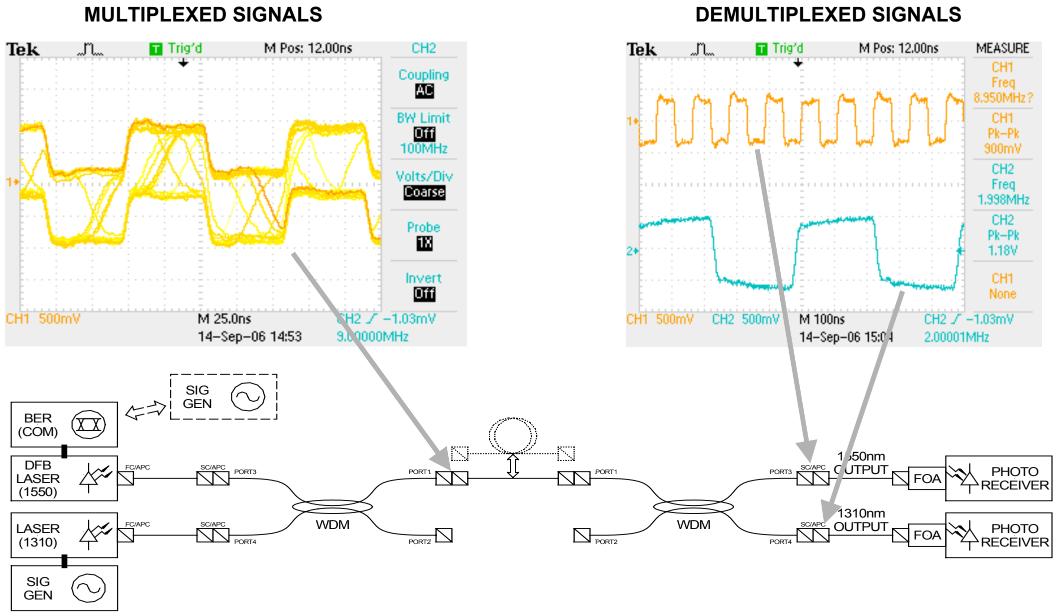


Figure 7: *WDM demonstration*

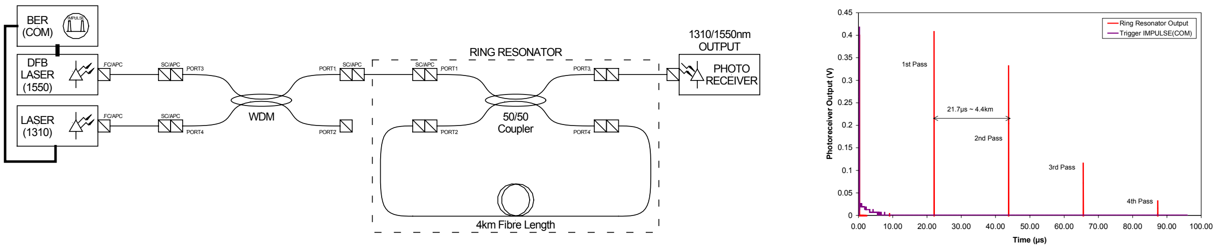
4.2.3 Characteristics of Optical Fibre

The channel in any communications system comprises every element between the output of the transmitter and the input to the receiver. In an optical system the channel comprises the optical fibre cable plus a few connectors and/ or splices, the receiver and transmitter interfaces (i.e. the terminations) and, in very long distance links, repeaters. The properties of the channel have a strong influence on the performance of the complete system. Digital signals transmitted by the channel are degraded by power loss (attenuation) and pulse spreading (dispersion) in the cabled optical fibre and additional losses are incurred at the splices, connectors and terminations. These effects in turn have a significant bearing on the maximum link length and bit rate.

OptoSci's ED-COM, Fibre Optic Communications, and BER(COM) kits examine these effects in detail using LED and laser sources at wavelengths around 800nm and multimode fibre [3,4]. With optical communications systems using 800nm sources and multimode fibre the attenuation and dispersion effects are larger than at 1310nm and 1550nm and, with appropriate educator kit design, enable dispersion measurements to be made with standard laboratory equipment. However, the general concepts demonstrated at 800nm are equally applicable to state of the art long haul, high capacity fibre links operating at 1310nm and 1550nm. In order to expand upon the experiments in the ED-COM and BER(COM) kits and investigate some of the characteristics of higher capacity fibre links, an experimental section was included in the ED-WDM: 1310/1550 WDM Systems extension examining some attenuation and dispersion phenomena at 1310nm and 1550nm.

The students start with a simple attenuation measurement of a fibre reel with a nominal length of 4.4km using the techniques described in the previous sections. An estimate of the fibre length is then made by applying an impulse modulation to the laser and measuring the time of flight. These measurements give typical attenuation co-efficients for the fibre of 0.22dB/km at 1550nm and 0.38dB/km at 1310nm – agreeing well with manufacturer specifications. This should emphases to the student that 1550nm is the lower-loss transmission wavelength.

The important topic of chromatic (intramodal) dispersion is then investigated by examining the transmission of the two wavelengths over various lengths of singlemode fibre. An elegant way of simulating different transmission lengths is by using a ring resonator arrangement as shown in Figure 8(a). The ring resonator is formed simply by connecting the coupled arm (Port 4) and second input (Port 2) of a 50/50 coupler with the fibre reel.



(a) *(b)*

Figure 8: *Fibre chromatic dispersion measurements with ring resonator at 1310nm & 1550nm*

Applying an impulse modulation to the lasers with this optical arrangement results in a series of pulses (of decreasing size) appearing at the receiver with time delays corresponding to integer multiples of the cavity length (nominally 0, 4.4, 8.8, 13.2, 17.6km) as is shown in Figure 8(b).

Taking a closer look at the output after each pass, as shown in Figure 9, demonstrates the effects of chromatic dispersion with the 1550nm pulse lagging the 1310nm by approximately 9.5ns every pass (4.453km). This illustrates the possibilities of pulse spreading caused by dispersion over long distances in optical fibre transmission channels.

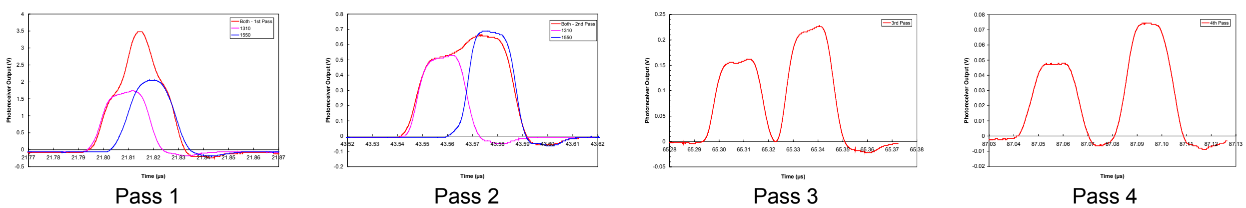


Figure 9: *Increasing separation of 1310 & 1550 pulses after each pass round the ring resonator*

4.2 DWDM Systems

With the ***ED-WDM: DWDM Systems*** extension students are expected to perform the investigation of practical DWDM systems. The following tasks are carried out:

- The examination of a two channel WDM system
- The investigation of WDM System cross-talk
- Examination of the effects of wavelength drift on WDM System performance particularly crosstalk
- Influence of system cross-talk on the Eye Diagram / BER in WDM Systems

The module provides a second DFB laser, operating at a channel adjacent to the original laser, dual InGaAs photoreceivers, a variable optical attenuator (VOA) and an additional OADM (at the adjacent channel wavelength).

In a manner similar to the 1310/1550nm WDM systems kit, this extension demonstrates the fundamental ability of the OADM components to efficiently multiplex and demultiplex signals onto a single optical fibre channel.

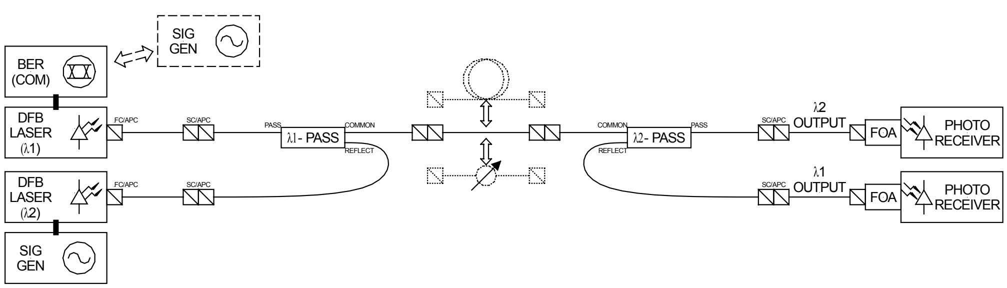


Figure 10: *Two-channel DWDM system*

The system constructed by the students is shown in Figure 10 with the basic results identical to the oscilloscope trace shown in Figure 7.

The major difference from the 1310/1550 set-up being highlighted is the 0.8nm wavelength separation of the dense WDM channels. The adjacent nature of the channels used can then be used to demonstrate the effects of crosstalk on DWDM systems. Using the experimental set-up shown in Figure 10, the students are directed to detune the wavelength of one lasers from its centre wavelength towards the adjacent channel and examine the effect on the output waveforms. Figure 11 shows the increasing levels of crosstalk appearing on the 1549.32nm output port as the 1550.12nm laser is tuned to 1549.9nm.

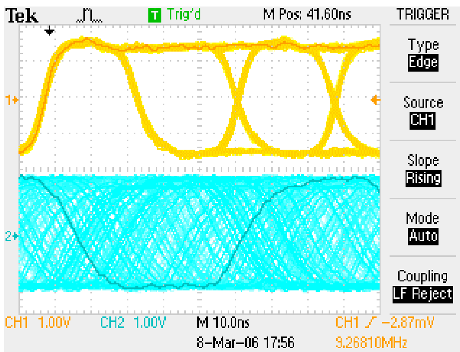
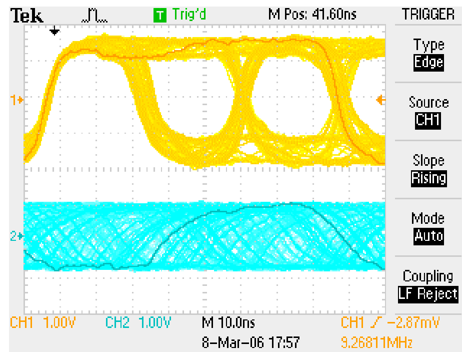
	
Test Condition Ch.1 = ITU35, 1549.32nm, Ch.2 = ITU34, 1550.12nm	**Test Condition** Ch.1 = ITU35, 1549.32nm, Ch.2 = tuned to 1549.90nm

Figure 11: *Demonstration of Crosstalk on a DWDM system*

A second possible DWDM scenario is then examined. In some WDM systems, Channels may be added and dropped at various points along the optical link. Figure 12 shows a system where a second channel is added at some considerable distance from the Channel 1 input (simulated by high attenuation, ≈25dB, produced by a variable optical attenuator of the Channel 1 signal) and then the Channel 1 signal is dropped a short distance beyond that. The students are then asked to experimentally investigate this type of system in which a strong signal is present at the drop point for a weak signal. In particular they are asked to investigate the effects of wavelength drift in the Channel 2 laser source resulting in crosstalk.

This arrangement can best be studied by using comparison of eye-diagrams and bit-error-rate (BER) analysis of the system operation as the laser wavelength is detuned. The OptoSci BER(COM) kit [4] provides a ready means to carry out this analysis and hence is recommended as a possible add-on. However any suitable PRBS generator may be used (directions for the use of external signal generators are provided in the technical appendices of the literature support).

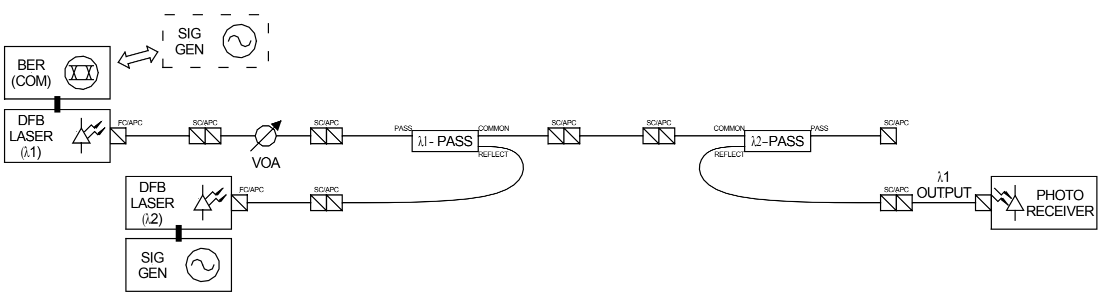


Figure 12: *Crosstalk demonstration by adding a strong signal on λ_2 (modulated) to a weak signal on λ_1 (PRBS). The receiver is looking at the weak λ_1 signal with crosstalk from λ_2.*

The students should find that there is a noticeable increase in the noise levels present on the output trace with an associated closing of the eye. This is due to the OADM configuration where channels are more susceptible to crosstalk as the effective isolation is reduced due to the large difference in power levels from the new add channel relative to the low level of the original (attenuated) signal. Using the BER(COM) and its accompanying software to allows analysis of the eye-diagrams and estimated the BERs, a typical set of results (again provided in the instructors supplement) is presented in Table 1.

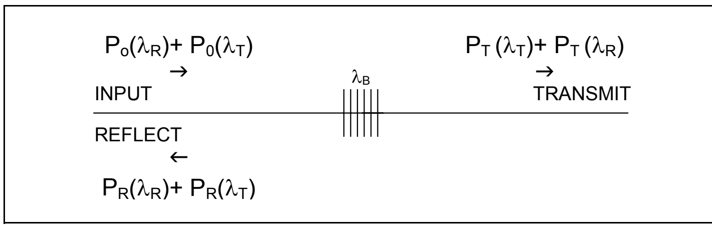
Channel 1 (nm)	Channel 2 (nm)	BER (Channel 1)
1549.32	1550.12	1.00×10^{-11}
1549.52	1550.12	3.30×10^{-10}
1549.54	1550.12	1.30×10^{-09}
1549.56	1550.12	3.10×10^{-08}
1549.58	1550.12	6.30×10^{-07}
1549.60	1550.12	8.69×10^{-06}
1549.62	1550.12	8.00×10^{-05}

***Table 1:** BER results for DWDM system.*

The performance of the system can be seen to degrade and bit error rates increase rapidly in the configuration shown in Figure 12 and hence the control and accuracy of the laser operating wavelength becomes critical.

4.4 Bragg Gratings

The ***ED-WDM: Bragg Gratings*** extension concentrates on the topic of fibre Bragg Grating (FBG) Sensors investigating the effects of temperature and examining possible uses as temperature sensors. The kit includes a Bragg grating on a temperature controlled mount and a thermo-electric-cooler (TEC) module.



Insertion Loss (Transit) (Log Measurements)	$[P_0(\lambda_T) - P_T(\lambda_T)]\,dB$
Insertion Loss (Reflect) (Log Measurements)	$[P_0(\lambda_R) - P_R(\lambda_R)]\,dB$
Reflectivity (Linear Measurements)	$\left[\frac{P_R(\lambda_R)}{P_0(\lambda_R)}\right] \times 100\%$

***Figure 13:** FBG definitions*

In order to perform the basic characterisation of a fibre Bragg the students are directed to use the experimental set-up shown in Figure 14. The insertion of the circulator is required to provide a measurement path for the reflected wavelength and to eliminate a return path to the laser source. Clear instruction is provided to ensure the resultant power levels are corrected for the additional power drops associated with passes through the circulator.

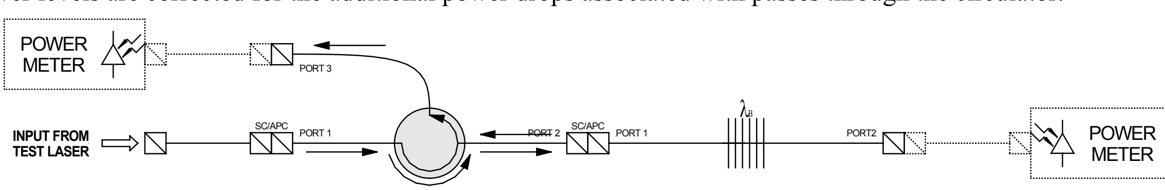
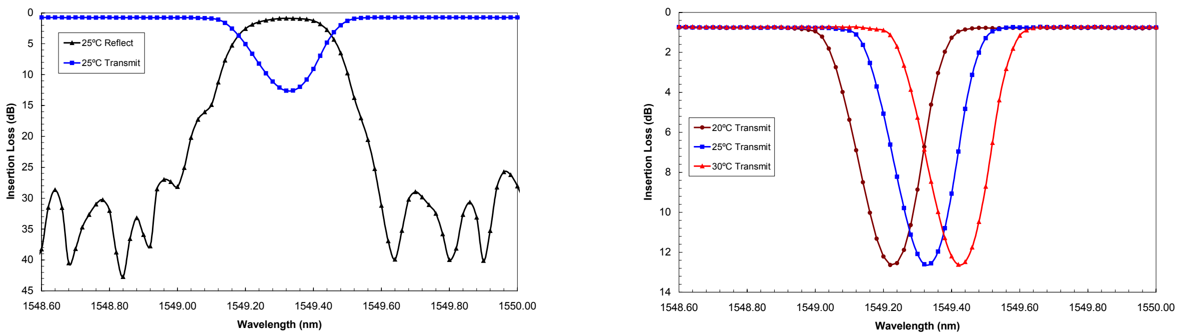


***Figure 14:** Fibre Bragg grating characterisation*

As mentioned earlier the response of the Bragg is very narrowband hence the use of the λ-scan software is recommended to achieve a full measurement set. A typical pair of responses for the transmit and reflect conditions is shown in Figure 15(a). Figure 15(b) shows how the transmission of the Bragg grating changes as the temperature is varied using the TEC module.



(a) *(b)*

Figure 15: *Bragg Grating spectral responses, (a) transmission and reflection at 25°C, and (b) transmission at 20°C, 25°C and 30°C*

From Figure 15(b) the temperature co-efficient can be calculated as 20pm/ºC. The changes in grating temperature trigger corresponding variations in the period of the grating and thus the wavelength of light that is reflected. This Bragg reflection shift makes it straightforward to use Bragg gratings to track variations in environmental parameters such as temperature and strain. The fact that multiple Bragg gratings can be written within an optical fibre also make these sensors amenable to direct and non-intrusive integration within the body of composite materials used in civil structures, aerospace platforms, etc. in order to provide detailed structural health monitoring information.

5. Conclusions

In this paper we have described a suite of laboratory based educational packages which has been developed to allow students to explore and examine the concepts, components and systems used in fibre optic WDM and experimentally demonstrate the effects of system crosstalk and chromatic dispersion. The packages provide the theoretical background of the operation of WDM components, measurement techniques and concepts of WDM systems before providing the hardware to allow the student to perform an experimental investigation.

Throughout the packages the emphasis is not only in presenting students with the theoretical background but also in offering an understanding of the practical side of fibre optic components and systems. Thus on completion of the package the student should have attained a good working knowledge of the components and be familiar with the operation of WDM systems.

The modular format adopted for the packages enables the instructor to target the specific areas or level desired to suit the students. This format has the additional benefit of allowing the instructor to build up the systems from the basics to the more advanced topics as the educational requirements demand and teaching budgets permit.

6. References

1. See www.optosci.com for extensive additional information on OptoSci's range of photonics educator kits.
2. W. Johnstone, B. Culshaw, D. Moodie, I. Mauchline and D. Walsh, "Photonics laboratory teaching experiments for scientists and engineers", 7th International conference on Education and Training in Optics and Photonics (ETOP), Singapore, 2001, Paper 304 and SPIE Proceedings 4588, 2002.
3. W. Johnstone, B. Culshaw, D. Walsh, D. Moodie and I. Mauchline, "Photonics laboratory experiments for modern technology based courses", *IEEE Proceedings: Special issue on Electrical and Computer Engineering Education*, pp41-54, 1999.
4. D. Walsh, D. Moodie, I. Mauchline, S. Conner, W. Johnstone, B Culshaw, "Practical Bit Error Rate Measurements on Fibre Optic Communications Links in Student Teaching Laboratories", 9th International Conference on Education and Training in Optics and Photonics (ETOP), Marseille, France, Paper ETOP021, 2005.

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Implementation of three functional devices using Erbium-doped Fibers: An Advanced Photonics Lab

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Abstract: This paper describes the design and implementation of an advanced photonics experiment aimed at the undergraduate students' level. The experiment uses erbium-doped fiber to implement three functions through slight modifications of the setup. The functions are a broadband light source, a multi-wavelength optical amplifier, and a tunable fiber laser. As part of an Optical Communication Systems course, the experiment is targeted towards fourth year engineering students at the University of Toronto. The design of the experiment is especially attractive for large classes, where feasibility and cost effectiveness play a pivotal role. In addition the scope of the experiment was designed to illustrate a broad set of topics covered in the course, where students gain knowledge in: i) constructing a broadband source using the erbium-doped fiber amplified spontaneous emission (ASE) and characterize its emission spectrum; ii) modifying the ASE source into a broadband multi-wavelength erbium doped fiber amplifier (EDFA); iii) studying gain tilt and noise figure (NF) of the EDFA with respect to input and pump parameters; and finally, iv) transforming the EDFA into a tunable erbium doped fiber laser (EDFL). Through this series of experiments, students will (i) appreciate the versatility of an important optical gain medium; (ii) develop a deeper understanding of the salient features of optical gain including stimulated and spontaneous emission, principles of laser and amplifier action; (iii) learn, through hands on experience, to operate advanced optical components and test and measurement instruments which all form an integral part of the optical communication industry; and finally(iv) integrate the building blocks they have encountered in textbooks into operational optical devices.

1. Introduction

Since its invention in the late 1980s, the erbium-doped fiber has proved to be a versatile material system with a wide range of applications, including broadband optical sources, wide-band optical amplifiers, and tunable lasers. Broadband optical sources have been applied in various areas such as optical device characterization, gyroscopes, and optical coherence tomography. Amplified spontaneous emission (ASE) in erbium-doped fiber has been used to construct light sources with the advantages of high output power and broad optical bandwidth [1]. The erbium-doped fiber amplifier (EDFA) was the first successful optical amplifier and has revolutionized the optical communication industry in the early 1990s. Today, they are widely used in all kinds of fiber communication systems, especially wavelength division multiplexed (WDM) systems [2] [3]. Erbium-doped fiber lasers (EDFL), one of the most popular fiber lasers, have shown tremendous progress in recent years. They have the advantages of good beam quality, wide tunable wavelength, small size, and lower cost etc. [4].

Lasers, optical amplifiers, especially EDFA, are all pivotal components in the state-of-the-art course of optical communication systems. The basic theory of optical amplifier and laser is a challenge for undergraduate students to grasp. Therefore it is essential to develop a practical experiment to help the students understand the basic performance of the optical amplifier and laser. Although there are EDFA education kits available in the market [5], we developed an experiment that use erbium-doped fiber to implement three functions: a broadband incoherent light source, a multi-wavelength optical amplifier, and a tunable fiber laser with more illustrative, flexible, and costive for large scale undergraduate course. The aim of the experiment is enable senior engineering students to: (i) construct an ASE broadband incoherent light source, an EDFA, and an EDFL based on same erbium-doped fiber and other components; (ii) characterize EDFA performance; (iii) establish deep understanding of the concepts of lasers, optical amplifiers; (iii) obtain practical experience of operating advanced optical components and instruments.

2. Principles

An erbium-doped fiber is an optical fiber of which the core is doped with rare-earth element erbium ions Er^{3+}. A simplified energy level diagram of Er^{3+} ion is shown in Figure 1. The energy levels are broadening due to the dc-Stark effect [6], which leads to a relatively broad emission bandwidth. When a 974 nm pump laser diode beam is fed into an erbium-doped fiber, Er^{3+} will be excited from the ground state E_1 to the higher level E_3. The excited Er^{3+} ions on E_3 will rapidly decay to energy level E_2 through nonradiative emission. The excited ions on E_2 eventually return to ground state E_1 through spontaneous emission, which produces photons in the wavelength band 1520 – 1570 nm. The spontaneous emission will be amplified as it propagates through the fiber, especially when the pump laser power is increasing. As amplified spontaneous emission (ASE) covers a wide wavelength range 1520-1570nm, we can use it as a broadband light source.

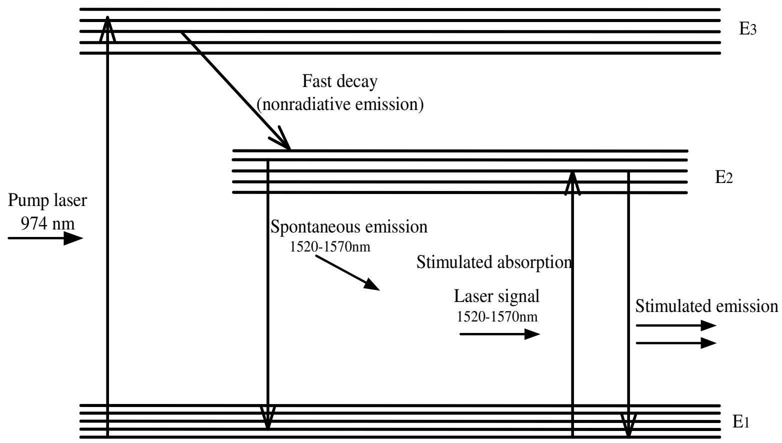

Figure 1 Simplified Energy levels of Er^{3+} ions in Erbium-doped fiber

If a laser signal with a wavelength between 1520 and 1570 nm, and a 974 pump laser are fed into an erbium-doped fiber simultaneously as shown in Figure 1, there are three possible outcomes for the signal photon: i) stimulated absorption: signal photon excites an erbium ion from the state E_1 to a higher level E_2 and become annihilated in the process; ii) stimulated emission: signal photon stimulates an erbium ion at state E_2 to decay to E_1, producing another identical photon. Thus the signal is amplified; iii) signal photon can propagate unaffected through the fiber. In the mean while, spontaneous emission always occurs between level E_2 and level E_1. When pump laser power is high enough that the population inversion is achieved between the energy level E_2 and E_1 of erbium-doped fiber, the input laser signal passing through the fiber is then be amplified. Thus we can use erbium-doped fiber and pump laser to construct an optical amplifier, which called erbium-doped fiber amplifier (EDFA). The spontaneous emission also could be amplified by pump laser. So ASE is always present in EDFA, and it is the main source of noise in these amplifiers.

The laser is simply the optical amplifier with positive feedback. If the output of EDFA is fed back to its input to build a fiber loop, when pump laser power is added into the fiber loop, the EDFA is transformed to a fiber laser, which is called erbium-doped fiber laser (EDFL). The laser wavelength varies with the cavity loss. Therefore, the laser wavelength can be tuned by adjusting the cavity loss.

3. Experiment Set Up

The schematic diagrams of ASE broadband light source, EDFA, and EDFL experiment setups are shown in Figure 2, Figure 3, and Figure 4, respectively. It is obvious that Figure 2 and Figure 4 are parts of the Figure 3.

In the Figure 3, the eight distributed feed back (DFB) laser sources with eight different wavelengths individually from λ_1 to λ_8 are fed into an 8 x 8 tree coupler. The eight wavelengths are:

λ_1 = 1530.33nm, λ_2 = 1535.04nm λ_3 = 1540.56nm λ_4 = 1545.32nm
λ_5 = 1550.12nm λ_6 = 1554.96nm λ_7 = 1559.79nm λ_8 = 1564.68nm

The eight outputs from the tree coupler can accommodate eight lab stations. Each output from tree coupler contains eight wavelengths from λ_1 to λ_8 but with a theoretical power loss of 9dB. One of the outputs from the tree coupler is connected to the input of a Variable Optical Attenuator (VOA). The output from the VOA is considered as the Input Signal of EDFA, which contains the wavelengths λ_1 to λ_8 and the power can be adjusted by different VOA settings.

The EDFA consists of a WDM component, two optical isolators, an erbium doped fiber strand with 7 meter in length, a pump laser, and a laser diode driver. All are attached on a plexiglass board. The Input Signal transmits through the Optical Isolator 1 to reach the 980/1550 WDM. The Pump Laser (974nm) that mounted on the Laser Diode Mount and driven by the Laser Current Source is fusion spliced to the 980/1550 WDM. The Pump Laser Power versus Drive Current relations should be measured before pump laser output fiber fusion spliced to 980/1550 WDM.

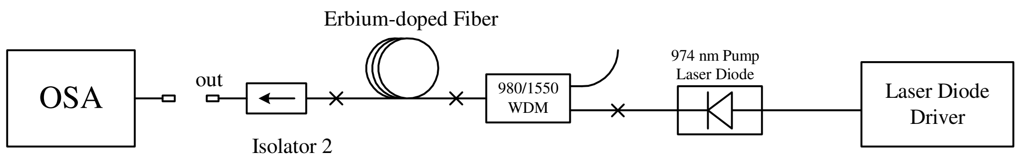

Figure 2 Schematic diagram of ASE broadband light source experiment set up (fusion fiber splices: x; fiber connectors: ▭)

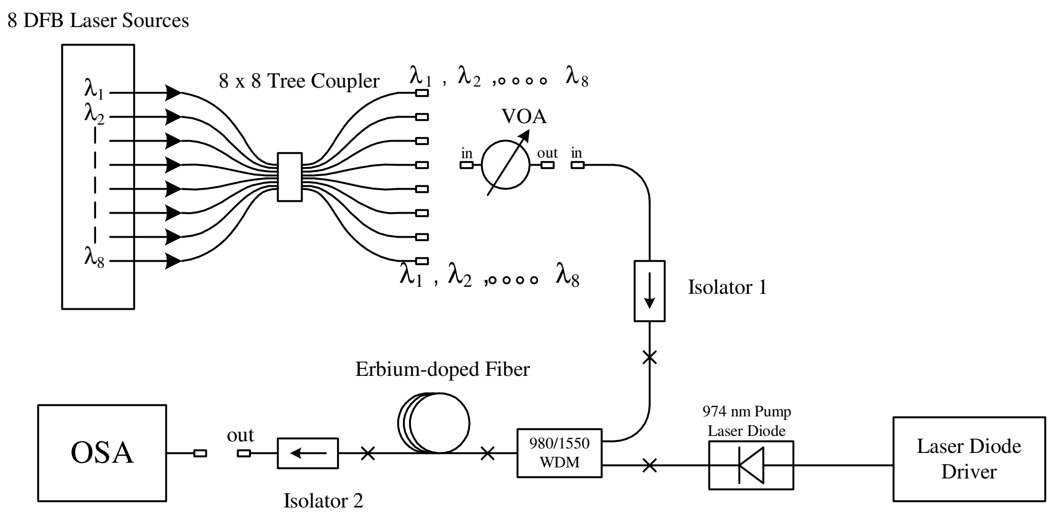

Figure 3 Schematic diagram of multi-wavelength EDFA experiment set up

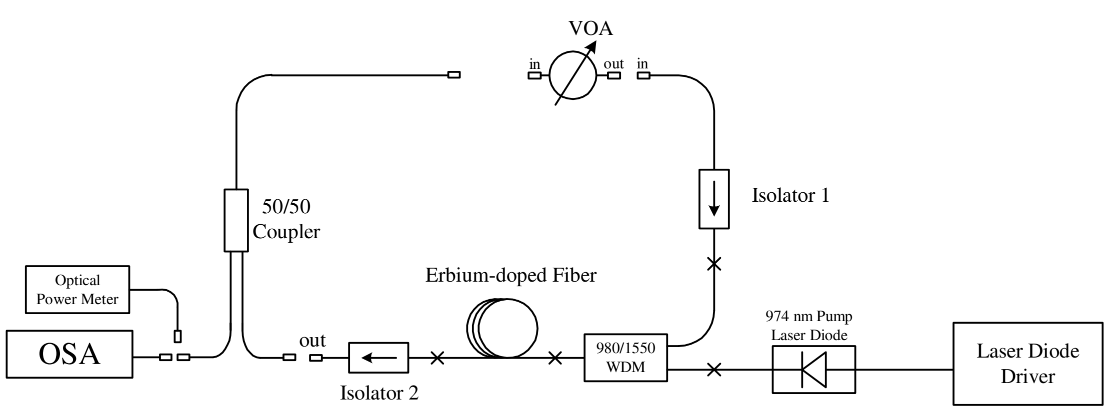

Figure 4 Schematic diagram of EDFL experiment set up

The Input Signal and Pump Laser are inputted into the 980/1550 WDM separately and come out through the common fiber, and then spliced to an Erbium-doped fiber (7 meter in length, Corning PureMode 1550C Photonic

Fiber). The amplified signal passes along another Optical Isolator 2 and is considered as the Output Signal of the EDFA which can be studied by the Optical Spectrum Analyzer (OSA).

4. Experiment Results and Discussions

4.1 Construct an amplified spontaneous emission (ASE) broadband light source and measure its emission spectrum

An ASE broadband light source is built by using a 974nm laser diode pumping an erbium-doped fiber as shown in Figure 2. Connect the output of the erbium-doped fiber to the Optical Spectrum Analyzer (OSA), gradually increase pump laser diode power. The optical spectra of the amplified spontaneous emission (ASE) at different pump powers are shown in Figure 5. The figure shows that ASE power spectrum covers a broadband wavelength range from 1520 to 1570 nm under the 974nm laser diode pumping. The total ASE power increases with the pump power.

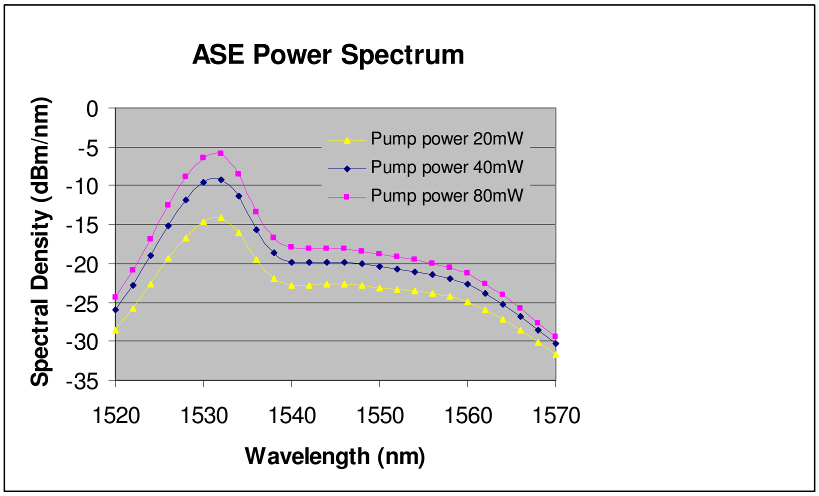

Figure 5 Amplified spontaneous emission (ASE) spectrum of erbium-doped fiber pumped by a 974 nm laser diode

4.2 Modify the ASE source into a broadband multi-wavelength erbium doped fiber amplifier (EDFA)

In this experiment, as shown in Figure 3, connect the output of VOA to the OSA by a patchcord to measure the input signal spectrum, and then connect the output of VOA to the input of isolator 1, connect the output of the isolator 2 to OSA to measure the output signal spectrum. The input signal and output signal spectrum of EDFA at VOA setting 20dB and pump power 80 mW are shown in Figure 6. The figure highlights the wavelength dependence of the gain and clearly shows how the ASE is added to the output spectrum as noise. The gain profile and noise figure (NF) performances of EDFA under various input and pump parameters are going to be further studied.

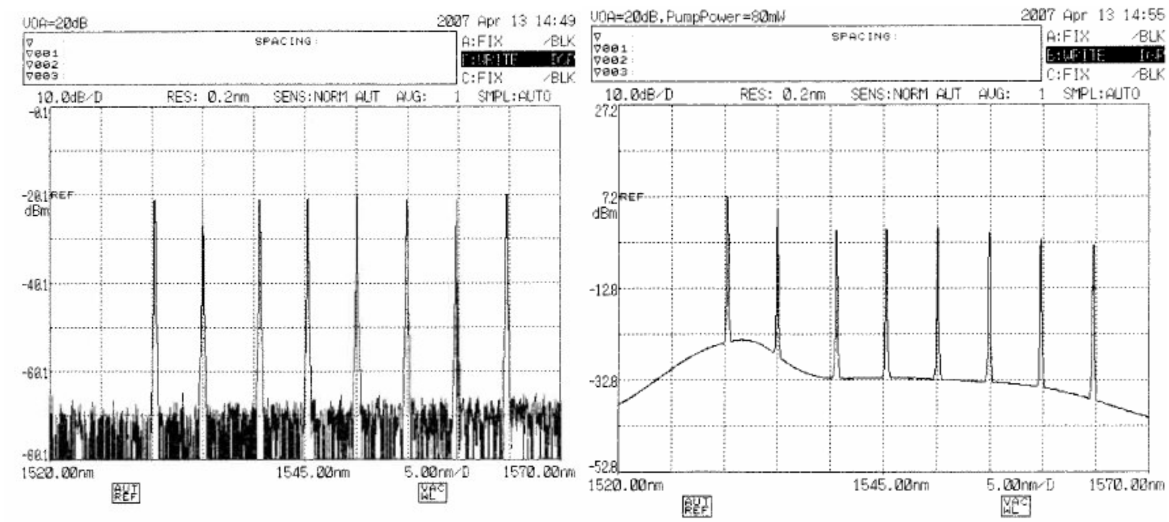

Figure 6 Input (left) and output (right) spectrum of multi-wavelength EDFA @ VOA setting 20dB and pump power 80 mW

4.2.1 EDFA gain profile versus input signal at fixed pump power

The peak powers of eight different input wavelengths from λ_1 to λ_8 at different VOA settings: 0, 5dB, and 10dB are measured firstly. Then set the pump power to 80mW and measure the output signal powers of each channel at different VOA settings: 0dB, 5dB, and 10dB respectively. The gain profile of EDFA at different input signal is shown in Figure 7.

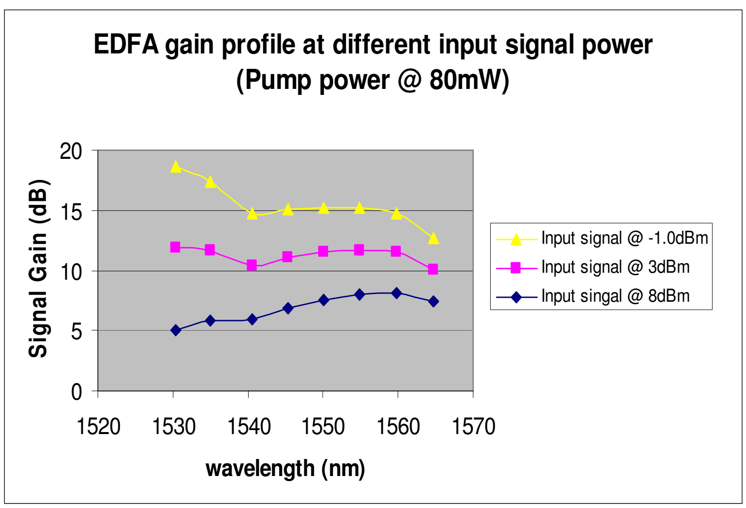

Figure 7 EDFA gain profile

Figure 7 displays the erbium doped fiber has a wide gain spectrum from 1530 t0 1565 nm. The wide gain spectrum of EDFA has made the use of optical amplifier particularly attractive for DWDM lightwave systems as all channels can be amplified. Figure 7 also displays that the gain profile is wavelength dependent and input signal power dependent. So the design of EDFA with flat gain over the wide wavelength range is crucial for practically use of EDFA.

4.2.2 EDFA gain versus input signal power at fixed pump power for specific channel wavelength 1550.12nm

From Figure 7 we find that for specific input signal wavelength, the signal gain decreases when the input signal power increases. Next, the EDFA gain saturation properties will be studied. In this configuration the output of VOA is connected to the optical spectrum analyzer (OSA) by a fiber patchcord. The input signal peak power at different VOA settings is measured from 40dB to 0dB in steps of -5dB for channel 5 at wavelength $\lambda_5 = 1550.12$nm. Then the patchcord between VOA and OSA is disconnected. The input side of optical isolator 1 is connected to VOA output and the signal is fed to the EDFA. The output side of optical isolator 2 is connected to OSA. Set the pump power to 100mW. The output signal powers of wavelength 1550.12nm at different VOA settings from 40dB to 0dB in steps of -5dB are measured.

The EDFA gain versus signal power at fixed 100 mW pump, and output power versus input power figures are shown in Figure 8, and Figure 9 respectively.

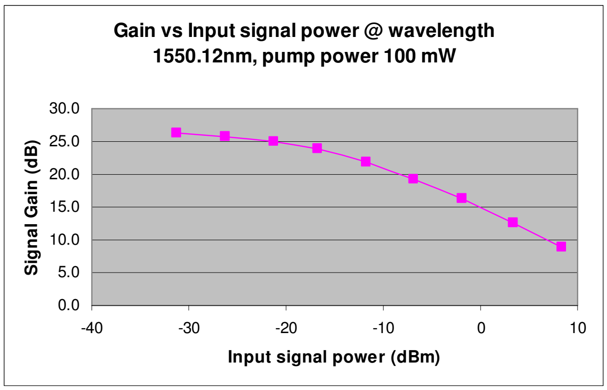

Figure 8 EDFA gain versus input signal

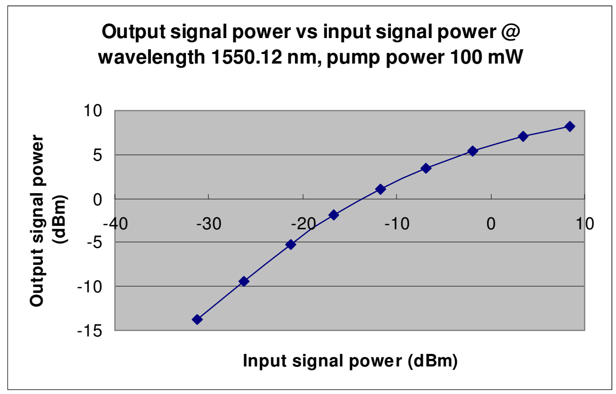

Figure 9 EDFA output power versus input signal power

The gain saturation of EDFA is obviously seen from Figure 8 and Figure 9. Under certain of pump power, the small signal gain keeps constant in a range of input signal power, and hence the output signal power increase linearly with the input signal power. However, the signal gain decreases when signal power further increases, and the output signal power trends to saturate accordingly. This gain saturation happens when all the pump power is consumed. The increase of pump power may increase the small signal gain.

4.2.3 EDFA gain versus pump power at fixed input signal power for channel wavelength 1550.12nm

The VOA is first set to 20 dB, the input signal power at wavelength 1550.12nm and total eight wavelength input power are measured. Then the pump power is changed to the values of 2mW, 5 mW, 7mW, 10 mW, 20 mW, 40 mW, 60 mW, 80 mW to 100 mW, which the output signal power at wavelength 1550.12 is measured to calculate the corresponding gain.

The EDFA gain versus pump power is shown in Figure 10. When gradually increasing the pump power, the initial gain is negative, which means stimulated absorption is stronger than stimulated emission. However, the gain increases linearly with the pump power. The threshold pump power where output power is equals to input power (i.e. gain = 0) can be determined. When the pump power continuously increases, the gain increases slowly till saturated, which indicates the pump saturation occurs. At low level of pump power, the population inversion is sufficient to provide gain. While at the high level of pump power, the pump light significantly depletes the population of the ground state.

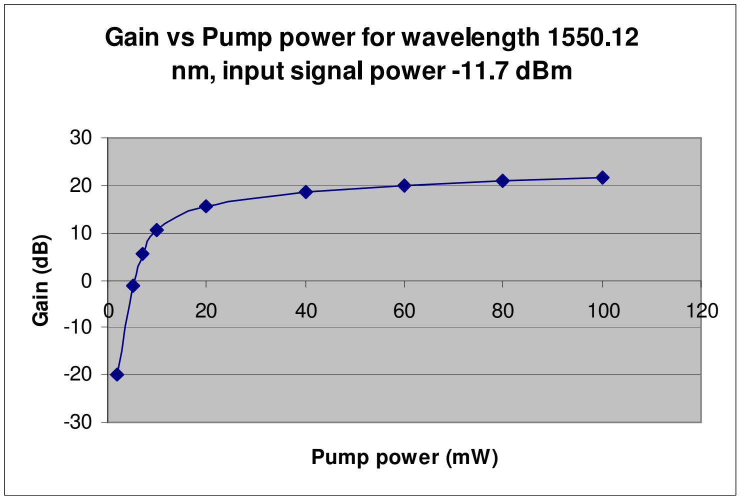

Figure 10 EDFA gain versus pump power

4.2.4 EDFA noise figure (NF) versus pump power at fixed input signal power for specific channel wavelength 1550.12nm

The noise figure of an amplifier is a measure of the degradation of the signal to noise ratio for a signal passing through the amplifier. The noise figure (NF) is defined as the ratio of the signal to noise at the input of the EDFA to that at the output of the EDFA ($NF = (SNR)_{in}/(SNR)_{out}$). It can be expressed as [2]:

$$NF(dB) = 10\log_{10}\left(\frac{P_{ASE}}{h\nu\Delta\nu G} + \frac{1}{G}\right) = 10\log_{10}\left(\frac{\lambda^3 P_{ASE}}{hc^2\Delta\lambda G} + \frac{1}{G}\right) \qquad \text{Equation (1)}$$

where λ is the optical wavelength, h is Plank's constant, c is the speed of light, Δλ is the optical bandwidth, P_{ASE} is the ASE power (linear units) measured in the bandwidth Δλ, G is the gain of optical amplifier (linear units). When use optical spectrum analyzer (OSA) to do measurement, The ASE power P_{ASE}, optical bandwidth Δλ, peak wavelength λ, and gain G can be measured by the Analysis Function of the OSA. The NF therefore can be calculated by Equation 1. The EDFA noise figure versus pump power at fixed input signal power for channel 5 is shown in Figure 11.

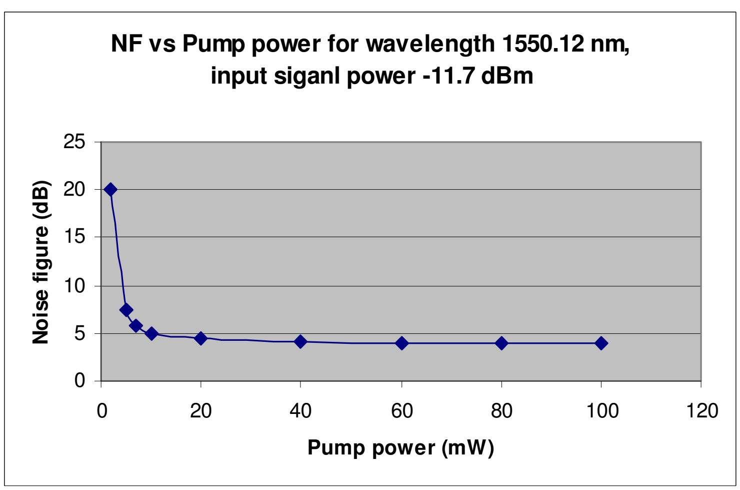

Figure 11 EDFA noise figure (NF) versus pump power

When the pump power is as low as 2 mW, the NF is as high as 20dB. A high noise figure indicates that the signal to noise ratio has been impaired by the amplification process. Actually, in this case, the pump power is too lower that the signal gain is negative (see Figure 10), which means stimulated absorption is stronger than stimulated emission between energy level E_2 and E_1, leading signal be absorbed when passes through EDFA. The NF decreases dramatically as the pump power increases until the pump saturation (see Figure 10) occurs. Although ASE can be used to build up a broadband light source as described in *4.1*, the ASE is the main noise in the optical amplifier which can be seen in Figure 6. All amplifiers degrade the signal to noise ratio (SNR) of the amplified signal because of spontaneous emission that adds noise to the signal during the amplification. The degraded NF is one of the major limits for the applications of EDFA in optical communication links and systems.

4.3 Construct a tunable fiber laser by erbium- doped fiber

The laser is simply the optical amplifier with positive feedback. As shown in Figure 4, an erbium-doped fiber ring laser can be constructed by connecting the output of EDFA board, i.e. the output side of Isolator 2, to the input of EDFA board, i.e. the input side of Isolator 1, by using 974 nm laser as a pump laser. In order to adjust the loss of the fiber ring laser, a VOA is inserted between Isolator 1 and Isolator 2. A 50/50 coupler is connected between the output of EDFA board and the input of VOA to measure the fiber laser power and spectrum performance by the optical power meter and OSA, respectively.

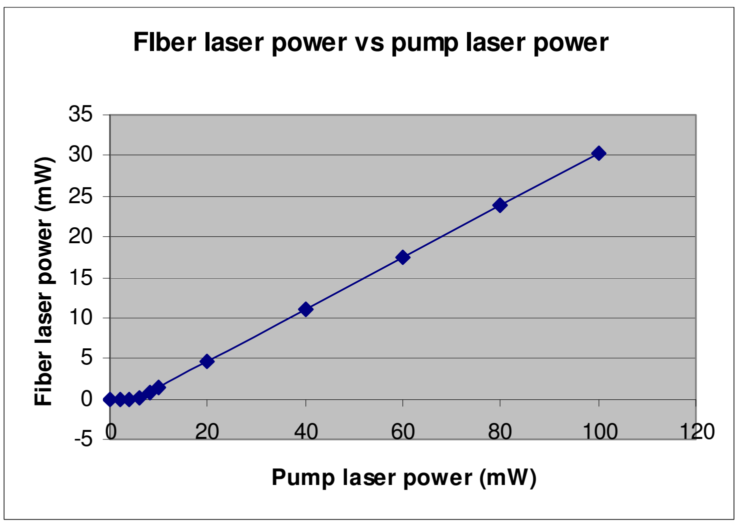

Figure 12 Erbium fiber laser power versus pump power

The fiber laser power versus pump power is shown in Figure12. The threshold pump power can be determined from Figure 12. The fiber laser spectrum can be observed by OSA. Figure 13 shows the laser spectra at which the VOA settings are 9dB and 1 dB. The laser peak wavelengths are 1532.92nm and 1559.60 nm respectively. The linewidth of the fiber is as narrow as 0.2-0.5 nm. This implies that the laser wavelength could be tuned by carefully adjust the cavity loss.

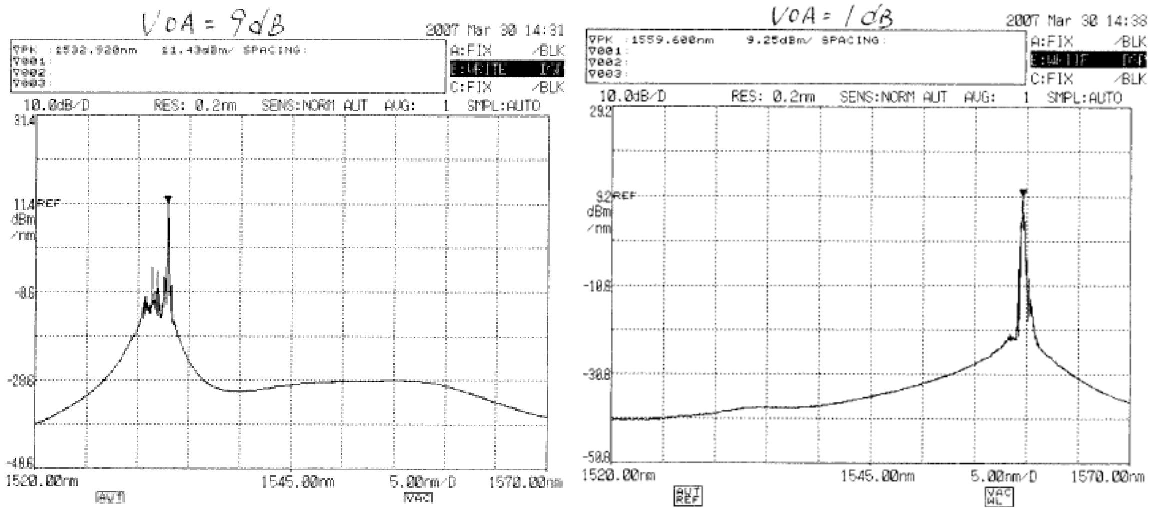

Figure 13 Erbium-doped fiber ring laser spectrum at different fiber loop loss (left: VOA=9dB, right: VOA=1dB)

5. Experiment cost

In order to give our students the exposure to state-of-the-art equipment and yet make them affordable, we have been purchasing refurbished equipment and components and assemble them into a complete system. The devices and components used in this experiment include: ILX FOM-7900B mainframe with eight DFB laser modules in C band, Anritsu MN9605 VOA, ILX LDX3525 laser current source, ILX laser diode mount, Bookham 974 nm pump laser, Ando 6317 OSA, Newport 1815-C power meter and detector, Corning PureMode 1550C Photonic erbium- doped fiber, isolators, tree coupler, 980/1550 WDM, and 50/50 coupler. The cost of each EDFA board which includes VOA, isolators, WDM, pump laser, erbium-doped fiber, and a coupler is around USD1300. The DFBs cost USD8000, while with an 8 x 8 tree coupler (cost USD500), it can accommodate eight lab stations to meet the demand of large scale course. Other equipment such as OSA (cost USD3500) and laser current source (cost USD1300) are very general and powerful equipment and also be used in other experiments in our lab, such as characterization of laser diode and LED, optical absorption and photoluminescence in semiconductors. With these advanced equipments, we can build new experiments conveniently and the cost distributed to each lab will be down.

6. Conclusions

The basic theories of erbium doped fiber amplifier and laser are very challenging to undergraduate students. Spontaneous emission, stimulated emission, and stimulated absorption are basic concepts of laser and optical amplifier. In this experiment, we use erbium-doped fiber as gain medium to build three devices: a broadband light source, a multi-wavelength optical amplifier, and a fiber laser.

In the first part of the experiment, students will construct a broadband source through an erbium-doped fiber pumped by a laser diode and measure its emission spectrum. The broadband light source is based on the amplified spontaneous emission and it is a typical example of incoherent light source. In the second part of the experiment, students will build a multi-wavelength erbium-doped fiber amplifier (EDFA) by simply adding the multi-wavelength laser sources to the first part of the experiment setup. The optical amplifier is based on stimulated emission. The laser signals within a wide range 1520 -1570 nm can be amplified without change their coherence properties when pass through an EDFA. To further understand the performance of EDFA, the gain spectrum and noise figure features of EDFA respect to input and pump parameters also be investigated. In the third part of the experiment, students will construct an erbium-doped fiber laser (EDFL) just by connecting the output of the EDFA to the input of EDFA. The laser wavelength is easily be tuned by adjust the laser loop loss. The fiber laser is based on the stimulated emission too with positive feedback. The switches between these three devices are very easy and convenient. From this series of experiments, students will have deep understandings the difference between laser and incoherent light source, the difference of laser and optical amplifier. The theoretical analysis of gain spectrum, gain saturation, noise figure of

EDFA as functions of input and pump properties are challenges to undergraduate students. The experimental results from this experiment are very straight forward and illustrative.

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Educational Kit for Optical Experiments

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Abstract: New educational kit and methodological instructions are presented in the paper. Methodological approaches and the kit design are improved and extended on the base of 10 years experience of the use of previous version of equipment. Basic approaches are the following: modular structure of the equipment with multifunctional blocks which are easily replaced; simplicity and unity of training equipment; diversity of light sources; possibility to rearrange the equipment and techniques both for universities and for high school; modified optical schemes for some experiments. The set of equipment includes: compact desk holographic installation, Hartle device, focal monochromator on the base of holographic lens, optical bench, prisms, lenses, gratings, collimator, several light sources (laser, LEDs, lamp), etc. Methodological instructions provided with this set include the list of demonstrations and laboratory works as well as links between various experiments and phenomena. Methodological instructions give recommendations for more than 50 demonstrations and practical works in various domains: light diffraction, interference of light, holography, geometric optics, Fourier optics, polarization effects, optics of spectrums, fiber optics, as well as a combination of the effects.

1. Introduction.

In comparison with the previous version of the kit [1], this equipment (UMOG-3) is more functional and provides more demonstrations and laboratory works. At the same time, the main principles of equipment design are the same – modular construction with the possibility to combine, rearrange and supplement the main blocks and elements; absence of complicated, precision and expensive units.

The kit allows realizing the number of demonstrations, including the following:

- edge diffraction;
- slit diffraction;
- hole diffraction;
- Young experiment;
- diffraction on a periodic structure;
- wedge interference;
- Newton rings;
- Lloyd mirror;
- polarization effects;
- Fourier-optics;
- phase contrast;
- observation of paths of reflected and refracted rays;
- total internal reflection;
- light propagation through inhomogeneous mediums;
- optical heterogeneity visualization by shadow method;
- modeling of the light propagation through the fiber;
- demonstration of aberrations (spherical aberration, coma, astigmatism, distortion);
- white light polychromatic structure.

The kit allows realizing the number of training labs, including the following:

- recording of Denisyuk holograms;
- recording of double-exposed holographic interferogram;
- measuring of plate deformation by holographic interferometry method;
- measuring of distance between 2 holes on Young pattern;
- measuring of diffraction grating period;
- measuring of light source wavelength;
- measuring of lens focal length;
- measuring of wedging of plane-parallel plate;
- radius of curvature measuring of plano-convex lens surface;
- Fourier-optics experiments;
- measuring of reflection and refraction angles;
- Snell law studying;

- Brewster angle measuring;
- measuring of prism internal reflectance angle and refractive index;
- Fresnel formulae;
- Malus law studying;
- measuring of diffraction grating efficiency;
- evaluation of relief of hologram profile;
- evaluation of holographic lens parameters;
- measuring of the fiber loss;
- spectrum measuring.

2. Set of equipment

The overall view of basic set is given in fig. 1.

Fig. 1. The base set of equipment

UMOG-3 is performed as a set of functional assemblies compatible constructively and ideologically with each other: optical bench, Hartle device, desk holographic camera, focal monochromator, Lloyd mirror, projecting microscope, light beam expander, cylinder reservoir with illuminators.

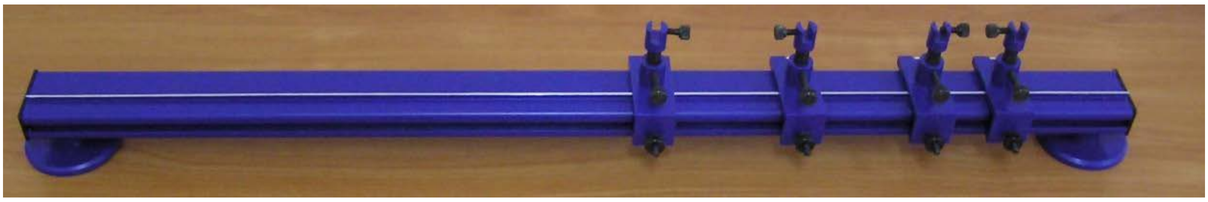


Fig. 2. Optical bench.

Optical bench (fig.2) is intended for breadboarding of experiment schemes and implemented in the form of guide where riders are fixed. The bench is mounted horizontally and has a ruler for riders' position measuring. In riders there can be mounted optical elements, adjusting devices, light sources, etc. In the kit the possibilities are foreseen both to mount optical elements on the axis of the bench and out of it.

Hartle device (fig.3) is meant for experiments of light refraction and fiber optics.

Desk holographic camera is meant for Denisyuk hologram registration and it is described in detail in [1].

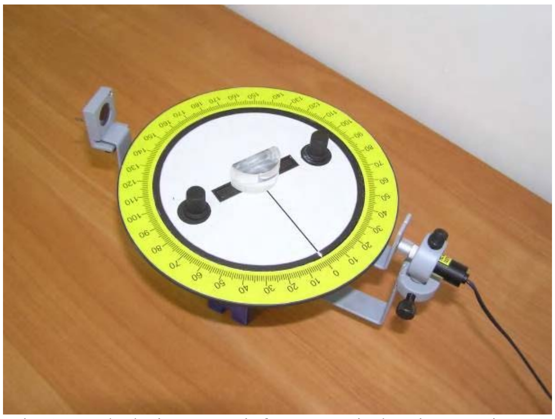


Fig. 3. Hartle device as a unit for geometrical optics experiments

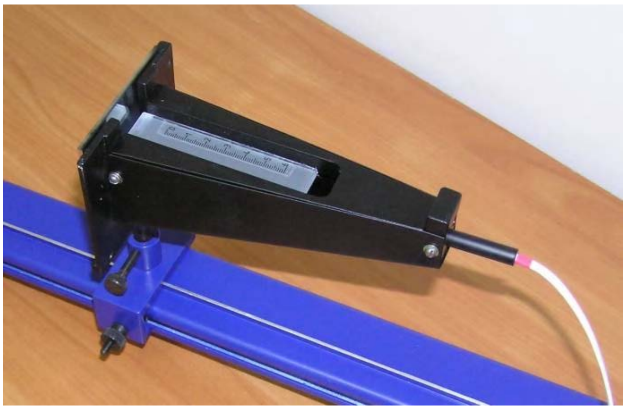


Fig. 4. Focal monochromator on a base of holographic lens.

Focal monochromator with holographic lens (fig. 4) is meant for the spectrum optics experiments and for spectral measurements. Spectrum is formed on the translucent screen with the measuring grid instead of that the CCD-censor can be mounted. Light from the light sources is introduced into monochromator by the optical fiber or from the LED directly.

Lloyd mirror (fig. 5) is meant for producing of two coherent sources for interference studying.

Horizontal projecting microscope (fig. 6) is meant for observation of enlarged by the microobjective images of objects on the translucent screen with the measuring greed. Instead of the screen a CCD-array can be mounted. The microobjective of the microscope is also used in holographic camera for beam expansion.

Fig. 5. Lloyd mirror.

Fig. 6. Horizontal projecting microscope.

Fig. 7. Light beam expander (collimator).

Fig. 8. Cylinder reservoir with illuminators.

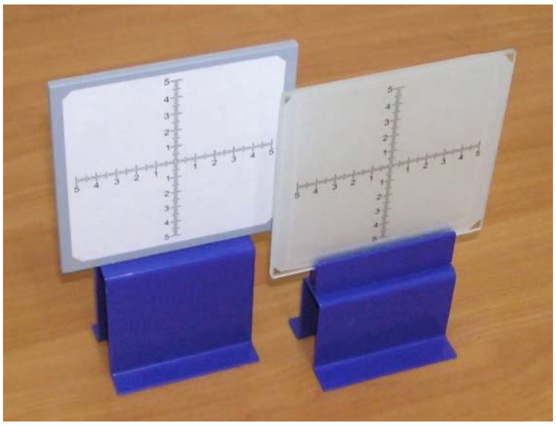


Fig. 9. Screens.

Light beam expander (fig. 7) is meant for parallel beam forming with 25 mm diameter. By the expander it is possible to form divergent (convergent) beam. Optical scheme (Galilean telescope) consists of microobjective and objective, changing distance between them one can obtain parallel or required divergent beam.

Cylinder reservoir with illuminators (fig. 8) is meant for “lighting stream” demonstration.

Screens (fig. 9) are meant for observation of images of objects, diffraction and interference patterns, etc., in transmitted or reflected light. For visual measuring the screens are supplied by grids.

Various light sources are included into kit: metal-halide lamp, laser semiconductor diode (λ=655 nm); light emitting diodes – red (λ=630-632 nm), blue (λ=471-475 nm), green (λ=520-530 nm), white (λ=632,520,473 nm). In holographic camera it is used He-Ne laser (λ=633 nm). Spectral characteristics of light sources are given in fig. 10.

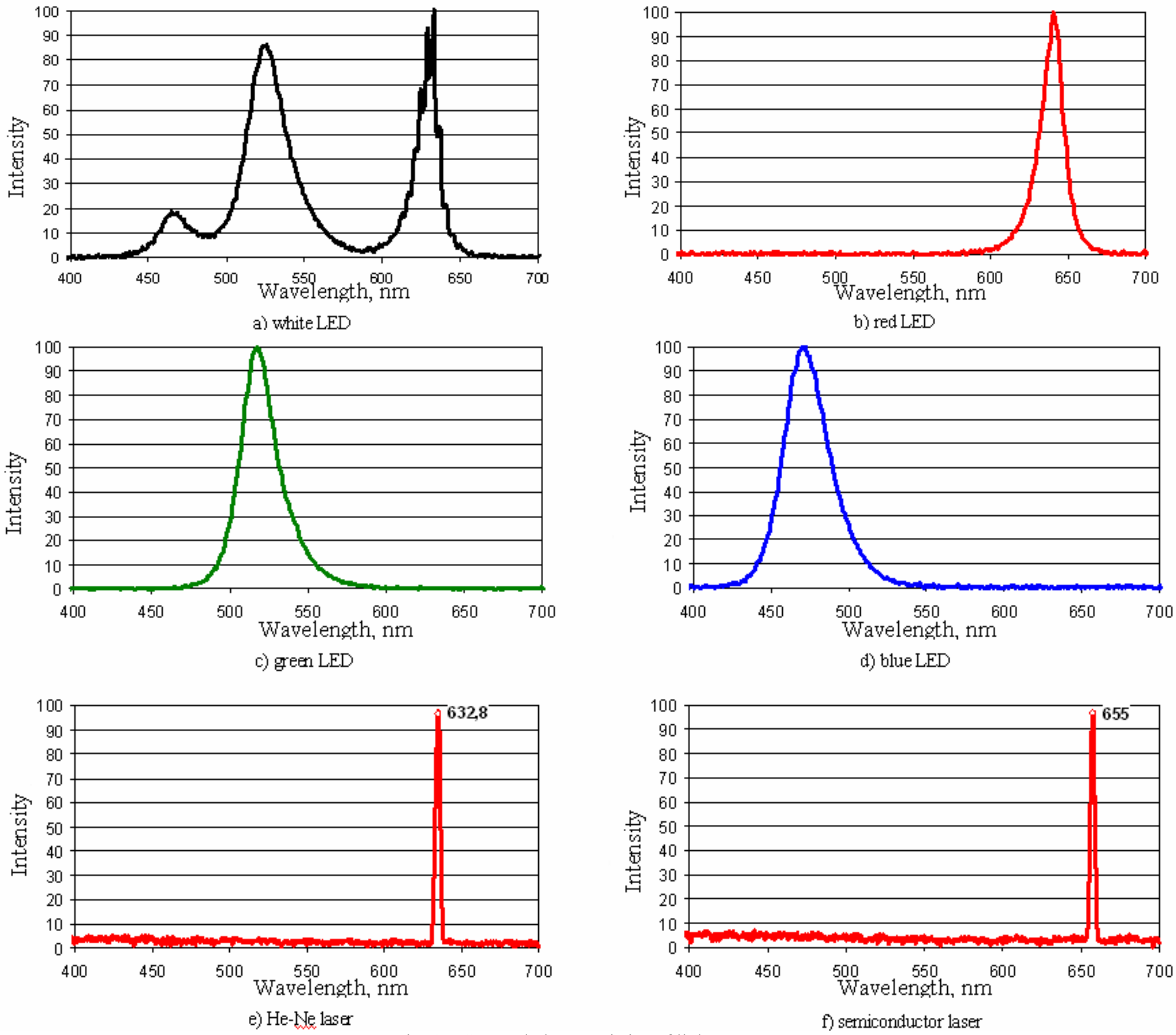
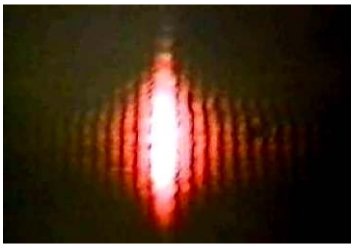


Fig. 10. Spectral characteristics of light sources.

The kit also includes a set of optical elements (fig. 1) with holes, diffraction gratings, lenses, prisms, fibers, etc.

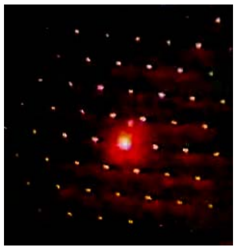
3. Methodological recommendations

The primary methodological recommendations for experiments in diffraction, interference, Fourier-optics, geometrical optics, holography are described in work [1]. The examples of observed patterns are shown in fig. 11. In this paper we give methodological approaches just for some additional experiments realized by new kit.



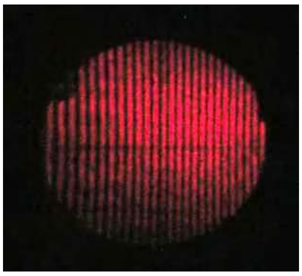
Slit diffraction

Diffraction on a circular grating

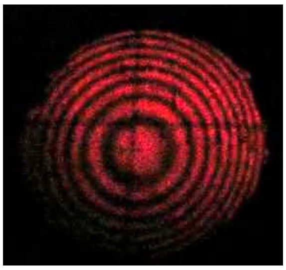


Diffraction on crossed gratings

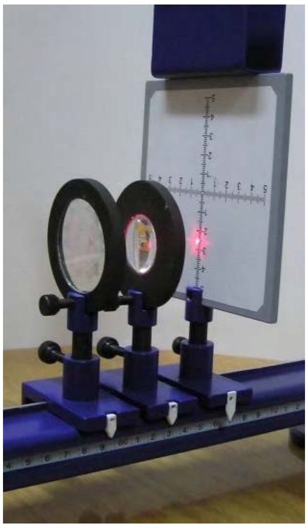
Young pattern



Wedge interference



Newton rings



Fourier-spectrum observation

"Lighting stream"

Hologram

Fig. 11. Examples of patterns observed by using UMOG-3.

3.1. Measuring of a positive lens focal length.

In the previous methodical recommendations two methods of focal distance measuring were examined – by using diffraction grating and in experiment with Newton rings. In this version new experiment is added - with the use of wedge. The experiment is based on using of horizontal microscope (fig. 6) for focal spot observation.

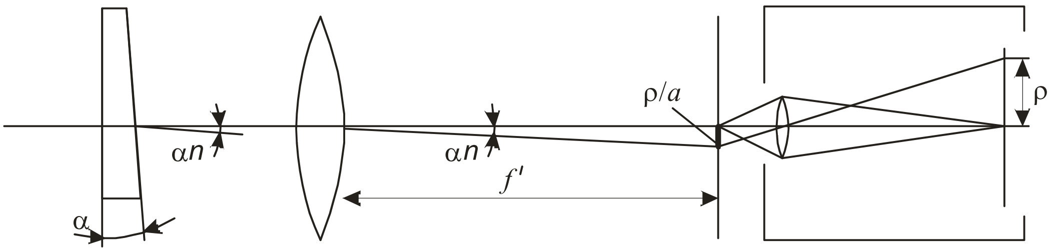


Fig. 12. Focal distance measuring using wedge.

Placing the wedge before lens and revolving it around the optical axis one can observe beating of focal spot on the microscope screen (fig. 12). Screen grid allows measuring circle radius ρ delineated by the spot. Then by known values of wedge angle α evaluated beforehand in technique [1], as well as microscope magnification *a,* one can define lens focal distance using formula $f' = \frac{\rho / a}{\alpha \cdot n}$, where n=1.52 - refractive index of wedge material. Here the fact is used that sine and tangent of small angle (that are α and αn) are equal to this angle.

For microscope magnification definition one can use one of diffraction elements with known period included in the optical elements set.

3.2. Fiber optics

3.2.1. Hartle device experiments

Modified Hartle device, as in previous kit, allows studying the internal reflectance effect, Brewster angle measuring, Fresnel formulae studying (fig. 13, 14). Placing diffraction grating with measured beforehand period, in the middle of the Hartle device disk (instead of half-cylinder prism), one can realize the experiment for measuring by photodiode of intensities of various diffraction peaks. Obtained data are used for grating profile evaluations.

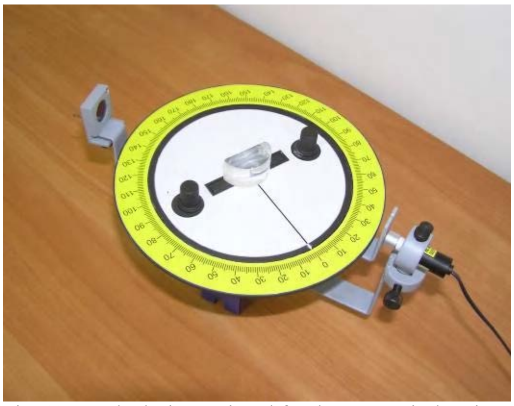


Fig. 13. Hartle device equipped for the geometrical optics demonstrations.

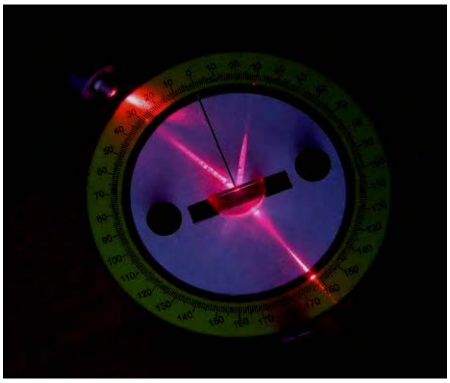


Fig. 14. Snell law demonstration.

In the realized version of UMOG-3 Hartle device is also used for fiber loss measurement that are caused by fibers angle misalignment. This effect is studied by two macro-models of light guides (fig. 15) – glass rods. The loss appears while disk revolving with fixed light guide within the limits provided by air-gap. Loss value is measured by the photodiode, angle of misalignment – by the scale of Hartle device.

3.2.2. Measuring of fiber loss caused by air gap between the fibers.

This effect is also studied by using of 2 light guide macro-models. The light guides are situated by holders in alignment with butts closely (fig. 16). On other butts of the rods the semiconductor laser diode and photodiode are fixed. The loss appears when air gap between butts appears. The loss value is measured by photodiode, air gap – by optical bench scale or by caliper.

Fig. 15. Fiber loss studying while misalignment of models of fiber optics elements.

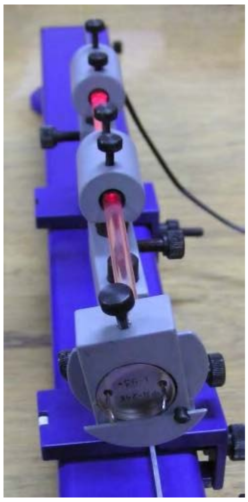


Fig. 16. Studying the loss caused by air gap between elements.

3.2.3. Loss caused by optic fiber bending.

When fiber is bending, the total internal reflectance law is not fulfilled for higher order modes. So light does not reflect from the cover but spreads in it and so is absorbed. Theoretical loss defined by the following method: $\alpha = -10\ lg[1-a/(R\Delta)]$, where a – core diameter, R – bend radius, Δ=0,01. Evaluation of the loss depending on fiber bend is made by scheme on fig. 17. For that it is used optical fiber, photodiode, one of light sources, proper holders from UMOG-3 kit as well as disks of various radiuses cut from fiberboard and fixed on plateau from UMOG-3 kit.

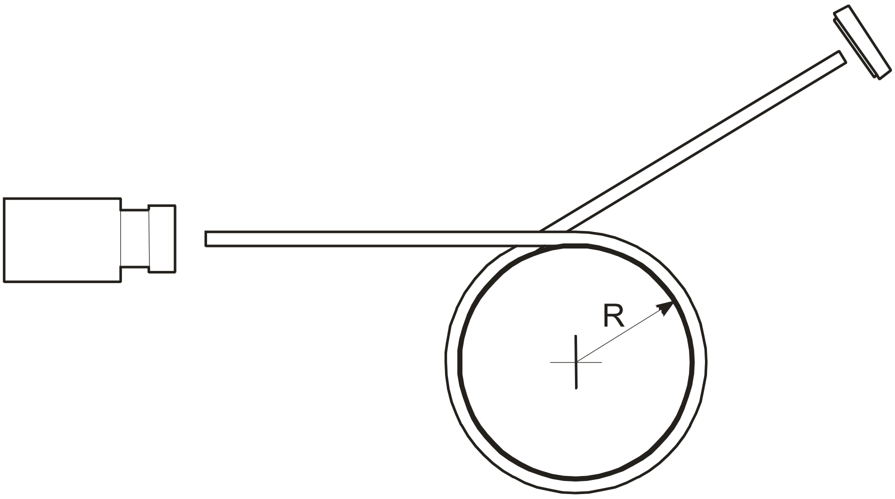


Fig. 17. Scheme for the fiber loss measuring depending on optical fiber bend.

During the work optical fiber is bent by turns to different radiuses and it is simultaneously measured received intensity. Knowing dissipation index for different disk radiuses one can for example determine fiber core diameter using the formula given above.

3.2.4. Fiber sensor of longitudinal shift.

The equivalent scheme of radiation putting into fiber is given in fig. 18. For that the incoherent light source 5.H and the objective 4.2.2 are fixed on the optical bench. Focal point is projected on the fiber butt 4.3.3. On another light guide butt the photodiode 6.1 is fixed. The efficiency of radiation putting in depends on the butt of light guide location relative to the focus. This dependence can be used for construction of shift sensor. In this work it is supposed to formulate this dependence. The photodiode here is used for photo-current measuring, for shift measuring one can use the caliper.

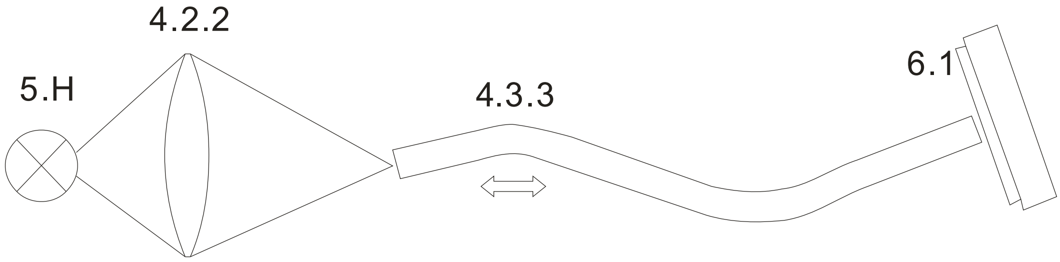


Fig. 18. Longitudinal shift sensor scheme.

It is clear that using of this scheme for real sensor construction is not expedient but it is possible. Here it is suggested for only methodical view.

More acceptable example is light guide sensor scheme (also realized using UMOG-3 kit) where light guide input butt is fixed and used for receiving of radiation scattered by moving surface. Surface lighting is executed by laser semiconductor diode. Luminous flux transmitted onto photodetector 6.1 over the fiber 4.3.3 depends on distance between the surface and input butt that is used in technical solution.

3.3. Optical spectrum experiments.

In the kit the possibility is provided to realize the traditional scheme of prism monochromator (fig. 19). The following items are fixed on the optical bench: incoherent light source 5.H, objective 1.7.O, slit 4.1.9, long-focus lens 4.2.1, and prism 4.2.4. Continuous spectrum of the source is observed in the plane of slit image on the translucent screen 6.4.P. For more effect one can use double monochromatization by the second prism.

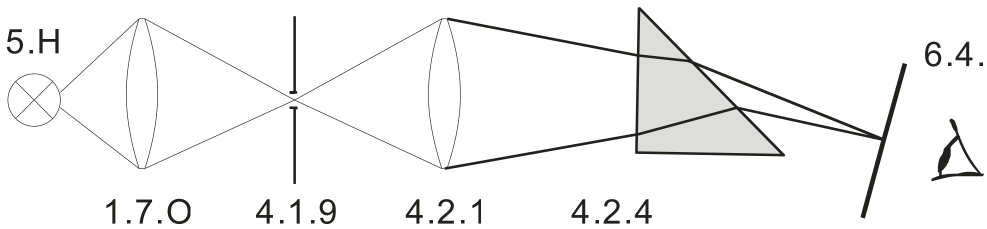


Fig. 19. Prism monochromator scheme.

At the same time it is useful for studying process to use focal monochromator on basis of holographic lens. While using one it is necessary to become proficient in most domains of interference, diffraction, holography, spectrum optics, etc. Special refinement is added to these experiments by using the same holographic optical element as dispersive and focusing unit.

3.3.1. Holographic lens theory.

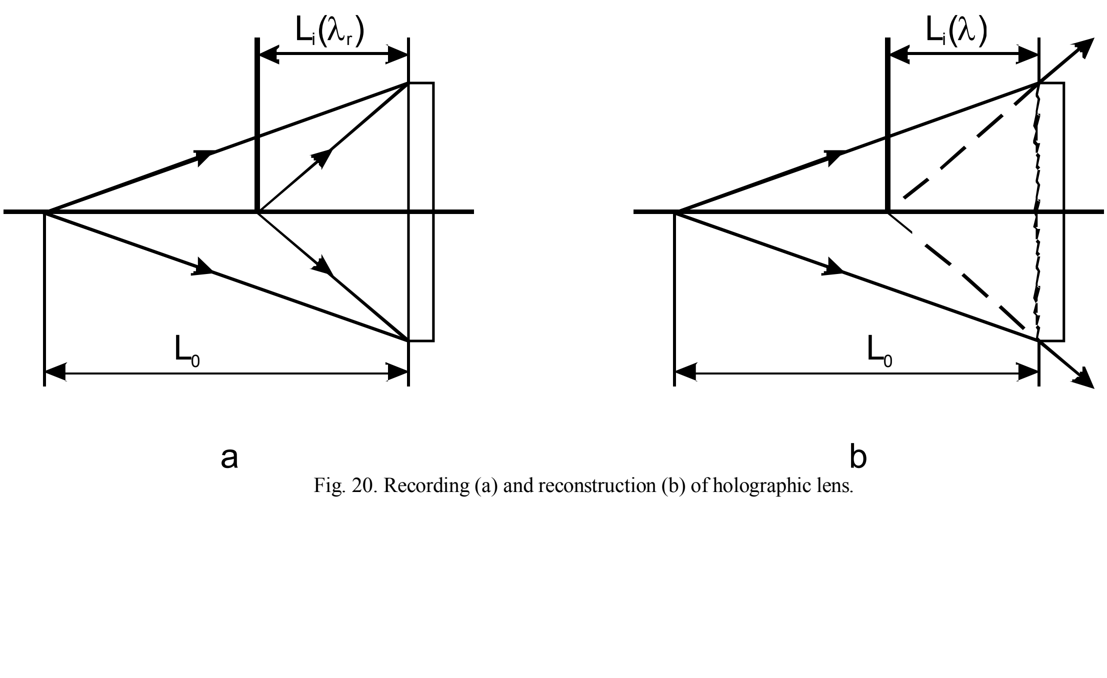


Fig. 20. Recording (a) and reconstruction (b) of holographic lens.

If one records on photographic plate an interference pattern from two spherical waves with wavelength λ_r and with centers of curvature of wave fronts on distances L_o and $L_i(\lambda_r)$ (fig. 20a), then after photographic development it will be planar hologram that possesses lens properties. If such hologram being illuminated with spherical wave (fig. 20b) the restored wave front is also spherical. Focal length of such lens is described by the formula:

$$\frac{1}{f'} = \frac{1}{L_0} + \frac{1}{\mathrm{L_i}(\lambda_r)} \tag{1}$$

When holographic lens is illuminated by reference radiation with wavelength λ from distance L_o , the image is observed on distance $L_i(\lambda)$ associated with registration parameters by equation:

$$L_i(\lambda\ ) = \lambda_r \frac{L_i(\lambda_r) \cdot L_0}{L_i(\lambda\ ) \cdot (\lambda - \lambda_r) - \lambda \cdot L_0} \approx \frac{\lambda_r}{\lambda} \cdot L_i(\lambda_r) \tag{2}$$

Here it is supposed that $(\lambda-\lambda_r)<\lambda$ and $L_i<L_0$.

Hence it follows that holographic lens possesses pronounced chromatism that can be used in design of spectral devices. Monochromator schemes utilizing dependence of focal distance from wavelength are known for a long time and are called as focal monochromators.

3.3.2. Focal monochromator with holographic lens (FMHL).

The FMGL scheme is given in fig. 21. If one makes chemical treatment of photo-plate so that to obtain relief-phase hologram and then apply mirror coating by vacuum deposition over the obtained relief, then it will be reflective dispersive element of focal monochromator with holographic lens that we will denote as HL. The HL is illuminated by light source with wavelength λ from distance L_0. Reconstructed image is observed from distance $L_i(\lambda)$ described by equation (2). Using in scheme the off-axis fragment of HL allows forming separately in space images formed by different wavelengths. Images in described here construction are observed on translucent screen with measuring grid (fig. 4).

Denote y_0 – size of light source, h_0 – coordinate of dispersive element point from that HL edge. The HL forms the image with size $y=\beta\times y_0$ where β - linear magnification coefficient of HL that is connected with recording - reconstruction parameters:

$$\beta = \frac{\mathrm{L_i}(\lambda\ )}{L_0} \tag{3}$$

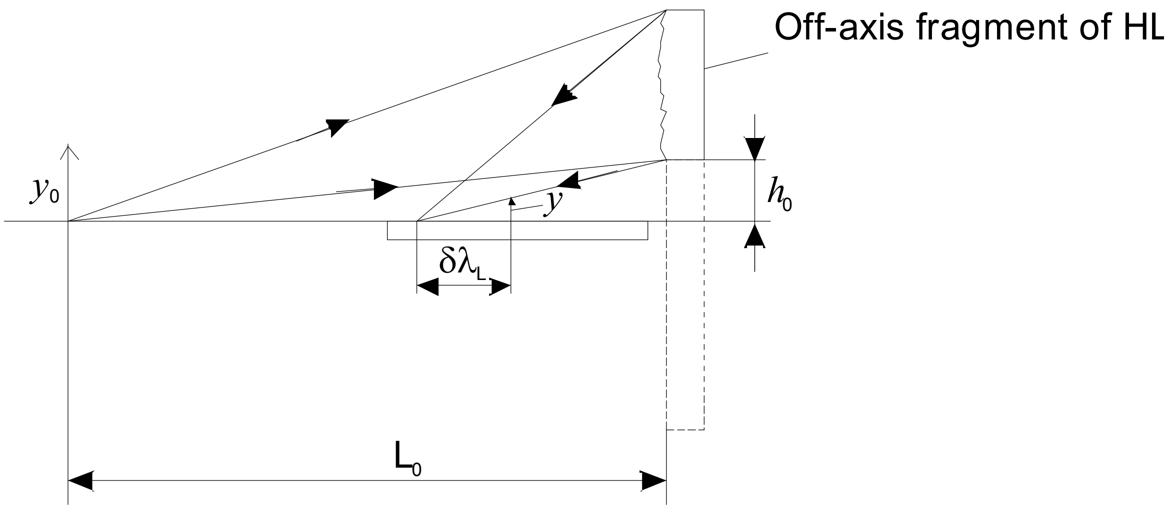


Fig. 21. Optical scheme of FMHL.

As long as on the translucent glass it is observed the projection of image of size y on optical axis then for its size $\delta\lambda_L$ we have evident equation:

$$\delta\lambda_L = \frac{y \cdot L_i(\lambda\ )}{h_0 - y} = \frac{L_i^2(\lambda\ ) \cdot y_0}{L_0 \cdot (h_0 - \beta \cdot y_0)} \approx \frac{L_i^2(\lambda\ )}{L_0} \cdot \frac{y_0}{h_0} \quad (4)$$

Then as spectral resolution of the focal monochromator with off-axis fragment of HL we may take value

$$\delta\lambda = \delta\lambda_L \cdot \frac{\Delta\lambda}{\Delta\lambda_L} \quad (5)$$

where $\Delta\lambda_L = L_i(\lambda_S) - L_i(\lambda_L)$ – area occupied on translucent screen of monochromator by spectral range $\Delta\lambda$ with shortwave limit – λ_S and longwave – λ_L.

The HL used in monochromator UMOG-3 has the following parameters

L_o = 150 mm; $L_i(\lambda_r)$ = 40 mm; λ_r= 632,8 nm; h_0= 10 mm.

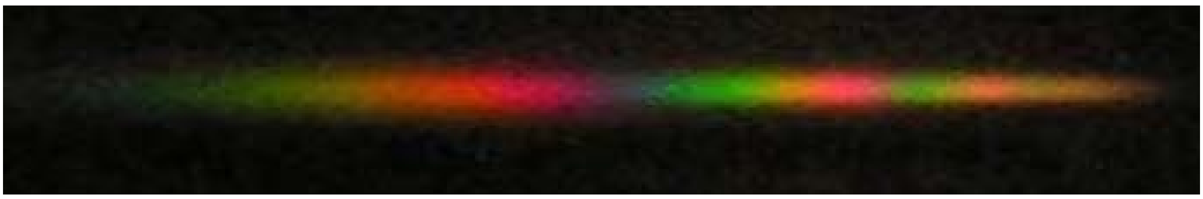
If optic fiber is used as light source then for y_0 it should be taken the diameter of fiber core equals 0.25 mm. Thus it is possible to bring light from different light sources from UMOG-3 kit into focal monochromator. The spectral resolution estimated by (5) is about 50 nm. This value can be improved by screening a part of HL.

Instead of the translucent screen it can be used CCD sensor. It allows observing formed spectrum in monitor and make proper measuring with digital signal.

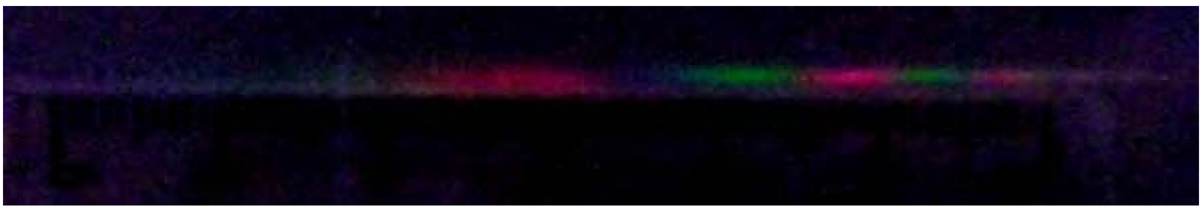
3.3.3. Spectral measuring with FMHL.

Relief-phase grating (HL) used in UMOG-3 is non-linear in principle. Thereby while diffraction on such structure there are observed several diffraction orders. It should be remembered while spectrum interpretation obtained by FMHL and try to make experiments at the same order. The higher diffraction order is, the bigger angle the beam deflects while interaction with the grating. Hence the more number of order is, the closer it is situated to HL.

White light polychromatic structure is observed on the translucent screen of monochromator while the light is used from halogen lamp or white LED. White LED consists of 3 crystals generating radiation of 3 wavelengths (linear spectrum). Therefore their images are seen separately in spectrum (fig. 22b) as against thermal source spectrum (fig. 22a) – metal-halide lamp – that is principally continuous.



a



b

Fig. 22. Different white light sources spectrums: a- metal-halide lamp, b- white LED.

In order *to measure the wavelength of monochromatic source* it is necessary to calibrate the device. From (2) it follows that

$$L_i(\lambda) = \frac{k}{\lambda} \cdot ,$$

where k is the constant depending on registration parameters.

Therefore using in FMHL the radiation from source with known wavelength λ_0 (for example from laser diode) and measuring image location $L_i(\lambda_0)$ on the translucent screen one can calculate for given monochromator and given diffraction order

$$k = L_i(\lambda_0) \cdot \lambda_0 .$$

For measuring $L_u(\lambda)$ one can use monochromator screen grid. Better results can be obtained by means of caliper.

After that one can introduce into monochromator the radiation from source with unknown wavelength and having measured $L_i(\lambda_U)$ obtain for its wavelength

$$\lambda_U = \frac{L_i(\lambda_0)}{L_i(\lambda_U)} \cdot \lambda_0$$

4. Conclusion

In this paper the new version is described of the educational kit for optical experiments. It is shown that the new version (UMOG-3) is more functional and provides more demonstrations and laboratory works. At the same time, the main principles of equipment design remain valid – modular construction with the possibility to combine, rearrange and supplement the main blocks and elements; absence of complicated, precision and expensive units. This approach to the design of such a set provides a possibility of its rearrangements, when necessary, to satisfy the needs of teaching process either for universities or for high schools. Moreover such methodical approaches and designs allow simplifying and unifying training equipment in optics and give an opportunity to concentrate an attention on phenomenon researched instead of on instrumental provision.

In the paper the methodological approaches are presented just for some additional experiments realized with the use of new kit: fiber optics experiments, spectrum experiments, spectral measurement.

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Quantum Optics Experiments with Single Photons for Undergraduate Laboratories

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Abstract: We present new results of interference experiments for undergraduates that underscore the quantum nature of the light. The experiments use parametric down-conversion to generate pairs of correlated photons. The experiments involve one- and two-photon interference schemes that rely on first and second-order coherence effects. They can be used as a complement to teaching quantum mechanics or quantum optics.

OCIS codes: (000.2060) Education, (270.0270) Quantum optics.

1. Introduction

Developments in the technology for producing and detecting correlated photon pairs via parametric down conversion have enabled the implementation of undergraduate-level laboratories for demonstrating fundamental quantum mechanical principles, such as superposition and entanglement. Whitman College and Colgate University have put much effort in developing undergraduate laboratories with correlated photons [1-5], and have recently started offering undergraduate quantum mechanics courses with associated laboratories based on these types of experiments.

Laboratories with correlated photons are important because they underscore fundamental concepts of quantum mechanics. They allow students to learn quantum mechanics via experimentation and thus start their quantum physics education from a position where they can gain valuable physical intuition. Experiments on interference of light at the single-photon limit serve as exercises in quantum mechanical concepts and algebra. Thus they constitute direct applications of a topic that is otherwise purely theoretical and abstract. An interesting feature of these types of experiments is that they give the instructor the flexibility to tailor the explanation of the results to his or her quantum mechanical formalism.

We use an increasingly popular source of correlated photons: spontaneous parametric down conversion. It consists of sending a pump laser beam to a nonlinear crystal to produce photon pairs that are correlated in time, energy, momentum and polarization. The pairs can be used as a source of non-classical light. In some cases one photon of a pair heralds the other one going through an interferometer, and in other cases both photons go through the interferometer for demonstrating richer quantum mechanical effects. Many experiments with correlated photons, in particular the ones presented in this article, cannot be reproduced by an attenuated source of light. With special modifications the source can produce photon pairs entangled in polarization, and thus enabling tests of Bell's inequalities [3,6,7].

In previous publications we presented interference experiments for use in undergraduate laboratories [1,2,5]. In this article we expand upon some of those reports with the results of more recent work. In Sec. 2 we present an experiment that combines single-photon interference in a polarization interferometer with the "single-photon test." The latter is a second order coherence correlation test that reveals, and even proves, the quantum nature of the photon. In Sec. 3 we follow with a two-photon interference experiment where we study the photon correlations coming off the two ports of a Mach-Zehnder interferometer.

2. Single-photon interference

In Ref. [1] we describe an undergraduate experiment that demonstrates that light is made of photons. By this we mean an experiment that requires a quantum mechanical treatment of the field for an explanation (i.e., an experiment that cannot be explained using a classical wave theory of light). One such experiment was performed by Grangier and coworkers [8], and it is this experiment that we have adapted. The basic idea is to show that if a single photon is incident on a beam-splitter it can be detected at the transmitted port, or the reflected port, but not both—there should be no simultaneously detected photons at the transmitted and reflected ports.

To generate the single photons we use spontaneous parametric down conversion. A crystal of beta-barium-borate (BBO) is pumped by the output of a 405nm laser diode, producing signal and idler photon pairs centered at 810nm via type-I down-conversion. The pairs go in separate directions: the idler photon goes to a detector *G* and the signal photon goes to a non-polarizing beam-splitter. The detection of an idler photon at detector *G* serves as a gate, which heralds the presence of a signal photon at the beam-splitter. This photon is then either transmitted to detector *T*, or reflected to detector *R*. Detector *G* has a narrow (10 nm bandwidth, centered at 810nm) interference filter located in front of it, whereas in front of detectors *T* and *R* there are color glass filters (RG780) that transmit all wavelengths longer than 780nm.

Let N_G be the number of detections at detector *G* in the time interval ΔT, N_{GT} be the number of coincidence detections between detectors *G* and *T* (N_{GR} is defined similarly), and N_{GTR} be the number of simultaneous three-fold detections. It was proved by Grangier et al. [8] that a classical wave incident on the beam-splitter must satisfy the following inequality:

$$g^{(2)}(0) = \frac{N_{GTR} N_G}{N_{GT} N_{GR}} \geq 1 \ . \tag{1}$$

Here $g^{(2)}(0)$ is the conditional degree of second-order coherence of the field incident on the beam-splitter—it is conditioned on the presence of a photon being detected at the gate detector [1,8]. If one measures $g^{(2)}(0) < 1$ the experiment is not explainable with classical waves and must be explained using a quantum mechanical field. We were able to measure $g^{(2)}(0) = 0.0177 \pm 0.0026$; after accounting for accidental coincidences this result is consistent with a single photon being incident on the beam-splitter.

Once students have shown that they can generate a field containing a single photon, the next obvious experiment is to show that a single photon will interfere with itself after traversing an interferometer. To do this we replace the beam-splitter with a polarization interferometer [2]; a diagram of the interferometer is shown in Fig. 1.

Light enters the interferometer vertically polarized. It then passes through a half-wave plate ("λ/2" in Fig. 1) that rotates the polarization of the beam to have both vertical and horizontal components. The beam then encounters a beam displacing prism (BDP), which is a piece of calcite cut so that the extraordinary (horizontally polarized) wave is displaced from the ordinary (vertically polarized) wave as it propagates. These beams will have equal amplitudes if the first half-wave plate is adjusted so that the light is polarized at 45° as it enters the BDP. The half-wave plate after the BDP is oriented such that it flips the polarizations of the two beams so that their behavior is reversed at the second BDP. This is a necessary step in order to equalize the path lengths between the two arms, as described

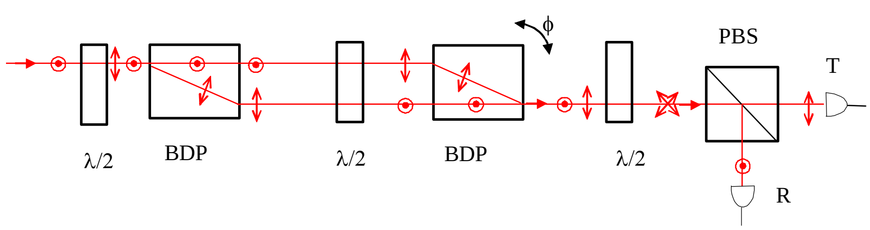

Fig. 1 The polarization interferometer with the polarizations of the beams indicated.

further below. The second BDP is oriented to recombine the two beams, but since they are orthogonally polarized at this point they do not yet interfere. These orthogonally polarized beams then pass through another $\lambda/2$ plate which rotates the two polarizations by 45^o. The beams then hit a polarizing beam-splitter (PBS) where they interfere. The interference can be observed by tilting one of BDP's to sweep the relative phase.

This interferometer design has several advantages. Most importantly it can be made extremely compact, and it is made entirely from transmissive optical elements; this means that it is *extremely* stable, which allows us to use long counting times to obtain accurate statistics. Also, since the individual photons have large bandwidths the lengths of the two arms must be matched to a high precision in order to observe interference; this is easily achieved in this interferometer by simply rotating one of the BDP's.

Interference fringes can be seen in Fig. 2. Figure 2(a) shows the singles counts on detector T, N_T. This simply shows the classical "white-light" fringes of our broadband down-conversion source. Figure 2(b) shows the GT coincidence counts; since the detections at T are now conditioned by a gate detection these represent events in which a single photon has traversed both paths of the beam-splitter and interfered with itself. The visibility of this interference pattern is 89%. Lastly, since we are able to measure both output ports of the interferometer, we have all of the information necessary to simultaneously measure $g^{(2)}(0)$ with the interference fringes. Equation (1) is still valid for $g^{(2)}(0)$ as we scan the path-length difference because $g^{(2)}(0)$ is independent of the splitting ratio of the beam-splitter; an interferometer may be thought of as a beam-splitter with a splitting ratio that depends on the path-length difference. In Fig. 2(c) we see that $g^{(2)}(0) < 1$ at all times, verifying that we have only one photon in the interferometer at a given time. Thus, in this experiment we are able to simultaneously observe both the wave-like [Fig. 2(b)] and the particle-like [Fig. 2(c)] natures of light. We note that this result is not new, having been obtained before by Kwiat and Chiao [9]. We have simplified the experiment, however, and in doing so have made it possible for undergraduates to perform it as part of a teaching laboratory.

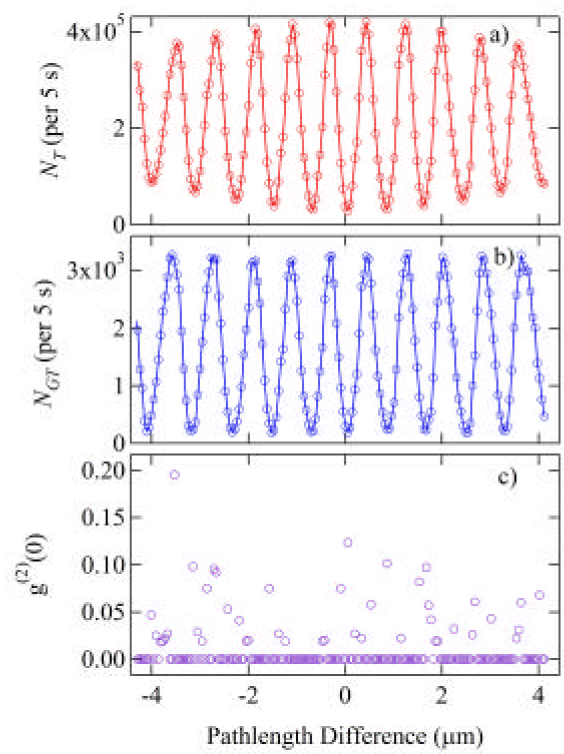

Fig. 2 a) shows measured singles counts on detector T, b) shows GT coincidence counts, and c) shows the measured value of $g^{(2)}(0)$. All data are plotted as a function of the path-length difference between the two arms of the interferometer.

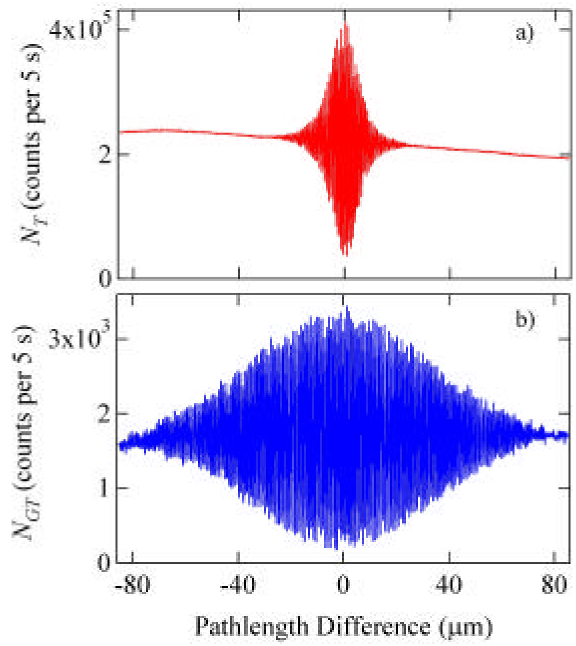

Fig. 3 a) shows measured singles counts on detector *T*, and b) shows *GT* coincidence counts. All data are plotted as a function of the path-length difference between the two arms of the interferometer.

It can be seen in Fig 2(a) that the visibility of the fringe pattern is decreasing at larger pathlength differences, while this is not apparent in Fig. 2(b). Figure 3 shows longer scans which more clearly display the visibility envelopes. Here it is clearly seen that the fringe pattern measured in coincidence (the single photon data) has a longer coherence time (narrower bandwidth) than the singles counts. Why is this? The coherence length of the unconditioned downconversion in Fig. 2(a) is approximately 12 microns, which corresponds to a bandwidth of roughly 57 nm; this is consistent with the bandwidth of the downconverted photons that we expect to collect. The coherence length of the conditioned downconversion in Fig. 2(b) is approximately 79 microns, which corresponds to a bandwidth of roughly 8.6 nm; this is close the bandwidth of the interference filter in front of detector G.

Thus, narrowing the bandwidth of the gating photons increases the coherence length of the interference pattern measured in coincidence. This is because the frequencies of the signal and idler are correlated—they are constrained by the fact that the sum of the signal and idler frequencies must be equal to the frequency of the pump photon. Indeed, the quantum theory of down-conversion indicates that the frequencies are entangled, but this experiment proves only that they are correlated. This effect was also seen in Refs. [9] and [5].

3. Two Photon Interference

Single-photon interference is a good starting point for studying quantum interference. Consider the Mach-Zehnder interferometer shown in Fig. 4. There are several ways in which one can use quantum mechanics to understand the interference of single photons going through the interferometer. One could use Feynman's approach of probability amplitudes for indistinguishable paths [10], state vector transformations by the interferometer elements [5], matrix operations of interferometer transformations [4], or even photon number state transformations [11].

In contrast to classical-wave interference, where interference depends on the number of paths, in quantum mechanics we consider the indistinguishable ways in which we can obtain a certain result. Two-photon interference provides such a distinction, because two photons traveling through the two possible paths of an interferometer interfere in four possible ways [5]. Thus, this experiment underscores the quantum mechanical view of interference. As described in Ref. [5], when all four possibilities are indistinguishable the probability for detecting the

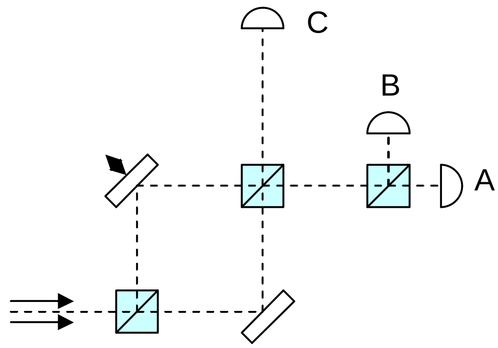

Fig. 4 Schematic of a Mach-Zehnder interferometer for two photons.

coincidences is

$$P = ¼\ (1 + \cos \delta)^2, \tag{2}$$

where δ is the phase difference due to the path-length difference of the interferometer arms. This is in contrast to single-photon interference, where the probability of the photon going through the interferometer is

$$P = ½\ (1 + \cos \delta). \tag{3}$$

In this section we expand on the two photon interference problem by considering the case where the two photons enter the Mach-Zehnder interferometer together but leave it separately. We will use the state vector appro ach to describe the experiment. Let's represent the state of the light moving in the x and y directions by $|x\rangle$ and $|y\rangle$, respectively. In going through the a beam splitter these states transform as

$$|x\rangle \to t|x\rangle + r|y\rangle \tag{4}$$

and

$$|y\rangle \to r|x\rangle + t|y\rangle, \tag{5}$$

where $t = 1/\sqrt{2}$ and $r = i/\sqrt{2}$ are the probability amplitudes for transmission and reflection at the beam-splitter, respectively. The state of the two identical photons before they enter the interferometer is given by the product state $|x\rangle_1|x\rangle_2$. In going through the interferometer the state of the light becomes

$$|x\rangle_1|x\rangle_2 \to r^2t^2\left(1+e^{id}\right)^2|x\rangle_1|x\rangle_2 + \left(r^2+t^2e^{id}\right)^2|y\rangle_1|y\rangle_2 + rt\left(1+e^{id}\right)\left(r^2+t^2e^{id}\right)\left(|x\rangle_1|y\rangle_2 + |y\rangle_1|x\rangle_2\right). \tag{6}$$

The first term corresponds to the case already investigated in Ref. [5]. The rate of coincidences in detectors A and B is proportional to the probability of ending in state $|x\rangle_1|x\rangle_2$, which is given by Eq. (2). The probability of ending in state $|y\rangle_1|y\rangle_2$ differs from the one given by Eq. (2) in that it has a minus sign instead of a plus sign. Here we are interested in the case where the photons come out from the separate ports of the interferometer. It is interesting that the algebra leading to the state of the light coming from separate ports gives the symmetric wavefunction

$$|y\rangle_{xy} = \frac{1}{\sqrt{2}}\left(|x\rangle_1|y\rangle_2 + |y\rangle_1|x\rangle_2\right). \tag{7}$$

This is of course what we expect because photons are bosons! The probability for ending in this state $|y\rangle_{xy}$ is

$$P = \tfrac{1}{4}\,(1 - \cos 2\delta\,). \qquad (8)$$

This is a very interesting result. The probability oscillates with twice the frequency of the single-photon result. Notice that the visibility for this case can be 1. This type of quantum interference has received much attention for improving over the classical limit of resolution [12]. This interference is similar to the one that gives rise to the Hong-Ou-Mandel interference [13], which produces a characteristic "dip." The dip disappears when the path length exceeds the coherence length of the down-converted light. In this case the visibility of the interference pattern will go to zero.

The picture of the experimental arrangement is shown in Fig. 5. Light from a GaN diode laser (402 nm) is sent through a BBO crystal producing photon pairs via type-I parametric down conversion. We orient the crystal for collinear down conversion of the pairs with equal energy (804 nm) [5]. A polarizer after the crystal eliminates the pump beam, which has a polarization orthogonal to that of the down-converted photons. The photon pairs enter a Mach-Zehnder interferometer. One of the mirrors of the interferometer is mounted on a linear stage that has a piezo-electric crystal as a spacer between the micrometer and the stage. After the interferometer the light is directed to three optical fiber couplers preceded by irises and 10-nm bandpass filters. The fibers are multimode and send the light to high efficiency single-photon avalanche photodiode detectors. More details of the apparatus, alignment, and cost can be found in our websites [14,15].

Figure 6 shows three data sets. The "+" symbols show the single-photon interference signal from detector *A* only. In order to display the data with the other two data sets we plot (N_A/80 + 1500). The data set represented by the symbols "x" shows the coincidences between detectors *A* and *B*, N_{AB}, displaying the type of interference represented by Eq. (2). The third set of symbols (filled circles) show the coincidences between detectors *A* and *C*, N_{AC}. Notice that the frequency of the interference is twice that of the single-photon interference, in agreement with Eq. (8). The apparent phase shift between the data sets is due to the placement of the irises after the interferometer.

This setup is harder to align than, for example, the setup of Sec. 1. The arms need to be aligned to near zero path-length difference. We have developed a method for systematically aligning the interferometer [15]. Once the interferometer is aligned then search for white-light fringes by putting a small incandescent bulb at the entrance of the interferometer and placing at the output a multimode fiber that sends the light to a low-resolution spectrometer. We have used this setup for the laboratory of the quantum mechanics course at Colgate University. For more details see our website [15].

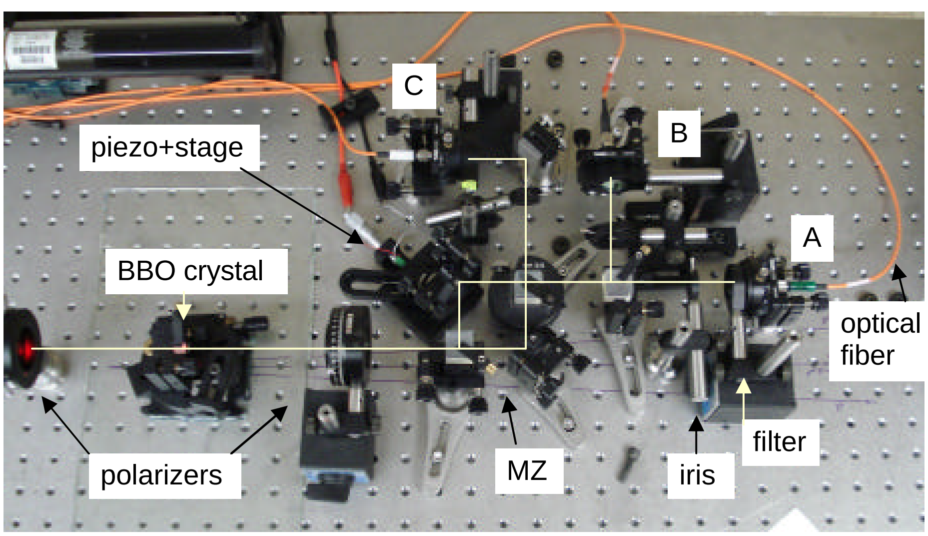

Fig. 5. Photo of the apparatus used for the two photon experiments.

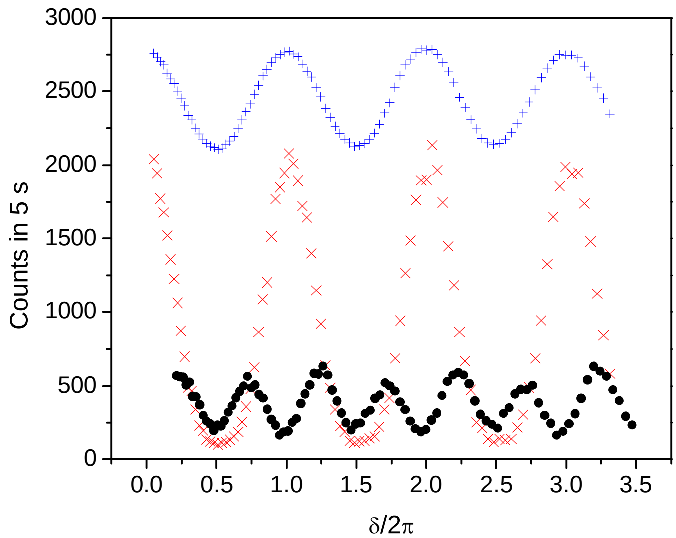

Fig. 5. Graph of the results of the two-photon interference experiment. Symbols (+) are proportional to the single-photon counts N_A; (x) represent the counts when both photons leave the interferometer through the same port N_{AB}; and (●) represent the counts when the photons leave the separate arms of the interferometer N_{AC},.

4. Conclusions

In conclusion, we present new results from one and two-photon interference experiments that underscore the quantum nature of light. The experiments are a useful laboratory aid for teaching quantum mechanics and quantum optics. These programs have been successfully implemented at our undergraduate colleges. We foresee that the experiments could also be implemented in graduate-level courses in quantum optics.

5. Acknowledgments

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I.

PHOTON PBL: Problem-Based Learning in Photonics Technology Education

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Abstract: Problem-based learning (PBL) is an educational approach whereby students learn course content by actively and collaboratively solving real-world problems presented in a context similar to that in which the learning is to be applied. Research shows that PBL improves student learning and retention, critical thinking and problem-solving skills, and the ability to skillfully apply knowledge to new situations – skills deemed critical to lifelong learning. Used extensively in medical education since the 1970's, and widely adopted in other fields including business, law, and education, PBL is emerging as an alternative to traditional lecture-based courses in engineering and technology education. In today's ever-changing global economy where photonics technicians are required to work productively in teams to solve complex problems across disciplines as well as cultures, PBL represents an exciting alternative to traditional lecture-based photonics education. In this paper we present the PHOTON PBL project, a National Science Foundation Advanced Technology Education (NSF-ATE) project aimed at creating, in partnership with the photonics industry and university research labs from across the US, a comprehensive series of multimedia-based PBL instructional resource materials and offering faculty professional development in the use of PBL in photonics technology education. Quantitative and qualitative research will be conducted on the effectiveness of PBL in photonics technician education.

1 Introduction

Photonics technicians are problem solvers – individuals who must skillfully apply their knowledge of lasers, optics, electronics, and related technologies in solving real-world problems [1]. Working side-by-side with engineers and scientists, photonics technicians are the "hands-on" side of an engineering team, responsible for designing experiments, building and troubleshooting prototypes, analyzing and interpreting data, and presenting experimental results to peers, supervisors and customers. Given the broad scope of duties required of the photonics technician it is ironic that photonics technician education programs are most often taught in a traditional instructor-centered manner that provides little opportunity for students to actively engage in real-world problem solving. This approach to education often results in graduates who do not have a full range of important employability skills and competencies needed in business and industry, such as the ability to: (1) apply their knowledge in new and novel situations, (2) communicate effectively, (3) work as members of an interdisciplinary team, and (4) engage in lifelong learning – skills deemed critical by ABET EC2000 [2]. As a result, photonics technicians often enter the workforce inadequately prepared to adapt to the complex and ever-changing demands of the 21st century high-tech workplace [3]. The PHOTON PBL project will address this challenge through the use of problem-based learning.

In this paper we present the PHOTON PBL project, a National Science Foundation Advanced Technology Education (NSF-ATE) project aimed at creating a comprehensive series of multimedia-based PBL instructional modules or *Challenges* and providing faculty professional development in the pedagogy and use of PBL in photonics technology education. Developed in partnership with the photonics industry and university research labs from across the US, each PHOTON PBL Challenge will present a re-enactment of an authentic photonics problem encountered by a partner company or university. Unlike traditional case studies where students are just passive observers, the PHOTON PBL Challenges will actively engage students in the actual problem-solving process using an instructor facilitated multi-tier approach designed to scaffold the development of students' problem-solving and critical thinking skills. The PHOTON PBL Challenges are directly linked to the highly successful NSF-funded PHOTON2 curriculum and laboratory materials [1], which have been adopted at over 80 secondary and post-secondary institutions across the US. Quantitative and qualitative research will also be conducted on the effectiveness of PBL in photonics technician education.

2 What is Problem-Based Learning?

Problem-based learning is an instructional method that challenges students to "learn how to learn" by collaboratively solving genuine real-world problems. PBL is based on the constructivist model of learning, whose major tenets are (1) learning and understanding are directly related to the environment or context in which learning occurs, (2) cognitive conflict or "puzzlement" is the stimulus for learning and determines the organization and nature of what is learned, and (3) social environment is primary in providing alternative views and additional information against which we can test the viability of our understanding and comprehension. Research shows that compared to traditional lecture-based instruction, PBL improves student understanding and retention of ideas, critical thinking, communication and problem-solving skills, as well as the ability of students to adapt their learning to new situations – the cornerstone of lifelong learning [4,5,6,7,8,9,10].

PBL teaches students the *process* of solving real-world, open-ended problems that may have a number of possible solutions. The pedagogical framework for the PHOTON PBL project is guided by Barrows' Model [8] originally developed at McMaster University in Canada for use in medical school education and subsequently adopted widely by medical, business, education, and engineering schools around the world. The Barrows Model involves a recursive problem-solving process that begins with a problem scenario presented in the context in which it is to be solved. Student teams work collaboratively in analyzing the problem by identifying relevant facts and learning issues, activating prior knowledge, generating hypotheses, reflecting on their beliefs about the problem, and generating learning objectives needed to solve the problem. This phase is followed by a period of self-directed learning whereby each student engages in learning specific content identified as relevant in the initial problem analysis phase. During this phase, the instructor serves as a consultant, guiding the student as they seek out required resources and providing additional information as needed, thus shifting the responsibility for learning onto the student. By shifting the responsibility for learning onto students and providing scaffolds for learning, students are more likely to develop the self-directed learning skills needed to successfully engage in lifelong learning [3]. Upon completion of the self-directed learning phase, students reconvene to assess and evaluate their problem solution based on their new understanding of the problem, and reformulate solutions if needed. This process, illustrated in Figure 1, may repeat itself several times in the process of solving a single problem. Student evaluation in PBL may take one of several forms, from a final patient diagnosis in medical education [8], to the generation and presentation of a formal proposal including cost/benefit analysis and/or feasibility analysis in an engineering education application [11]. In either case, the final problem solution takes the form of what would be most appropriate in that particular context.

While PBL has been used extensively in medical education since the early 1970's and has been widely adopted in other fields including business, law, and education, it is only beginning to emerge as an alternative to the traditional lecture-based approach to engineering and technology education [5,6,7]. For example, Nashville State Technical College has adopted PBL in its two-year engineering technology program through its NSF-funded CaseFiles® project [10]. Four-year engineering institutions such as University of Buffalo, University of Delaware, Worcester Polytechnic Institute, and several others have also adopted PBL in selected engineering courses, reporting increases in problem-solving skills, critical thinking, retention, and motivation for learning [11,12,13]. Given the practical nature of photonics technology education where students must learn to apply their knowledge in solving complex, real-world problems, PBL appears well-suited for educating technicians capable of addressing the ever-changing needs of today's technological and multicultural society.

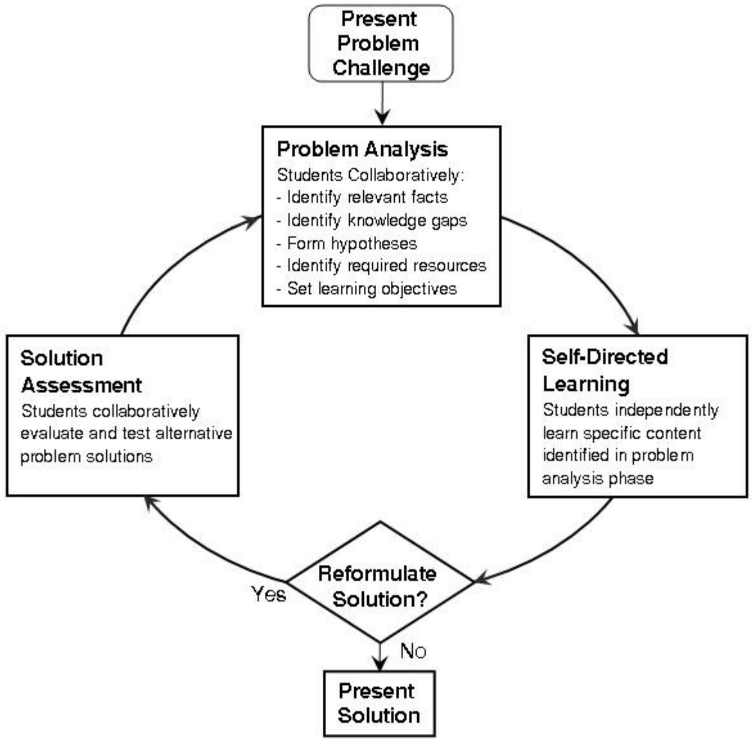


Figure 1. The PBL Process

3 The PHOTON PBL Project

The main obstacles for educators in adopting PBL in technology education are the overall lack of instructional resources and faculty training in the use of PBL in the classroom. This is especially true in the field of photonics, where limited instructional resources have always been an issue for educators. These instructional resources include genuine real-world problems linked to course content, problem-solving strategies, assessment and evaluation methods, alternative problem solutions, supplementary online resources, and other relevant information needed to help educators implement PBL in their curricula. The main purpose of these instructional resources is to help faculty create a learning environment that emulates the context in which students must ultimately apply their knowledge – the workplace. Research shows that solving genuine problems is more likely to engage and motivate learners [14]. This is a major departure from traditional "end-of-chapter" problems whose parameters are well-defined and solutions artificial. PBL instructional materials must effectively guide students through the problem solving process, requiring that students not only properly frame the problem, but also identify knowledge gaps, set learning goals, and seek out the resources needed to converge on a solution, both individually and collaboratively. This process is vital in developing the metacognitive skills needed for lifelong learning [1,3,15].

3.1 PHOTON PBL Instructional Resource Development

To address the lack of instructional resources for PBL in photonics technology education, the PHOTON PBL project, in partnership with selected photonics industry partners and university research laboratories from across the US, will create a series of eight multimedia PBL Challenges (DVD) and instructional resource materials covering a broad range of photonics applications. Active participation of industry and university partners in providing genuine real-world photonics problems that can be used in the classroom, actual problems whose solutions have been documented and tested, serves as the centerpiece of the PHOTON PBL project. Unlike traditional case studies in which students passively study and critique problem situations encountered by others, the PHOTON PBL Challenges are designed to actively engage students in the problem-solving process by virtually "inserting" them into the context and environment in which the problem is to be solved, thus emulating the actual workplace experience.

For each PHOTON PBL Challenge, both a student version and an instructor version will be developed. The student version will contain a multimedia introduction to the specific company or university research lab to set the context for the problem challenge followed by a re-enactment of the problem statement by actual industry/university personnel, the problem-solving process engaged in by actual engineers and technicians, and a detailed presentation of the problem solution. A problem solving "toolbox" will be incorporated into each PHOTON PBL Challenge to provide students with the learning resources needed to successfully guide them through the problem-solving process. The instructor version will contain all of the information contained in the student version plus additional instructional resources including an instructor's "toolbox" containing instructional strategies, assessment and evaluation tools, industry standards related to the problem challenge, a solution guide detailing alternative problem solutions, and information regarding alignment with national science, math, language arts and technological literacy standards. The instructor version will also contain a generic PBL template and instructions to help them develop their own PBL Challenges.

Each PHOTON PBL Challenge is directly linked to the highly successful NSF-funded PHOTON curriculum and laboratory materials [1], which are aligned with national science, math, language arts and technological literacy standards, and have been adopted at over 80 secondary and post secondary institutions across the US. These field-tested instructional materials and laboratory equipment have been developed to support instruction in topics including geometric and wave optics, laser principles and applications, fiber optics, lighting and illumination, environmental sensing, laser materials processing, optical fabrication and testing, and biophotonics. Each PHOTON PBL Challenge is designed to be completed by students in a one- to four-week time frame and can be customized by the instructor for complexity allowing for multiple problems to be presented within a typical 15-week semester.

Another obstacle in adopting PBL in technology education is its departure from traditional didactic methods. A common complaint among students introduced to PBL for the first time is the stress and anxiety associated with open-ended problems and self-directed learning. Most students are accustomed to traditional lecture-based methods of instruction in which information is passively "transferred" from the instructor to the student in an environment that is well structured and where problem parameters are clearly defined and closed-ended. Conversely, "The sudden propulsion to the uncertain, self-directed technique and the responsibility associated with PBL exposes learners to an uncertain and unknown dimension, thus, eliciting fear, anxiety, and the desire to hold on to something familiar when the outcome is unknown [9]." This frustration and anxiety can not only lead to disengagement from the learning process among students, but can also create a stressful situation for faculty trying to transition to PBL from more traditional instructional methods. To ease this transition, the PHOTON PBL Challenges are designed to be implemented using three levels of structure ranging from Level 1 (Instructor Led - Highly Structured), to Level 2 (Instructor Guided - Moderately Structured), to Level 3 (Instructor as Consultant - Open-Ended) depending on the technical nature of the problem and the ability level of the students. By providing scaffolds for learning that allow students (and faculty) to progress through the PBL Challenges along a continuum, from a low autonomy mode (structured) to high autonomy mode (open-ended) over time, faculty will be more likely to adopt this new mode of instruction and students more likely to develop the skills and confidence needed to take responsibility for their own learning [16,17,18,19]. This is illustrated in Figure 2 and described in the proceeding sections.

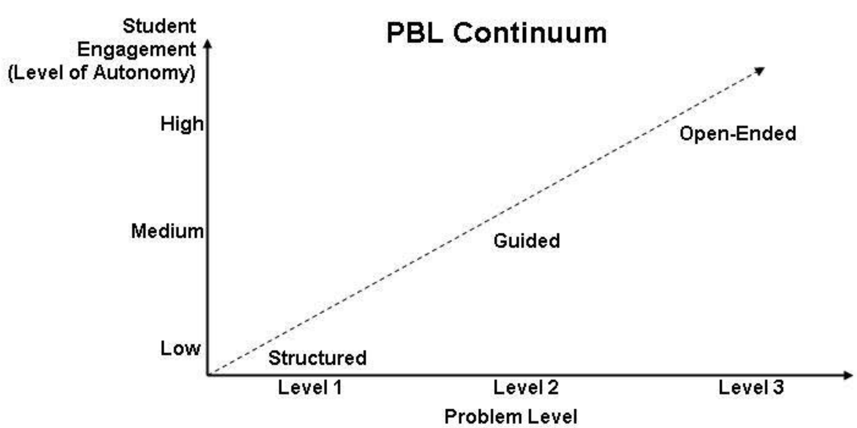
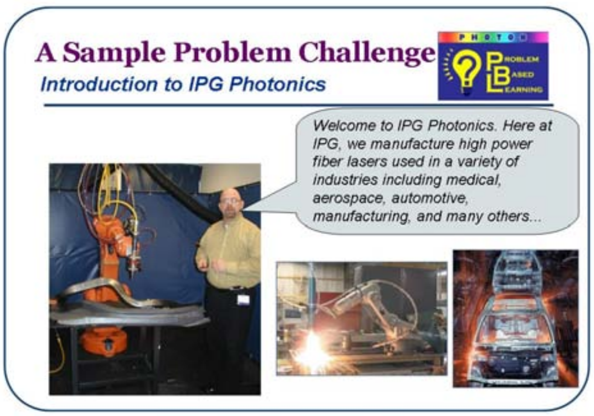


Figure 2. The PBL Continuum

3.1.1 Level 1 (Instructor Led – Structured)

In Level 1, students are presented with the PBL challenge in its entirety as a multimedia-based case study. This includes a multimedia introduction to the environment (industry/university research lab tour) in which the context of the particular photonics application is presented, a re-enactment of the problem statement, group problem analysis and discussion, and problem solution recorded at the industry/university partner site. The purpose of Level 1 is to introduce the student to the concepts, principles, and procedures associated with problem-based learning. In Level 1, the instructor guides the student through each phase of the problem-solving process in a highly structured format which includes defining and framing the problem, identifying resources needed to solve the problem, generating possible problem solutions, testing hypotheses, and converging on an optimal solution as a team effort. During the presentation of the PBL Challenge, the instructor has the option of pausing the multimedia presentation at specific points to encourage student discussion of the problem-solving process, technical content, and other situational factors and constraints that must be taken into consideration in the solution of the problem. This active learning strategy will help develop students' ability and confidence to engage in the problem-solving process as well as critical thinking and metacognitive skills [1,3].



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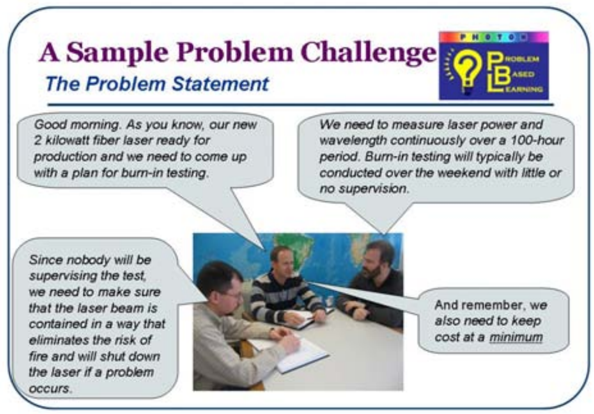

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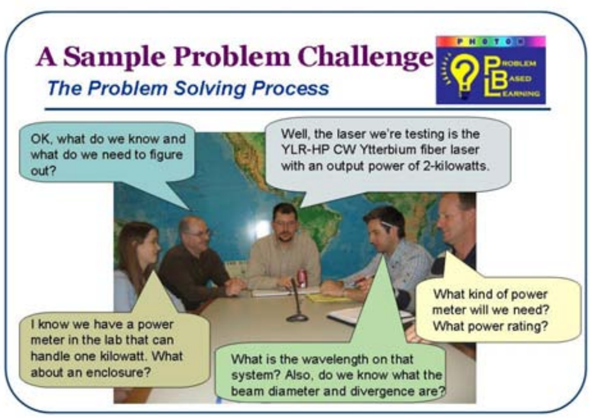

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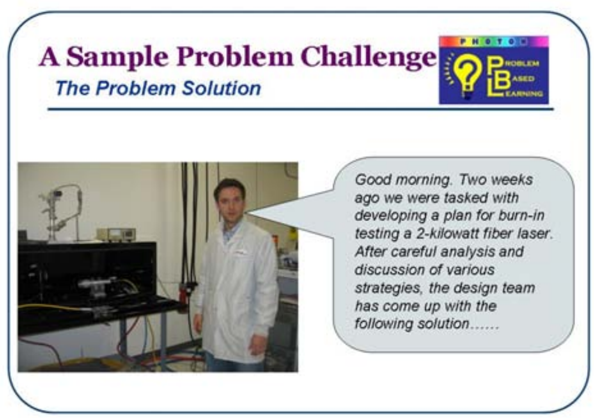

(d)

Figure 3. Graphical Representation of a PHOTON PBL Challenge created in partnership with IPG Photonics, Oxford, MA: (a) Scene 1: The Introduction – Presented in Levels 1, 2 & 3. (b) Scene 2: The Problem Statement - Presented in Levels 1, 2 & 3. (c) Scene 3: The Problem Solving Process – Presented in Levels 1 & 2 initially; Level 3 only at the end of the Challenge. (d) Scene 4: The Problem Solution - Presented initially in Level 1 only; Presented in Levels 2 & 3 at the end of the Challenge

3.1.2 Level 2 (Guided)

In Level 2, students have been exposed to the overall problem-solving process through Level 1 and have begun to develop their own problem-solving skills. As in Level 1, students are presented with the multimedia-based introduction, re-enactment of the problem statement, group problem analysis and discussion to guide the problem-solving process (Scenes 1-3), but the solution is held back until the end. Working in small teams, students use the information provided to seek the resources needed to solve the problem and generate possible solutions. During this phase the instructor acts as a guide or facilitator to ensure that students stay on track, but refrains from providing solutions or answers to specific questions. This strategy is intended to further develop students' ability to think critically by allowing them to "get dirty and make mistakes," but at the same time providing a safety net so that learning occurs without risk of failure. After converging on and presenting their own solution to the problem, students are presented with the industry/university partner solution and a subsequent group reflection activity is conducted to compare and contrast results.

3.1.3 Level 3 (Open-Ended)

In Level 3, students are presented with the most realistic representation of the problem statement as it would be encountered in the "real world" – a true problem-based learning challenge. Students are provided only with information from Scenes 1 and 2, and are required to formulate their own solutions as part of a mock design team. Drawing from the problem-solving knowledge and skills acquired through engagement with Level 1 and Level 2 Challenges, students engage in the problem-solving process by defining and framing the problem, identifying resources needed to solve the problem, generating and testing alternative solutions, and converging on the most appropriate solution for the given context. During this process the instructor acts as a consultant, providing hints or clues on request, but for a price (e.g., points deducted from a mock budget). Only after the solution has been presented by the student design teams in a formal presentation in a simulated design review is the actual industry/university problem-solving process and solution revealed. Student processes and solutions are then reviewed and critiqued against that of the industry/university partner and recommendations for improvements are discussed.

3.2 Professional Development in Problem Based Learning

Just as important as the lack of instructional resources and materials for PBL in photonics technology education is the lack of pedagogical knowledge among technology educators needed to teach PBL. This is common in technology education. While great progress has been made over the past decade in upgrading the technical skills of technology faculty through professional development programs sponsored by NSF and other funding organizations, less attention has been given to the instructional methods used to teach these skills to students. The old adage "teachers teach the way they were taught" still rings true [20]. Technology educators are typically highly trained experts in a very specific technical field. Unfortunately, most have had little or no formal training in education and pedagogy [21]. Like their predecessors, technology educators most often employ an instructor-centered approach in their teaching, attempting to "fill" the student with knowledge rather than assisting the student in developing the capacity to learn. If PBL is to be successfully adopted, technology educators must be provided with professional development designed to introduce them to the pedagogical underpinnings of PBL, in a way that changes their way of thinking about teaching and learning as well as their practice: the design, evaluation, and delivery of instruction. They must learn how to effectively integrate content and pedagogy in a way that actively engages students in individual and collaborative problem-solving, analysis, synthesis, critical thinking, reasoning, and skillfully applying knowledge in real-world situations [22,23].

Researchers [24] argue that for professional development to be effective, it must extend beyond the typical one- or two-day workshops, which overall have been shown to be ineffective in producing changes in teacher practice. In fact, research on the effectiveness of professional development efforts aimed at producing changes in practice show that only about 15 percent of what is learned in classroom settings is ever applied on the job because these efforts are usually short-term, lack continuity through adequate follow-up and ongoing feedback from experts, are isolated from the participants' classrooms and school contexts, take a passive approach to training teachers, and allow little opportunity to learn by doing and by reflecting with colleagues [25,26]. In one example, Saylor and Kehrhahn [27] found that compared to the typical 10-20 percent transfer of knowledge rate typical of short-term workshop models, the continuous nature of a yearlong professional development program with middle school teachers resulted in an 80 percent transfer of knowledge to the classroom.

The PHOTON PBL project will address the need for change in instructional practice by providing high school and community college technology educators from across the US continuous professional development in the principles and applications of PBL over a two-year period. By involving instructors directly in the PBL Challenge development process, providing ongoing instruction, support and feedback, and time for collaboration with colleagues and mentors in the implementation of PBL in their classrooms, they will build the capacity to develop their own PBL challenges in other courses. In its first year, the PHOTON PBL project has recruited 16 seasoned technology educators (8 high school; 8 college level) trained in the use of the PHOTON curriculum and laboratory materials to be part of the PHOTON PBL Challenge development team. These educators will experience PBL firsthand by working with the PHOTON PBL Project team in developing and alpha testing the first four prototype PBL challenges in their classes. Working through the PBL cycle, instructors will use the development and implementation of the PHOTON PBL Challenges as an actual problem-solving activity – using PBL to teach PBL. Through this process, the instructors will evaluate, update and refine the PHOTON PBL challenges in preparation for alpha testing a second group of four additional PHOTON PBL challenges to be developed during year two of the project. Instructors will be provided with ongoing mentoring and support throughout the duration of the project through online collaboration, site visits, and periodic meetings. Photonics industry and PBL experts from across the US will serve as mentors to the instructors through a dedicated list server. In all, eight PHOTON PBL Challenges will be tested by 16 instructors using the using the PBL process. An additional outcome of this effort will be the development of a teacher's guide to PBL, developed for teachers by teachers.

3.3 Research in Problem-Based Learning

While PBL has been used successfully in the medical profession for decades with great acclaim, less is known about the effectiveness of PBL in engineering, and especially in technician education. A review of the literature on PBL identified several studies conducted to validate the efficacy of PBL in engineering education with researchers reporting mixed results. For example, in a study conducted at Maastricht University [6], researchers found that PBL was more effective in the first years of an engineering program, but only when integrated with some directive instruction. In another study conducted at South Dakota School of Mines [5], researchers examined the effectiveness of PBL as an alternative to traditional instructional methods in the freshman year of engineering. Overall they found that students in the experimental cohort (PBL) performed better academically, had a higher retention rate, and were generally more satisfied than those students in the control group, which used a traditional lecture approach. In another study in which researchers examined the effects of PBL on self-regulated learning, results revealed that PBL students had higher levels of intrinsic goal orientation, task value, use of elaborative learning strategies, critical thinking, metacognitive self-regulation, and peer learning compared to control group students (traditional instruction) [28]. Conversely, in a review of the literature on PBL, researchers found that while evidence suggests that students in PBL have a more positive attitude and are more likely to take responsibility for their own learning, PBL requires time and effort in gaining acceptance and that more effort is needed in developing skill in facilitation and attitude toward self-directed learning [9]. In an effort to resolve these and other variations in the reported effectiveness of PBL as compared to traditional lecture-based instructional methods, researchers at Middlesex University [29] conducted a meta-analysis involving 91 citations. The results of the meta-analysis showed that variations in instructional methods, implementation, and assessment of learning outcomes yielded inconclusive evidence upon which to provide robust answers to the questions about the effectiveness of PBL. The researchers concluded that while PBL appears to be a promising alternative to traditional lecture-based methods of instruction in engineering and technology education, more research is needed to assess its efficacy.

To address the need for more research on PBL in technology education, the PHOTON PBL project will work in partnership with researchers from the University of Connecticut NEAG School of Education to conduct quantitative and qualitative research on the effectiveness of PBL as compared to traditional lecture-based methods with regard to learning outcomes, problem-solving and critical thinking skills, metacognitive development, self-efficacy, and motivation. Researchers will also examine the extent to which specific professional development activities contribute to changes in teaching practices (i.e., transfer of training) among participating faculty. Data sources will include instructor and student questionnaires, classroom observations, personal interviews, anecdotal data, documents and other artifacts. The research will result in a series of published articles and may also provide a basis for doctoral research for project participants pursuing graduate degrees in education at the University of Connecticut.

4 Conclusion

PBL has been shown to be an effective educational approach that improves student learning and retention, critical thinking and problem-solving skills, and the ability to skillfully apply knowledge to new situations – skills deemed critical to lifelong learning. In today's ever-changing global economy where photonics technicians are required to work productively in teams to solve complex problems across disciplines as well as cultures, PBL represents an exciting alternative to traditional lecture-based photonics education.

In this paper we presented an introduction to the PHOTON PBL project, a three-year National Science Foundation Advanced Technology Education (NSF-ATE) project aimed at creating, in partnership with the photonics industry and university research labs from across the US, a comprehensive series of multimedia-based PBL instructional resource materials and offering faculty professional development in the use of PBL in photonics technology education. Over the three-year period that began in Fall 2006, the PHOTON PBL project will: (1) create eight multimedia PBL Challenges (DVD) and instructional resource materials covering a broad range of photonics applications, (2) train 16 high school and community college technology educators from across the US in the use of PBL for photonics technology education, (3) conduct quantitative and qualitative research on the effectiveness of PBL in photonics technician education, and (4) disseminate the multimedia PBL instructional materials and research findings through a dedicated website, peer-reviewed educational journals and conference presentations to inform engineering education pedagogy.

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Funded in part by the Advanced Technological Education program of the National Science Foundation (ATE 0302528). Principal Investigator, Fenna Hanes (Project Manager), New England Board of Higher Education; Co-Principle Investigators, Judith Donnelly, Three Rivers Community College; Marijke Kehrhahn, Neag School of Education (University of Connecticut); Nicholas Massa and Barbara Washburn, both Springfield Technical Community College

Project PHOTON: A Curriculum Development, Teacher Enhancement and Laboratory Development Project
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II.

Using Misconceptions Research in the Design of Optics Instructional Materials and Teacher Professional Development Programs

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Abstract: To create the Hands-On Optics program and its associated instructional materials, we needed to understand a number of basic optics misconceptions held by children (and adults) and how to address them through a proper educational approach. The activities have been built with an understanding of the naïve concepts many people have about light, color, and optical phenomena in general. Our own experience is that the concepts that children and adults have of light are often not that different from each other. This paper explores the most common misconceptions about light and color, according to educational research, and describes how they can be addressed in optics education programs. This understanding of misconceptions was useful as well in the professional development component of the program where educators were trained on the Hands-On Optics modules. The professional development work for the optics industry volunteers who worked with the educators was also based on research on how an optics professional can work more effectively in multi-cultural settings–an area with great applicability to industry volunteers working in the very different culture of science centers or after-school programs.

Keywords: optics education, professional development, inquiry, misconceptions

1. Introduction

The Hands-On Optics (HOO) is a National Science Foundation-funded program designed to address the disconnect between the ideas held by young children about light and basic optical concepts (Pompea et al. 2005). The program works to instill a sensible conceptual foundation for a limited number of optics concepts. The HOO materials are partially based on previous inquiry-based materials developed through the Lawrence Hall of Science Great Explorations in Math and Science program. These materials (e.g. the *Invisible Universe* book) explore the electromagnetic spectrum using inquiry (Pompea and Gould 2003; Pompea and Gek 2002). In a survey of topics appropriate for formal optics education (Pompea and Stepp 1995) and for informal education programs (Pompea and Hawkins 2002) a number of optics areas of particular educational interest were identified. However, the proper approach to these topics can be complicated and must rely on an understanding of naïve theories held by many students.

Unfortunately, viewing the field of optics from an optical expert's point of view does not always serve the educational process. One must understand how a novice approaches light and color and appreciate the perspective a child brings to learning about optics. A student does not reason like a scientist and prior knowledge may impede progress in learning the key concepts. Novices differ from experts in that novices do not notice meaningful patterns in a given field of study. Novices do not have the organizational structure of the content knowledge that an expert possesses. The knowledge of an expert has a sense of context or conditions; it is not a set of facts, propositions, or theorems. Experts are very flexible in their thinking processes and also have the ability to retrieve important knowledge sets with little efforts. Their knowledge is ingrained in them rather than attached to them and they have an intuitive feel for their subject.

This paper is an attempt to consider briefly what research on human learning tells us about this transition from novice to expert and how an understanding of optics misconceptions and approaches to dealing with them can guide us in the design of instructional materials.

2. Background

A program such as Hands-On Optics must directly address common misconceptions that students (and educators) have about basic optics principles such as reflection, the nature of light, and how images are formed. Research on misconceptions reinforces the notion that misconceptions among students are the rule rather than the exception. Some of the common misconceptions include not viewing light as something that travels but rather only as its source (the Sun, a light bulb, etc.). This leads to difficulty in understanding the formation of shadow and the direction they take. The research shows that middle-school students (ages 10-13) understand that mirrors can reflect light. However, they often reject the idea that everyday objects also reflect light, according to Guesne (1985) and Ramadas and Driver (1989). Similarly, many elementary and middle school students do not realize that their eyes receive light when they look at an object. The notion that the eyes generate light that radiates outwards is a common one. These students therefore have quite a varied set of conceptions about how vision works. Some 5th-graders, though, can understand seeing as "detecting" reflected light after specially designed instruction (Anderson & Smith, 1983) For more details on optics concepts such as waves see the *Atlas of Science Literacy*. This volume uses concepts maps to understand the relationship between a number of key science concepts. For additional study, Driver *et al.* (1994), Stepans (1996), and Comins (2001) all have excellent discussions of misconceptions.

3. Approaches to Dealing with Misconceptions: Conceptual Change Models

A number of approaches to dealing with misconceptions have been proposed. One of the more practical perspectives is provided by Stepans (1996) who proposed a conceptual change model to help students become aware of their misconceptions and examine their validity. Stepans' model has six steps:

1. Students become aware of their own preconceptions about a concept by thinking about it and making predictions (*committing to an outcome*) before any activity begins.
2. Students *expose their beliefs* by sharing them, initially in small groups and then with the entire class.
3. Students *confront their beliefs* by testing and discussing them, initially in small groups and then with the entire class.
4. Students work toward resolving conflicts (if any) between their ideas (based on the revealed preconceptions and class discussion) and their observations, thereby *accommodating the new concept*.
5. Students *extend the concept* by trying to make connections between the concept learned in the classroom and other situations, including their daily lives.
6. Students are encouraged to *go beyond*, pursuing additional questions and problems of their choice related to the concept.

Another step that can be done even before these steps is for the educator or educational designer to do a "front end" study of the naïve theories and misconceptions of the audience. This can best be done through careful interviewing of the audience in a supportive, low-stress setting. With thoughtful in-depth questioning and especially with attentive listening a significant amount of information can be obtained. Nearly all museum exhibitions employ front-end studies to help the designer understand the knowledge base of the expected audience.

This type of interviewing technique was used successfully in the Harvard Private Universe Project (Schneps and Sadler 1989) that unveiled serious misconceptions about basic science area (such as the seasons, or simple electric circuits) from college graduates as well as children. Sadler (2000) explored how student concepts of light and color can change. To understand and measure conceptual development, Bardar *et al.* (1996) developed a light and spectroscopy concept inventory test that is now being widely used. These research results have informed and continue to inform our development process for Hands-On Optics materials and professional development. In our professional development program we train after-school educators and science center educators on the HOO modules and concepts. Most often the professional background of these educators is not strong in science or in science education.

4. Common Naïve Conceptions about Light

In the Hands-On Optics project we explicitly address a number of misconceptions or myths about light, building on the work done in the American Institute of Physics *Operation Physics* project (1988). We describe below fifteen commonly held beliefs and how they are approached in the HOO modules. The excerpts below constitute advice for museum and after-school educators, and optics industry volunteers, on how to address these selected myths.

Myth 1: Light only reflects off mirrors and other smooth surfaces.

Many people believe you need a smooth surface for reflection to take place. This misconception is reinforced by our use of language. We say that you see your reflection in a mirror. Since you don't see your reflection in other surfaces, many people assume that light doesn't reflect off those surfaces. You may wish to start by showing your students the plane mirror. Ask them what they see in the mirror. Once your students agree they see their reflection in the mirror, ask them to look at a table or wall. Ask them if light reflects off the table or wall. This question may start a lively discussion about reflection.

The green laser is a nice demonstration tool to illustrate reflection. Point the green laser at a table or wall. It may help to dim the lights. You can see the laser does reflect off these surfaces! You may hold up a piece of paper or screen to help see the reflections.

Ask the students what they notice about the shape of the reflections. The laser produces a nice sharp dot on the surface. The reflection, however, is very spread out. Ask students what the difference is between the laser reflecting off of a mirror versus the laser reflecting off of a table or wall. Remind the students of the difference between specular and diffuse reflection. Reflection off the mirror is specular, where reflection off of the rough surfaces is diffuse. Remember the law of reflection always holds – for both smooth and rough surfaces.

Try other surfaces around the room. Coins can produce interesting reflections. Try to produce reflections off books, backpacks, or anything else you can think of.

Myth 2: Objects are black because they do not reflect any light.

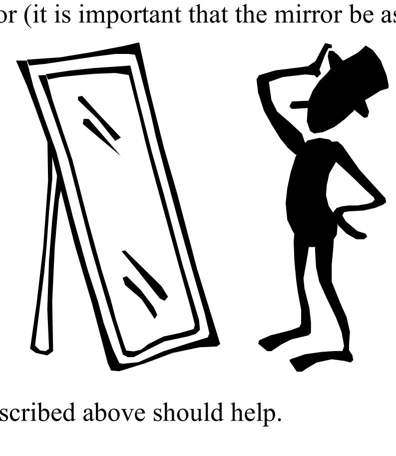
In many textbooks, black is referred to as the absence of light. Many people assume that black objects do not reflect light. Take the glossy black plastic plate included in the kit. Ask the students if they think the black plate reflects light. Have them look at the plate and ask them if they can see their reflection. Discuss whether or not this implies the plate reflects light.

Next, take the green laser and point it at the glossy side of the black plate. Ask the students if they see a reflection from the plate. If the black plate does not reflect light, how can it cause a reflection? The black plate does reflect light. It is enough for you to see a reflection of yourself or the laser. Ask the students if the rough side of the plate will reflect light. They cannot see their own reflections in the rough side. Shine the laser onto the rough side of the plate. Ask them if they see a reflection and if how the rough side is different than then shiny side.

The rough side of the place also reflects a significant amount of the incoming light. Light incident on the rough side undergoes diffuse reflection as you can see from the spread out nature of the reflection.

Myth 3: If you are five feet tall, you need a five-foot tall mirror to see your entire body at once.

You have a 12"x12" mirror in the kit. If the above statement is true, you should only be able to see 12" of your face at one time. Have a student hold a ruler next to the face and look into the mirror (it is important that the mirror be as close to vertical as possible). Does the ruler just fill the mirror, or can the student see more?



Next, give the student a meter stick or tape measure. Have the student hold the meter stick next to their face and measure how much of the meter stick can be seen at one time. The student will probably see about two feet of the meter stick, or twice the size of the mirror!

Since we can see an object twice the size of the mirror, we can conclude you need a mirror only one half your height to see your entire body at once. Using ray diagrams, it is easy to show that a mirror must be a minimum of 1/2 the person's height in order to see the image as a whole person. However, ray diagrams just aren't intuitive for the kids. The demonstration described above should help.

You may have some students claim they cannot see their entire body in certain mirrors that seem large enough – for instance, a bathroom mirror above a sink. The sink may block the view of their feet. They may also have problems if the mirror is mounted too low or too high. The top of the mirror should be lined up roughly with the top of the head if you are truly going to see yourself in a mirror only one half your height!

Myth 4: You can see more of yourself if you move farther away from a mirror.
Many people believe that if you move farther away from a mirror, you can see more of yourself in the mirror, although this directly contradicts the idea that you need a mirror as tall as yourself to see your entire reflection!

Place the 12”x12” mirror vertically on a wall. Ask the students if and how they can use the mirror to see their entire body at once without moving the mirror. They will invariably try to move farther away (a crafty student may take the mirror off the wall and look into it at a steep angle, but this is outside the bounds of the question…more on this later).

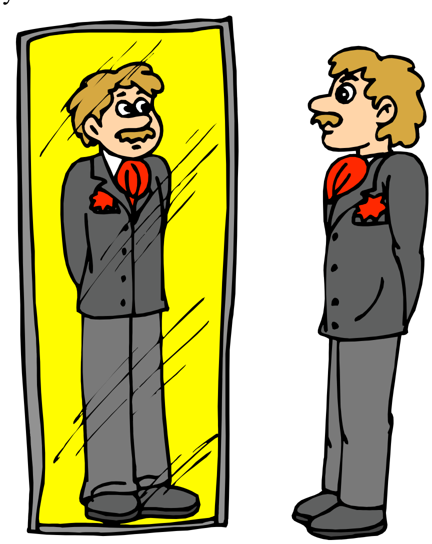
Students will find that they cannot see their whole body at once! In the previous example, students saw the amount of their bodies they could see was twice the height of the mirror. Now they will see that this ratio holds even if they move closer to or farther away from the mirror.

If the students are still skeptical, try this. Have a student stand in front of the mirror. Tell the student to draw a circle on the mirror around his face with a dry erase or other washable marker. Have the student slowly back up and observe how the size of his or her face changes with respect to the size of the circle. The student will see that his or her face always takes up the same amount of space on the mirror!

Finally, place the mirror flat on the floor. Have a student stand close to (but not on top of!) the mirror. The student will be able to see almost the entire reflection (save for a small portion near their feet). Why they can see their entire body in this configuration? Nearly every part of your body sends light toward the mirror at a very large incident angle (remember, this is measured relative to the normal line).

Myth 5: Light stays on a mirror during reflection (light doesn’t travel).
Many students believe that light stays on the surface of a mirror during a reflection. Light reflects off a mirror to your eyes. You do not see an image of an object unless the light enters your eyes. You can show light reflecting off a mirror with a flashlight and paper. Shine the light on the mirror. Hold the paper so you see the reflection. Move the paper closer and farther away from the mirror. You always see light on the paper. The light must leave the surface of the mirror to travel to the paper.

Myth 6: The image you see forms on the surface of the mirror.
Students see an image in a mirror and assume the image is on the surface of the mirror. The concept of a virtual image comes into play here. A virtual image is formed by diverging light rays and forms BEHIND the mirror. Virtual images cannot be projected onto a screen like real images. It is very counterintuitive to say an image forms behind the mirror as no light can travel through the mirror.



One way to counter this belief is to have a student look in a mirror. Have the student move away from the mirror. What happens to the reflection? The reflection appears to move away from the mirror in the opposite direction. The virtual image is where the student’s reflection appears. The image appears behind the mirror, even though we know all light reflects from the surface of the mirror.

Myth 7: An object is “seen” because light shines on it.
Light can shine on an object but it may be invisible (i.e., we can’t see it). Try this. Take a Pyrex test tube. Fill a beaker with Wesson Oil. Put the Pyrex test tube in the Wesson Oil and watch it disappear!

How can this be? There is clearly light shining on the test tube. However, no light is being reflected from the test tube. In order to see an object, light must reflect off the object and enter your eye. If there is no light reflected, you may not be able to see the object.

This demonstration works because Wesson Oil and Pyrex have the same index of refraction. If two substances have the same index of refraction, no light is reflected at the boundary between the two objects. If you put the Pyrex test tube in tap water, it will be clearly visible.

Myth 8: Mirrors reflect all light that shines on their surfaces.
No mirror reflects 100% of the light that shines on it. Good mirrors reflect 95% of the light that is incident on them. The remaining 5% is absorbed and converted to heat. If you use a very intense light source, such as the Sun on a hot summer day, you can feel the mirror heat up from the energy it absorbs.

If students make careful observations during the activity in Module 2 called "Making a Dollar Out of a Penny." They may notice that the pennies that appear farther away are also dimmer. It takes more reflections to make the pennies that appear farther away. Each reflection causes some light to be lost and each new penny appears slightly dimmer. Astronomers are very concerned about light lost during the reflection process. Astronomical telescopes use special coatings on their mirrors and lenses to try and minimize the amount of light lost by reflecting off the mirrors in a telescope.

Myth 9: Light always travels in a straight line.
By now, students should have seen at least two examples that show light does not always travel in a straight line. They have seen light reflect off mirrors in Module 1 and observed light refract when it passes from air to the acrylic block in Module 3.

Light does travel in a straight line when it is traveling in a uniform medium. The direction light travels changes when the medium through which it travels changes. This change in medium can cause reflection, refraction, or even absorption of the light. Through these modules, students have only seen sudden changes in the direction of light, such as when light reflects off of a mirror or when it travels from air to plastic. The change in index of refraction can also be gradual, causing the path of light to gently curve. An example of this phenomenon is when sunlight encounters Earth's atmosphere. The upper layers of the atmosphere are very thin and have a lower index of refraction. The lower layers of the atmosphere are thicker and have a higher index of refraction. This changing index of refraction causes the path of the sunlight to curve.

An interesting consequence of this is that refraction slightly alters the time of sunrise and sunset. Refraction will make the Sun appear about half a degree higher in the sky than it really is (34 arc minutes on average). Therefore, the Sun appears to rise a few minutes earlier and set a few minutes later than it would if Earth had no atmosphere!

Myth 10: Light travels infinitely fast.
Light travels fast, but it has a finite speed just like everything else. Light in a vacuum travels at $3X10^8$ meters per second. The speed of light in a vacuum is sometimes called the speed limit of the universe. Direct evidence that light has a finite speed is difficult, but not impossible to illustrate. Another interesting way to see the effect of the speed of light is using satellite television. Set up two televisions side by side. Have one of the televisions connected to an antenna. Connect the other television to cable or a satellite dish. Tune them both to the same local channel. You will notice that the television connected to the antenna receives the signal first!

What's going on in this case? Cable or satellite television bounces the signal to a satellite in geosynchronous orbit about 22,000 miles above the Earth's surface. The signal for cable or satellite television must travel to the satellite and back – meaning it gets to the television later due because it travels a greater distance.

Myth 11: You can use a telescope to magnify objects as much as you desire.
Many people believe you can always increase the magnification of a telescope. It is not uncommon to see advertisements for telescopes with diameters as small as 2 inches that claim to operate at 575 power!

Small telescopes cannot achieve such large magnifications for a variety of reasons. Even assuming perfect optics, a telescope is limited by its resolution or resolving power. Resolution is the ability of a telescope to see fine detail and separate closely spaced objects. Resolution depends primarily on the diameter of the telescope. If you try to magnify an object beyond the resolution of a telescope, you get a dim, fuzzy image.

A general rule of thumb for astronomers is that the maximum useful magnification for a telescope is about 50X (50 power) per inch of aperture. Therefore, a 2 inch diameter telescope generally cannot magnify more than about 100X. The 50X per inch of aperture assumes you have very good optics (not always the case in inexpensive telescopes) and that the atmospheric seeing is very good.

The atmospheric seeing is another limiting factor in telescope resolution. If you have ever looked at hot pavement on a summer day, you have probably seen "heat waves." The heat waves are due to the fact that the index of refraction of air is very temperature-dependent. As the pavement heats up, the hot air above the pavement rises and causes turbulence. As light passes through air of different temperatures, its path is changed, leading to the heat waves.

Earth's atmosphere has a similar effect on light from the stars and planets. You can see this effect in the twinkling of stars. Even on a relatively calm night, a telescope will magnify any distortion present in the atmosphere. The best observing sites in the world rarely have seeing much better than one-half to one arcsecond (one arcsecond is $1/3600^{th}$ of a degree). More common observing sites have 2 to 3 arcsecond seeing or worse.

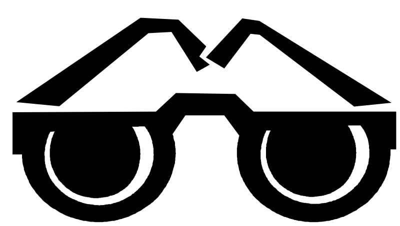
The Hubble Space Telescope was launched to get above the Earth's atmosphere. Although the Hubble has a relatively modest sized 2.5-meter diameter primary mirror, it does not have to look through Earth's atmosphere, so it yields much sharper views. The Hubble Space Telescope has a resolution of about 0.1 arc seconds, 10 times sharper than is typically possible from the ground.

In recent years, great advances have been made in overcoming the effects of atmospheric seeing through a process called adaptive optics (AO). Adaptive optics systems work by observing a star to precisely measure the distortions caused by Earth's atmosphere. Once the distortions are measured, they can be removed by quickly and precisely changing the shape of a small, flexible mirror in the telescope. Ground-based telescopes can produce images as good as the Hubble Space Telescope using adaptive optics systems.

Myth 12: An image is always formed at the focal point of the lens.
The focal point of a lens is where light rays that start out parallel will converge and form an image. Many physics books state that light rays from a distant object are parallel. While the light rays are not truly parallel, they are moving apart very slowly and will converge very close to the focal point.

For an object that is close to a lens or mirror, the incoming light rays are traveling in very different directions. Since the light rays are not close to parallel, they will not converge at the focal point. You can find where they will converge through careful ray tracing or by using the equation $\frac{1}{f} = \frac{1}{O} + \frac{1}{I}$ where f is the focal length of the lens, O is the object distance and I is the image distance from the lens.

Myth 13: Polarizing filters are just dark plastic or glass.
A single ideal polarizing filter reduces the intensity of the transmitted light by 50%. Looking through a polarizing filter leads many people to conclude they are looking through an ordinary, gray filter. Gray filters reduce the intensity of light by absorbing light. Gray filters absorb light that is polarized in all orientations. If a gray filter absorbs half of the vertically polarized light, it will also absorb half of the horizontally polarized light. If unpolarized light enters a gray filter, the transmitted light is also unpolarized.



A polarizing filter, on the other hand, absorbs all light except for one particular orientation. A polarizing filter can absorb all the vertically polarized light and let through the horizontally polarized light. If unpolarized light falls on a polarizing filter, the intensity of the transmitted light will be 50%, just like in the previous examples. In this case, the transmitted light will be polarized. Some sunglasses are polarized and some are not. Unpolarized sunglasses can reduce the intensity of sunlight and protect your eyes from harmful UV radiation. Polarized sunglasses help reduce the glare, especially from horizontal surfaces such as roads or lakes. However, unpolarized sunglasses will not block glare from reflected light.

Myth 14: All radiation is harmful.
Many people hear the word "radiation" and think of radiation poisoning or cancer. However not all radiation is harmful. Visible light is a form of electromagnetic radiation and we need to use it every day to see. Radio waves have very low energy and are generally considered harmless.

X-rays and gamma rays are called ionizing radiation. Ionizing radiation can penetrate the skin and cause cell damage. However, even X-rays and gamma rays can be useful in certain medical therapies if used correctly. Ultraviolet light can cause sunburn and long-term exposure can cause skin cancer. Radiation can be harmful, but there are many types of harmless radiation and it is often useful in a wide variety of applications.

Myth 15: Lasers emit tight, parallel beams of light.
Most lasers are manufactured to produce a thin beam of light. We have come to expect lasers to look like this due to their portrayal in popular medial such as movies. Lasers are point sources and emit waves that spread out in a circular pattern as all other point sources do. Imagine dropping a rock in a pond and watching the waves spread out. This picture is close to a 2-D wave from a point source. In order to imagine a 3-D wave, you have to imagine spherical waves spreading out instead of circular waves.

So how we make lasers into thin beams? There are two ways this can be accomplished, both of which use techniques mentioned in *Hands-On Optics* modules. If you place a point source at the focal point of a lens, the lens will create a parallel beam of light. You can achieve the same effect by placing the point source at the focal point of a mirror. It is actually the lens or mirror that makes laser light into a parallel beam.

5. Conclusion

Misconceptions and naïve theories held by students are valuable to the educator and educational designer. To treat students as *tabulae rasae* would be serious mistake. An understanding of research on misconceptions and conceptual change has been extremely valuable to the Hands-On Optics project and in the creation of our materials and related programs. An understanding of common optics misconceptions provides an assessment not only of the knowledge base of the student but also on the basic structure of that knowledge. An understanding of this foundational knowledge is critical to our approach, much as it is in the construction of a building on a firm foundation. The underlying student knowledge base may have to be dismantled. If gaps are present in an otherwise sound base it may able to be rebuilt with an understanding of how conceptual change takes place.

Without this understanding of a student's knowledge base, a proper program in optics education cannot be designed. This is because new knowledge obtained through an education program will often be overlaid on top of the older, well-established, personal theories of how things work. In extreme cases, the new knowledge will be rejected because it does not conform to the previous (but wrong) knowledge that the student believes is solid. Often this old knowledge seems to adequately explain natural phenomena. Only by employing a conceptual change process can the required cognitive dissonance be created to allow the newer (correct) knowledge to find a stable niche or attachment point.

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II.

Active Learning of Introductory Optics: Interactive Lecture Demonstrations and Optics Magic Tricks

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Abstract: Widespread physics education research has shown that most introductory physics students have difficulty learning essential optics concepts even in the best of traditional courses, and that a well-designed active learning approach can remedy this. This active presentation will provide direct experience through audience participation with methods for promoting active involvement of students in the learning process. The focus will be on *Interactive Lecture Demonstrations (ILDs)*[1,2]—a learning strategy for large (and small) lectures, including the use of special *Optics Magic Tricks*. Sample *ILD* materials and instructions on how to do the tricks will be distributed.

Keywords: Introductory physics, active learning, introductory optics, introductory laboratory, lecture demonstrations, activity based physics, image formation

1. Introduction

There is considerable evidence that traditional approaches are ineffective in teaching physics concepts, including light and optics concepts.[3,4] A major focus of the work at the University of Oregon and at the Center for Science and Mathematics Teaching (CSMT) at Tufts University has been on the development of active, discovery-based curricula like *RealTime Physics* labs[4,5,6] and *Interactive Lecture Demonstrations*.[1,2] Among the characteristics of these curricula are:

- Use of a learning cycle in which students are challenged to compare predictions—discussed with their peers in small groups—to observations of real experiments.
- Construction of students' knowledge from their own hands-on observations. Real observations of the physical world are the authority of knowledge.
- Confronting students with the differences between their observations and their beliefs.
- Observation of results from real experiments in understandable ways—often in real time with the support of microcomputer-based tools.
- Encouragement of collaboration and shared learning with peers.
- Laboratory work often used to learn basic concepts.

With the use of the learning cycle and the microcomputer-based tools it has been possible to bring about significant changes in the lecture and laboratory learning environments at a large number of universities, colleges and high schools without changing the lecture/laboratory structure of the introductory physics course. *RealTime Physics* and *Interactive Lecture Demonstrations* are described briefly below.

2. RealTime Physics Active Learning Laboratories (RTP)

RealTime Physics is series of lab modules for the introductory physics course that often use computer data acquisition tools to help students develop important physics concepts while acquiring vital laboratory skills. Besides data acquisition, computers are used for basic mathematical modeling, data analysis and some simulations. *RTP* labs use the learning cycle of prediction, observation and comparison. They have been demonstrated to enhance student learning of physics concepts.[3,4] There are four *RTP* modules, *Module 1: Mechanics, Module 2: Heat and Thermodynamics, Module 3: Electric Circuits* and *Module 4: Light and Optics.*[5] Each lab includes a pre-lab preparation sheet to help students prepare, and a homework, designed to reinforce critical concepts and skills. A complete teachers' guide is available online for each module. This presentation will not include work with *RTP* labs.

3. Interactive Lecture Demonstrations (ILDs)

ILDs are designed to enhance conceptual learning in large (and small) lectures. Real physics demonstrations are shown to students, who then make predictions about the outcomes on a prediction sheet, and collaborate with fellow students by discussing their predictions in small groups. Students then observe the results of the live demonstration (often displayed as real-time graphs using computer data acquisition tools), compare these results with their predictions, and attempt to explain the observed phenomena. Besides data acquisition, computers are used for interactive video analysis. The eight-step *ILD* procedure incorporating this learning cycle is followed for each of the basic, single concept demonstrations in an *ILD* sequence. *ILDs* have been demonstrated to enhance student learning of physics concepts.[2,3] Complete materials— including student sheets and teachers' guides—are available for most introductory physics topics.[1]

In this session, after an introduction to active learning, the eight-step *Interactive Lecture Demonstration* procedure will be illustrated through active audience participation. Examples will be drawn from the four sets of optics *ILDs: Reflection and Refraction of Light, Image Formation with Lenses, Mirrors* and *Polarized Light*. Guidelines for creating effective *ILDs* will also be discussed.

Do students learn optics concepts from *ILDs*? Here we report on assessments of learning gains for the *Image Formation with Lenses ILD* sequence. Students in the algebra-trigonometry-based general physics course at the University of Oregon had only a 20% normalized learning gain on our physics education research-based *Light and Optics Conceptual Evaluation* after all traditional instruction on image formation. With just one additional lecture consisting of this *ILD* sequence, their learning gain from the pre-test was 80%. In addition, the last question on the test shows the real image of an arrow formed by a lens, with two (non-principal) rays from the bottom of the arrow and two (non-principal) rays from the top of the arrow incident on the lens. (See Figure 1). Students are asked to continue these four rays through the lens to illustrate how the image is formed by the lens. While after traditional instruction, only 33% were able to continue these rays correctly, after experiencing the *ILD* sequence, 76% completed this exercise correctly.

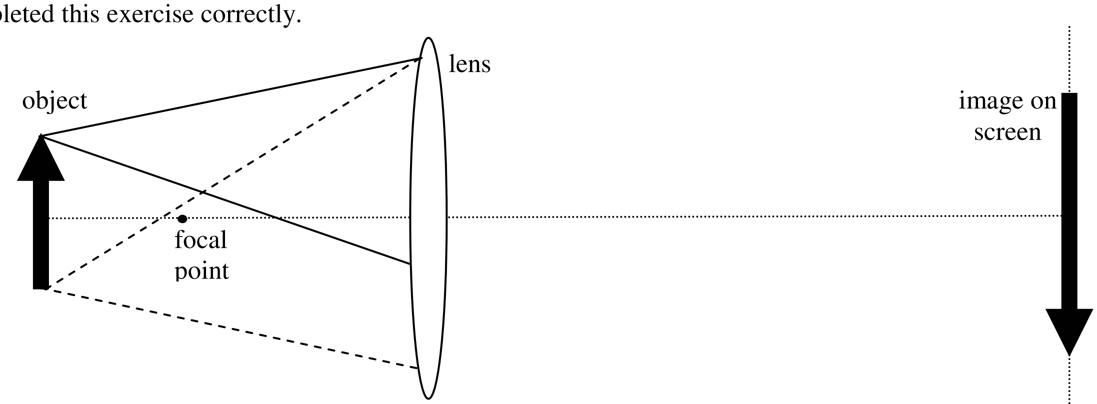

Figure 1: Diagram from last question on the *Light and Optics Conceptual Evaluation*

4. Optics Magic Tricks

A series of *Optics Magic Tricks* that introduce students to basic optics concepts will also be presented. There are a total of 10 tricks, illustrating concepts in reflection and refraction, image formation with mirrors, total internal reflection, light scattering and polarization.[7] These include *The Reappearing Test Tube*, an illustration of the importance of index of refraction for seeing transparent media, *Carbon to Silver*, an example of total internal refraction and *Candle Burning Under Water,* an illustration of image formation with a plane mirror. All are presented in a highly active way through the use of optics conceptual learning questions. The remainder of this paper will give details on preparation and presentation of the tricks.

4.1 The Reappearing Test Tube

Objective: To understand the importance of a difference in optical properties (indexes of refraction) of transparent media in the reflection and refraction of light.

Equipment and Supplies: 2 600 ml clear glass beakers, 3 small clear Pyrex culture or test tubes, hammer or block of wood, envelope, vegetable oil or light and heavy mineral oils. (In Europe, paraffin oil and Duraglas test tubes will work and may be more readily available.)

Preparation Notes: The index of refraction of vegetable oil is very close to that of Pyrex. Or, you can mix the mineral oils to match the index of refraction more closely to the index of the tubes. Fill one beaker with this "magic fluid" and completely submerge one or two tubes in it. You should not be able to see the submerged tubes. Fill the other beaker with water. It is best if the lights are dimmed somewhat, and a white background behind the beakers helps to make the tubes invisible.

Presentation Notes: Take a dry tube and place it in the envelope. Smash it with the hammer or block of wood. Ask a volunteer to look into the envelope to verify that the tube is smashed. Tell the students that the beaker contains a magic fluid that will repair the tube. Drop the pieces of the tube into the beaker with the mineral oil. Say some "magic" word(s) and/or wave a magic wand. Then reach in and pull out a whole tube! For laughs, you can say that this trick is even more amazing, and pull out a second tube!

The Optics Learning Questions for this trick are shown in Figure 2. Break down the class into small groups, and ask the groups to discuss these questions. Then ask for volunteer(s) to answer them.

Reappearing Test Tube Learning Questions

1. How do you think that the test tube was made to reappear?

2. Why can you see a test tube in air or in water, but not in the magic fluid? What is special about the magic fluid?

3. What property of transparent media determines whether reflection takes place at the boundary between them? What has to be true about this property for the two materials in order for reflection to take place?

4. What about the light that is transmitted through the test tube? How is it affected when the test tube is in the magic fluid and when the test tube is in air?

Figure 2: Optics Learning Questions for *Reappearing Test Tube*.

Explanation: Clear objects only reflect and refract light when they are in a medium with different optical properties (a different index of refraction). Since the "magic fluid" has the same index as the tube, no light is reflected by the submerged tube to your eyes. Therefore, you cannot see it. Show that you can see the tube in air because air has a different index than the tube. Also show that you can see it in water. Take a dry tube and submerge it open side up so that the vegetable (or mineral oil) flows over the rim. It will appear to the students to disappear from the bottom up! Some students have even described that it seems to disappear in a flash!

4.2 Candle Burning Under Water

Objective: To explore the properties of a virtual image formed by a plane mirror.

Equipment and Supplies: Candle, matches, container of water, 600 ml clear glass beaker, large (at least 60 cm x 60 cm) acrylic or glass sheet supported vertically, black (or other dark colored) cloth large enough to cover the sheet.

Preparation Notes: Place the candle in front of the acrylic sheet facing the students, and the beaker a distance behind the sheet so that the image of the candle as seen from in front of the acrylic sheet appears to be in the center of the beaker. The black cloth should be over the acrylic sheet. It is best if the lights are dimmed.

Presentation Notes: Light the candle, and pretend to light a candle in the beaker behind the sheet as well. Remove the black cloth. Say the magic word(S), and fill the beaker behind the sheet with water. It will appear to students that there is a candle burning under water in the beaker.

Use small groups and the Optics Learning Questions in Figure 3. Ask for volunteer(s) to explain how the trick works.

Candle Under Water Learning Questions

1. How do you think that it was possible for the candle to burn under water?

2. Describe the image of the candle formed by the glass (acrylic) mirror. Is the image real or virtual? Define both of these types of images.

3. Is the image upright or inverted compared to the candle? Compare the size of the image to the candle.

4. Compare the "handedness" of the image in a plane mirror to that of the object. That is if the object is a right hand, is the image a right or left hand?

5. What property of the glass (or acrylic) allows the sheet to act as a mirror?

Figure 3: Optics Learning Questions for *Candle Under Water*

Explanation: The acrylic sheet acts as a plane mirror, forming a virtual image of the lit candle in the beaker behind the sheet. Even though the sheet only reflects about 4-8% of the light from the candle, this is enough to have a clear, and somewhat convincing image.

4.3 Candle Appearing in a Box

Objective: To explore the properties of a real image formed by a concave mirror.

Equipment and Supplies: Small candle (about 2 cm in diameter and 4 cm tall), large, front-surface, concave mirror (around 150 cm radius of curvature) with holder that allows fairly precise vertical and horizontal adjustment, wooden box about 30 cm high with 15 cm x 15 cm cross-section with three sides hinged so that they open to 90°.

Preparation Notes: Put the box on the table with the long dimension vertical, and with one of the opening sides facing the students and one facing away. (This demonstration will only work in this form with a small group of students. For larger groups, it is possible to use a video camera to project the image formed on a monitor or screen.) Place the candle on top of the box. With the sides of the box open, set up the mirror so that it forms a real, inverted image of the candle inside the box, and just below the real candle. (The distance of the mirror from the candle should equal the radius of curvature of the mirror—twice the focal length.) Close the sides of the box. It is best if the lights are dimmed.

Presentation Notes: Light the candle. Open the side of the box facing the students and show them that there is no candle inside. Close the side, say the magic word(s) and then open both sides. The inverted image of the candle will appear inside the box.

Ask for volunteer(s) to explain how the trick works.

Explanation: The concave mirror forms a real, inverted image at the location of the candle, but slightly displaced below. It looks like there is really a candle there! It is at the same location as the candle because the distance of the candle from the mirror equals the radius of the mirror (twice the focal length of the mirror). Contrast this image to the one formed by a plane mirror in the previous demonstration. Is it real or virtual? How do you know? (Put a piece of paper where the image is formed, and note that rays of light are really focused to that location, unlike the virtual image from the plane mirror in which no rays are focused behind the mirror where the image is formed.)

4.4 The Magic of Spoons

Objective: To compare the real image formed by a concave mirror to the virtual image formed by a convex mirror.

Equipment and Supplies: For a large class, it is best to make a large "spoon" from a large concave or convex mirror with no backing (both concave and convex sides reflect). Attach a handle to the mirror. The size of the mirror should be appropriate to the size of the class. The focal length should be small enough so that the students are much further away than the focal point. For small group(s) of students, individual real spoons that are polished enough to reflect an image work fine.

Presentation Notes: Hold up the "spoon" with the concave side facing the class (or have the students observe their images in the concave side of the spoons). Have them note whether the image is upright or inverted. (The image will be real and inverted.) Say the magic word(s), and flip the spoon so that they are looking into its convex side. Have them note that the image is now upright.

Ask for volunteer(s) to explain how the trick works.

Explanation: The object (student's face) is outside the focal point of the concave mirror. Therefore, the image formed is real and inverted. A convex mirror can only form a virtual upright image, and therefore, this is what is seen when the "spoon" is flipped around.

4.5 Demonstration 5: Coal to Silver

Objective: To observe total internal reflection at the interface between two transparent media.

Equipment and Supplies: Ball (about 5 cm in diameter) made of non-flammable/non-melting material mounted on the end of a rod and covered with soot (carbon) from a candle flame, 600 ml beaker of water.

Preparation Notes: Light the candle and rotate the ball in the flame until the ball is covered all over with soot. Fill the beaker with water.

Presentation Notes: Tell the students that while the alchemists tried to turn lead into gold, you have discovered how to turn coal into silver. Say the magic word(s) and submerge the ball in the water. The students will see light reflected off the surface of the ball, and it will appear to have a shiny silver-like surface.

Use small groups and the Optics Learning Questions in Figure 4. Ask for volunteer(s) to explain how the trick works.

Explanation: A layer of air is trapped around the surface of the ball by the carbon layer. Therefore, light from outside incident on this layer can be totally internally reflected back into the water and back to the students' eyes. It appears that the light is being reflected from the "shiny" surface of the ball. Total internal reflection takes place when light is incident from a medium with a larger index of refraction (water) on a medium with a smaller index of refraction (air layer).

Carbon to Silver Learning Questions

1. How do you think that the carbon ball was made to appear like silver?

2. What could cause the carbon ball to become a reflecting surface when it is submerged in water?

3. Compare the index of refraction of the air layer around the ball to the index of refraction of the water. What name is given to the reflection at this air layer?

4. Why is the surface of the ball not a "perfect" mirror?

Figure 4: Optics Learning Questions for *Carbon to Silver*

4.6 Falling Laser Beam

Objective: To observe total internal reflection at the interface between two transparent media—the mechanism of fiber optics.

Equipment and Supplies: Clear glass or acrylic container filled with water with a small (about 5-10 mm) hole on one side near the bottom sealed by a stopper, laser, trough or pan on floor to catch water stream, blackboard eraser with chalk on it.

Preparation Notes: The laser is aligned so that it can be shined from the other side of the container through the water incident on the stopper from inside the water.

Presentation Notes: Shine the laser across the room, and hit the eraser with your hand to suspend chalk dust in the laser beam. Note that the beam goes in a straight line. Then shine the laser on the stopper as described above. Say the magic word(s) and remove the stopper. The water streams out along a curved path, and the laser beam follows this path, apparently falling downward with the water.

Use small groups and the Optics Learning Questions in Figure 5. Ask for volunteer(s) to explain how the trick works.

Falling Laser Beam Learning Questions

1. What caused the laser beam to curve around and stay within the water stream?

2. Compare the index of refraction of the water to that of the air around it.

3. What name is given to the reflection of the light at the surface of the water stream?

4. What practical devices work on the same principle?

Figure 5: Optics Learning Questions for *Falling Laser Beam*

Explanation: The laser beam within the stream of water is incident on the interface between water and air, from higher index of refraction to lower index of refraction. Since the light is incident at an angle larger than the critical angle, the beam is totally internally reflected back into the water and seems to be trapped. This is the same mechanism that is exploited in fiber optics.

4.7 Bouncing Laser Beam

Objective: To observe curving of light in a medium with a continuously variable index of refraction—the mechanism of an oasis or mirage.

Equipment and Supplies: Acrylic trough about 15 cm deep, 5 cm wide and 75 cm long, thick corn syrup (e.g., Karo Syrup), laser, blackboard eraser with chalk on it.

Preparation Notes: At least one hour before the demonstration, pour the syrup into the trough to a depth of about 4 cm. Pour water slowly to a depth of about 4 cm above the syrup. Mix carefully with a stirring rod so that the layers partially mix, but not enough so that they totally mix. Let stand for awhile. The idea is to get an index of refraction gradient with the smallest index (just water) at the top and the largest index (just syrup) at the bottom.

Presentation Notes: Shine the laser across the room, and hit the eraser with your hand to suspend chalk dust in the laser beam. Note that the beam goes in a straight line. Say the magic word(s), and then set up the laser so that it is incident on the trough through the 15 cm x 5 cm face, near the top of the fluid mixture. You may need to aim the beam down slightly. You should see the beam curve downward, reflect off the bottom, curve downward again (forming a half loop) after it reflects from the bottom, etc., etc. In other words, you should see several half loops of the beam, like a bouncing ball.

Ask for volunteer(s) to explain how the trick works.

Explanation: The index of refraction of the fluid increases from top to bottom. As the beam moves through this changing index, instead of refracting sharply at a surface, it bends slowly downward. When it hits the bottom, it is reflected upward again. It continues to bend, finally reaching an angle greater than the critical angle, and reflecting back down again, continuing to bend until it hits the bottom again.

4.8 Colors from a Magic Solution

Objective: To observe one of the manifestations of optical rotation.

Equipment and Supplies: Thick corn syrup (e.g., Karo Syrup), 600-1000 ml glass or clear plastic jar with sealable lid, sheet of Polaroid, slide projector, Polaroid slide, opaque slide, transparent slide and screen.

Preparation Notes: Cut the sheet of Polaroid so that it fits inside the jar and covers one half of the surface of the jar (half cylindrical shape). Place the Polaroid inside the jar against the surface. Fill the jar with the corn syrup, and then seal the jar with the lid. (This jar can be used over and over again.) Cut another piece of Polaroid the size of a slide for the projector. Place the three slides in the projector in this order: transparent, opaque, Polaroid. The axis of the Polaroid slide should be at 90° with the axis of the Polaroid in the jar with the jar vertical. Set up the projector so that it will shine through the jar and either be focused onto the screen or shined into the students' eyes.

Presentation Notes: With the transparent slide in place, shine the projector through the jar with the Polaroid side facing the students. Rotate the jar around an axis perpendicular to the front face. Nothing happens. Then move the opaque slide into place. Say the magic word(s), and quickly move the Polaroid slide into place. Now rotate the jar as before, and the students will see different colors of light appear.

Ask for volunteer(s) to explain how the trick works.

Explanation: The corn syrup has the property that it can rotate the axis of polarization of incident polarized light. Initially the incident light is un-polarized, so the corn syrup has no net effect. The Polaroid in the jar (the analyzer) does nothing. When polarized light is shined through the jar, the corn syrup rotates the axis of polarization different amounts for different wavelengths of the incident white light. Depending on the angle of the analyzer, a different color is passed through and seen.

4.9 Appearing Message

Objective: To observe the effect of bi-refringence.

Equipment and Supplies: Large sheet of Polaroid (e.g., 25 cm x 25 cm), thin sheet of plastic (e.g., overhead transparency), slide projector, Polaroid slide, opaque slide and transparent slide.

Preparation Notes: Cut letters of a message out from the thin plastic sheet. ("OOH, AAH" is a fun message to use!) Tape them to the back of the large sheet of Polaroid. Cut a piece of Polaroid the size of a slide for the projector. Place the three slides in the projector in this order: transparent, opaque, Polaroid. The axis of the Polaroid slide should be at 90° with the axis of the Polaroid sheet. Set up the projector so that it will shine through the large sheet of Polaroid towards the class, with the Polaroid facing the class and the letters behind it.

Presentation Notes: With the transparent slide in place, shine the projector through the Polaroid sheet toward the students, with the letters on the projector side. Nothing happens. Then move the opaque slide into place. Say the magic word(s), and quickly move the Polaroid slide into place. Now the letters appear.

Ask for volunteer(s) to explain how the trick works.

Explanation: The plastic sheet material is bi-refringent and does not have a completely uniform thickness. It rotates the axis of polarization of the Polarized light by different amounts depending on its thickness at different spots.

Some of this light that has its axis rotated to a different angle than 90° goes through the Polaroid sheet (the analyzer), so the students see the message.

4.10 The Sunset

Objective: To observe polarization by scattering, and how scattering produces the blue sky and the colors of the sunset.

Equipment and Supplies: Sheet of Polaroid (e.g., 15 cm x 15 cm), 1800 ml clear plastic or glass beaker 3/4 filled with water, 40 ml saturated sodium thiosulfate solution, 25 ml concentrated hydrochloric acid, stirring rod, projector and screen. (Alternatively, drops of milk can be added to the water instead of using the sodium thiosulfate and acid. However, the sodium thiosulfate and acid produce a more dramatic effect.)

Preparation Notes: Set up the projector so that it shines through the beaker onto the screen. Just before lecture, add the sodium thiosulfate to the water in the beaker and stir well. Have the acid ready to add to the beaker, and the Polaroid ready to hold in front of the beaker (between the beaker and the students).

Presentation Notes: Turn on the projector, and tell the students it represents the sun. The water in the beaker represents the sky. Tell them that you are going to produce a sunset in class. Say the magic word(s), add the acid to the beaker and quickly stir. Shortly, bluish light will be scattered out of the side of the beaker. If you rotate the Polaroid, it will be apparent that this light is partially polarized. The light passing through the beaker to the screen will at first appear yellow, and then redder and redder.

Ask for volunteer(s) to explain how the trick works.

Explanation: The acid precipitates tiny particles of sodium in the water. These particles scatter the light out of the sides of the beaker. The scattering process is more effective the shorter the wavelength. Therefore, blue light is scattered more than yellow or red. At low concentrations of sulfur, the light that gets through to the screen is yellow. As time passes and the concentration increases, the color of the light passing through becomes redder.

In the sky, the blue scattered light is what we see during the day. (Actually, violet is scattered more effectively, but our eyes are much less sensitive to violet than to blue.) When the sun is setting, however, we are looking directly at the sun. Rather than seeing the scattered light, we are looking at the light left behind after scattering by a relatively thick layer of the atmosphere, and this is reddish in color.

Conclusions

All of these curricula have been used successfully by the author in his introductory college level physics course, and recently in a series of *Active Learning in Optics and Photonics (ALOP)* in developing countries (presented to date in Ghana, Tunisia, Morocco and India, and planned for Tanzania, Brazil and Mexico). These have been sponsored by UNESCO, OSA, ICTP and SPIE. More details on the *ALOP* project will be presented in a separate paper, “Active Learning in Optics and Photonics: Achievements and Outcomes to Date,” with principal author M. Alarcon.

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The Laser Teaching Center at Stony Brook University

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Abstract: The Laser Teaching Center is a unique university-based educational environment primarily devoted to highly personalized active learning through the development of individual hands-on student projects broadly related to optics and lasers. The participants include local high school students and young undergraduates who are new to optics and research, and graduate students in an optics rotation course. We describe the history and facilities of the Center, its educational philosophy and methods, and the experience obtained in nine years of operation.

Keywords: optics education, active learning, project-based learning

1. Introduction

The education and training papers at ETOP conferences typically describe specific programs, courses, curricula or methods that involve or can potentially impact relatively large numbers of students, sometimes hundreds or even thousands [1]. This paper, in contrast, describes a very modest optics learning environment, the Laser Teaching Center (LTC) at Stony Brook University, that has no set curriculum and only a small number of participants (fewer than ten) at any one time. Nevertheless, for a significant number of our students the LTC environment provides an invaluable or even life-changing experience, which encourages them to pursue a long-term interest in or career related to optics. These students will be our future colleagues and will educate future generations of students. Others benefit in more subtle ways by acquiring an appreciation of optics or the process of science, learning that it's possible to learn for oneself outside a classroom, developing a hands-on skill, or just becoming a better writer.

The primary activity of the Laser Teaching Center can be described as project- or inquiry-based active learning ("learning by doing"). Even the youngest of our students have a chance to really *do* science for themselves, starting from scratch. This is an invaluable opportunity since, as one of them once said: "you can't learn to ride a bicycle by reading a book." An essential component of the project-based learning process is learning to write about and freely discuss one's experiences, questions and results in a variety of settings, and eventually, to teach others.

The current LTC participants are mostly high school students, college freshmen from a Women in Science and Engineering (WISE) program, other undergraduates, and graduate students in an optics rotation course. All collaborate one-on-one with the LTC director and other mentors to develop individual projects related to optics which are specific to their interests, experience and ability. The projects utilize simple materials and equipment but can be as open-ended and intellectually challenging as time, interest and ability allow. Secondary LTC activities include running a small-group program for WISE high school students, hosting tours, and developing and conducting demonstrations. All of the activities of the Center are documented on its web site [2], mostly through reports and research journals written by the students.

As Kenneth Brecher has pointed out at this conference: "hands-on … learning can offer students a unique opportunity … [but such] learning from direct experience can be time consuming and expensive." [3] We certainly agree, and for this reason our personalized in-depth approach to optics education is not likely to be duplicated. The intent of this paper is not to offer a recipe or program to follow but rather to simply give a full description of an unusual educational experiment that naturally incorporates many proven pedagogies, such as learning-to-learn and writing-to-learn. Hopefully some of our ideas or methods will be of interest or prove useful to others.

Section 2 of this paper describes the background and early history of the LTC. Sections 3 and 4 describe the physical layout of the LTC laboratory and its equipment and resources, including the Linux and other computers that have an important educational role. The remainder of the paper summarizes the current activities of the Center (Sect. 5), its educational philosophy and pedagogy (Sect. 6), and results and recognition obtained (Sect. 7).

2. Background and Early History

Stony Brook University (SBU) is located on the north shore of Long Island, 100 km east of New York City [4]. Founded 50 years ago, it is now the leading research campus of the State University of New York (SUNY) system with almost 24,000 students, about two-thirds of whom are undergraduates. The program for the approximately 80 undergraduate physics majors includes an optics concentration and an advanced course in laser physics. Current optics-related research in the department involves primarily laser-atom interactions and ultracold atoms, coherent control of molecular processes with ultrafast lasers, and x-ray optics. There is unrelated applied optics research on campus in the department of electrical and computer engineering. There is a growing number of optics-related companies in the area, but the density of these is nowhere near that in the well-known optics clusters in the US.

In the following, we describe how the Laser Teaching Center originated from student projects carried out in the 1990’s in the research laboratories of Prof. Harold Metcalf, a pioneer of laser cooling of atoms and related topics. Since 1999 the Center has had its own dedicated laboratory in the SBU physics building and a full-time director.

Harold Metcalf was named a Distinguished Teaching Professor of Physics in 1999, in recognition of his widely-recognized ability as a teacher and his many education-related initiatives over the previous three decades at Stony Brook. He was the first member of the department to be so recognized. In addition to the LTC, Metcalf established the Symposium on Undergraduate Research in 2001. The seven Symposia to date have provided nearly two hundred undergraduates a chance to present their optics-related research at the annual Frontiers in Optics joint meeting of the Optical Society of America (OSA) and the Division of Laser Science (DLS) of the American Physical Society [5].

Starting about 1980 Prof. Metcalf welcomed high school students (age 16-18) into his research laboratory each summer. They carried out small projects in a lively environment surrounded by graduate students, postdoctoral fellows and visitors. Initially these projects were connected in some way with the on-going research on diode lasers and laser cooling. Students could receive financial support through the Simons Summer Research Fellowship [6] established in 1984 by James Simons, the former head of the Stony Brook mathematics department and the founder of Renaissance Technologies Corporation, an investment company located close to the university. By the early 1990’s there were about two students each summer, many of whom were Simons Fellows. Most of the students came from nearby Ward Melville High School or other local high schools relatively close to the university.

By the mid 1990's the student projects involved significantly more high school students from a wider range of schools as well as undergraduates supported by National Science Foundation (NSF) summer research fellowships and university grants. Also around 1995 the range of topics considered in the student projects began to take on a life of its own, inspired in part by exciting new developments related to optics. Single bubble sonoluminescence, first observed in 1989, was popularized by articles in the February 1995 issue of Scientific America magazine [7,8]. The simple setup described [8] was duplicated and has been used for some ten separate projects of varying complexity to date. Single beam optical tweezers, first reported in 1986 [9], was another focal point of student research at that time that continues to be of great interest.

A common feature of the student projects in the 1990's was the creation of printed reports. High school students often submitted reports to national science competitions such as the Intel Science Talent Search (Westinghouse STS prior to 1988). More advanced students, such as exchange students and visitors from European universities, typically prepared their reports in LaTeX. The library of these reports became an important legacy for future students.

Prof. Metcalf soon recognized the need for a permanent home for this sort of student research activity and sought funds to convert open corridor space in the basement of the physics building into a dedicated teaching laboratory. It took several years of effort to reach this goal, but funds for the renovations were eventually obtained from several private (non-government) sources. The donors included companies in local optics-related industries, who recognized the importance of such a facility for nurturing their future optics work force. One such company donated surplus lab benches and work tables to equip the new laboratory. The new permanent facility was dedicated October 1998 in a small “ground-breaking” ceremony at the hallway site. Participants included department and university officials, James Simons, and William D. Phillips, who shared the 1997 Nobel Prize in physics for his work with Metcalf on the laser cooling of atoms.

It was apparent that the new facility would need a full-time manager to be a success. Metcalf was able to convince the department and university to support a dedicated executive director, who would develop and run the facility as well as be the primary teacher/mentor. The author, a tenured staff member in the department with a background in nuclear and accelerator physics, enthusiastically accepted the position when it was offered. One of the new director's first tasks was to come up with an appropriate name for the new facility, which had been referred to by a variety of generic terms such as “optical sciences lab” since its inception. The choice *Laser Teaching Center* was meant to convey a sense of excitement about optics research, and be appealing to young people. It was also sufficiently unique so as not to be confused with the many other optics-related Centers. A logo and distinctive signs and banners that incorporated the Laser Teaching Center name soon followed.

Early 1999 was a period of intense activity as the new laboratory was planned and set up. Considerable thought went into how the renovated space would be utilized, and the decisions made then have generally proven to be quite sound. The first summer program commenced that June with five high school and two undergraduate students carrying out projects in the new space. The most advanced project was by a 17-year-old high school student, Tina Shih, on a topic in non-linear optics (second harmonic generation in PPLN) [10]. It was later recognized through numerous awards.

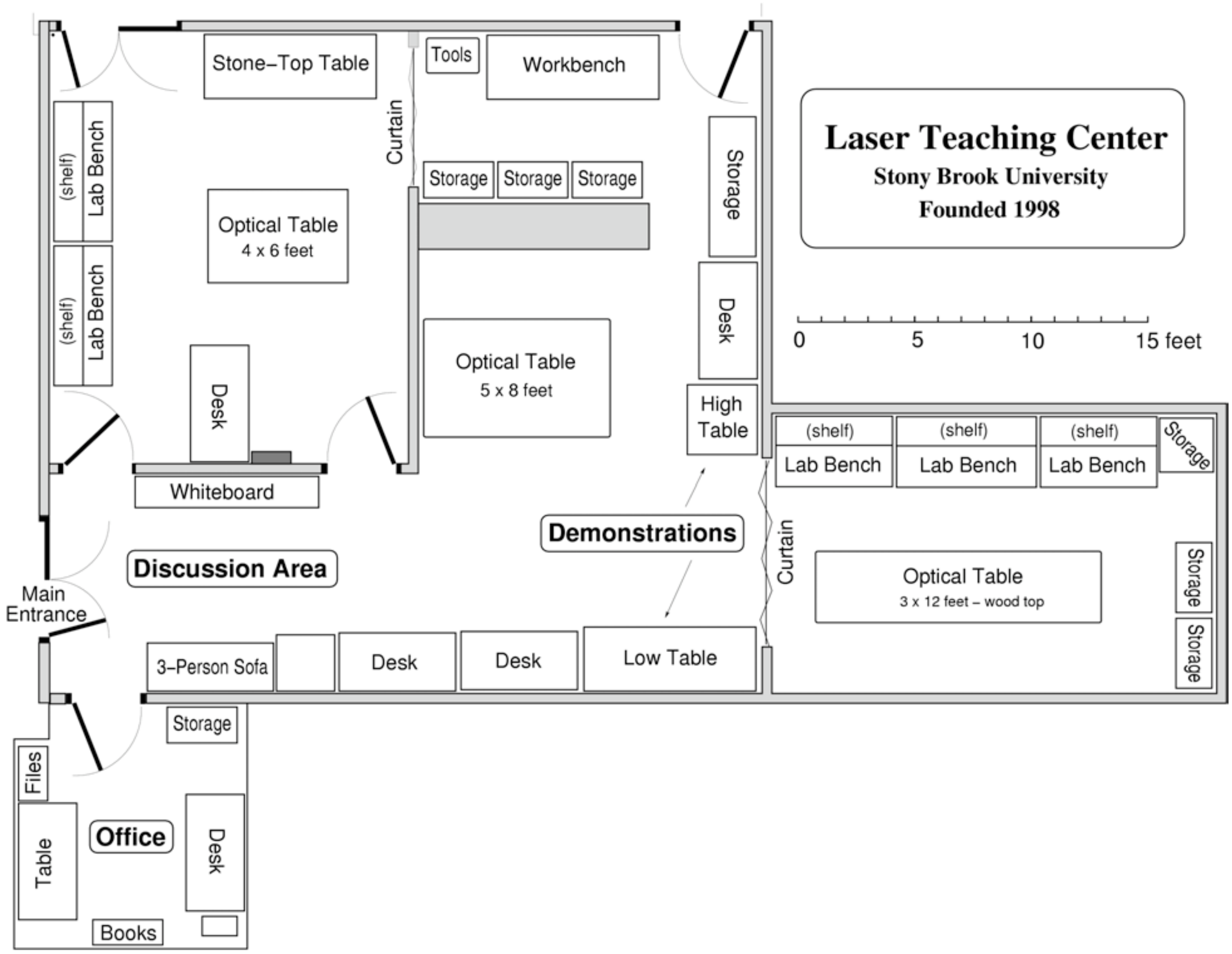
The 1999 students shared a modest Linux computer with the apt node name “laser.physics.” It hosted the LTC's web page and was used to prepare reports in LaTeX. In June 2000 “laser” was upgraded to its present form and a small network of three Linux-based terminals set up. Students working from these terminals created individual web pages, writing hand-coded html with a text editor. By the following summer (2001) the student web pages included lengthy research journals and detailed reports illustrated with graphs, drawings and pictures.

Fall 2000 marked the start of an important expansion of the Center's activities through a continuing partnership with the Stony Brook Women in Science and Engineering (WISE) program, which has both a high school and a college component [11]. One year earlier the LTC supported the first of many graduate student projects through the department's Optics Rotation course, whose participants carry out half-semester-long studies with their choice of several possible mentors. These academic-year activities have significantly broadened the scope of the LTC past the original concept of a facility for summer projects by high school students.

3. Laboratory Layout

The LTC is located in several connected rooms with a total area of about 100 m^2. Its basement location is ideal, as it is both favorable for optics experiments (dark and quiet) and very close to optics research labs and the AMO (atomic, molecular, and optical) physics conference room. The main entrance door to the laboratory is at the foot of a prominent staircase leading down from the physics building lobby and the departmental office. A large colorful sign over the door announces “Welcome to the Laser Center” and displays our “laser-splash” logo. A small alcove next to the laboratory entrance has a whiteboard and chairs, and adjacent hallways have numerous showcases that display student posters and demonstrations. The focal point of this basement lobby area is an attractive display of the eleven Century of Physics Timeline posters from the American Physical Society [12], which was set up by the LTC in summer 2001. The final poster in this series features promising young scientists of the time, illustrated with pictures of some of the 40 finalists at the 1997 Westinghouse Science Talent Search competition in Washington, DC. One of these finalists was Long Cai from Ward Melville High School, whose project on x-ray focusing with Fresnel zone plates was one of those carried out in the Metcalf labs before the opening of the Laser Teaching Center.

The irregular floor plan of the laboratory (see figure, next page) was dictated by the shape of the hallway space available for the renovation. There is one relatively large room (26 m^2) and one quite small one (10 m^2) that can be isolated with doors, but the remainder of the space is open. Simple (bathroom-shower) curtains were installed in two doorways to isolate otherwise connected areas. The furnishing of the lab was dictated in a similar way by the pieces that had been donated or were otherwise available surplus on campus. (Only the large tool chest and a few plastic shelving units were purchased.) The high-quality 5x8 foot optical table is a key piece that is used for many small projects and demonstrations.



In retrospect, a very important 1999 decision was to create a discussion area just inside the main entrance door, with a whiteboard and facing sofa at a very comfortable distance (see figure). Much of the learning in the laboratory happens at this whiteboard. Shelves under it hold a variety of optics-related journals and magazines, which students are encouraged to explore. The small table next to the sofa has drawers with various supplies and demonstration items, and the "Mirage" toy [13] sits on top, prominently displayed. A bulletin board above the sofa is framed in decorative lights and covered with photos, project figures, and other memorabilia. Above this is a copy of the large LTC Welcome sign that that appears over the entrance door. This cozy area has turned out to be an excellent setting for quiet study, one-on-one discussions, or (with a few added chairs) working with small groups of students.

Another important laboratory space is the small office used by the LTC director. It contains the "laser" computer, a workgroup printer, a large reference library of optics books, and various files and special materials. A side chair at the desk welcomes students and visitors for conversations or shared internet research. The optics books are available to all, but can't be removed from the lab.

In the central area of the lab, several desks hold the computer stations that students utilize for their writing and internet research, and two tables hold a variety of additional demonstrations such as fish-tank optics, and polarized light effects. This area can accommodate groups of up to about fifteen standing students on tours. Elsewhere in the laboratory the closed room with the 4x6 foot optical table has been primarily used for longer-term experiments, including sonoluminescence, optical tweezers and Rb spectroscopy. The entire laboratory is decorated with posters somehow related to optics, including a number from past student projects. There are also two more large (2x8 foot) whiteboards (made from a cut 4x8 foot Melamine coated sheet) adjacent to the 5x8 and 3x12 foot optical tables.

4. Research Equipment

Our research equipment has been intentionally kept very simple. This is in part to keep costs down but also for important pedagogical reasons. Most of the optics-related equipment has been donated or obtained surplus.

These items include:

- A variety of sealed HeNe lasers at 543 (green), 594 (yellow) and 633 nm (red), which deliver from under 1 mW to as much as 20 mW, and matching power supplies. A larger HeNe (Spectra-Physics 127, 33 mW) is on loan to us for an optical tweezers experiment, which also includes a donated 1970's vintage Nikon inverted microscope.
- An open-cavity HeNe laser (633 nm) based on a surplus Melles-Griot 05-LHB-570 tube. This is a very popular and useful tool for experimenting with laser modes. Learning to work with it can be very rewarding indeed.
- An 80 mW single-longitudinal-mode 532/1064 nm dual-wavelength laser (Lightwave 142-DW).
- Diode lasers at 780 nm (25 mW) and 404 nm (5 mW). The former have been used for optical tweezers and (with an external grating) rubidium spectroscopy.
- A fiber-optics breadboard with a small HeNe laser, two mirrors, and a fiber coupler. This setup provides an opportunity for new graduate students in particular to practice an important hands-on research skill, and it is also a useful source of spatially-filtered light for certain projects. Replacing the usual 633 nm HeNe with a 543 nm green HeNe allows interesting experiments with few-mode fibers.
- A basic computer-connected CCD camera (Electrim Model 1000N). This camera has been used in a number of experiments (including studies of imaging and the camera itself) and has been an important resource.
- A 1.2 m Gaertner slide, which has been used for projects on the Talbot effect and Fresnel zone plates.
- A large double-grating spectrometer (Optronic Labs, Model 740). Students have developed computer controls for this, enhancing its utility.
- Several silicon photodetectors (Thorlabs DET110) and a compact Hamamatsu photomultiplier for low-light measurements were purchased new. A donated linear-diode array has been useful for spectroscopy.
- Standard optical components such as mounts and rotators, polarizers and filters, lenses and mirrors. Some of the hardware items were donated, but most were purchased new from Thorlabs. We have found Surplus Shed [14] to be a convenient and inexpensive source for many optical elements.

Regarding electronic devices, most experiments require nothing more than a digital multimeter (DMM) for manually recording light level readings, but some projects utilize more advanced tools such as oscilloscopes, data acquisition devices, waveform generators, and sensitive amplifiers. Our oscilloscope is a $500 surplus Tektronix 485. Its bright analog display works well for demonstrating sound waveforms, and it is also fast enough to reveal > 500 MHz beats between laser modes. Data acquisition can now be done with inexpensive USB-connected devices, but some past experiments have quite effectively used a Radio Shack DMM that writes one reading a second to a serial port.

A Sony Mavica camera (Model FD-73) that saves images on floppy disks has been very important tool for most of the history of the LTC. Although its 640x480 resolution is meager by current standards it is still quite appropriate for web-page images. The camera has an excellent lens with macro and 10x zoom capability. Students enjoy using it to document their projects, and some have carefully analyzed images to quantify a point-spread function or an interference pattern. Most of the thousands of pictures on the LTC web site were taken with this camera.

Computer technology is also intentionally kept simple, in large part for pedagogical reasons. There are currently four platforms in active use: DOS, Microsoft Windows 95, Microsoft Windows XP, and Linux.

- Our legacy DOS computer supports the 1980's era Quattro-Pro spreadsheet program, which has proven to be a very effective instructional tool for plotting, data analysis and simple numerical simulations. QPRO produces attractive .eps plots with little effort, and most of the plots on student web pages have been done with it.
- Our Windows 95 desktop computer on a roll-around cart also supports just one application: the legacy Electrim CCD camera described above and Scion Image software. It can be connected to the network for file transfers.

- Our Windows XP desktop computer supports a wider, and growing, variety of student research and instructional needs. PowerPoint is used for presentations, by high school WISE program students in particular. Mathematica, available at no cost under a campus license, is excellent for creating interactive simulations. BEAM2 [15] is a very affordable and useful tool for ray tracing studies, as described in a separate paper at this conference [16].
- Our Linux server "laser" and the thin-client terminals mentioned in Sect. 2 continue to be the heart of our system and are of great importance for learning. It is impressive that young high school and undergraduate students with no significant prior computer experience can adapt so easily to writing html code in a text editor like pico or emacs, once they learn a few basic Linux commands and experience the reward of creating a visually attractive and informative web journal or report. It is common for students to log in to "laser" from their home or dorm room to continue their work. Our X-windows environment is a very basic version of FVWM, and there is no graphical "desktop." Especially useful applications include xfig for creating vector graphics, xv and ImageMagick for image processing, and gnuplot for plotting. It is testimony to the efficiency of Linux that a modest PC with a 4 GB hard drive can support several users at once and almost 150 user accounts (web pages).

The trend for the future is for our eclectic computing environment to become ever more diverse. Today's students often bring their own laptops to the lab, and access their accounts and web pages on the Linux server through the network. Students have also begun to prepare LaTeX reports directly on their laptops, using easily-installed open-source software. More and more laptops run Apple OS-X or Linux. Another trend is that research tools such as cameras, data acquisition devices and compact spectrometers are increasingly interfaced through USB connections, and computers linked to wireless networks. We plan to respond by purchasing one or more modest laptop computers that can easily be moved around the lab, while remaining connected to the central "laser" computer.

5. The LTC Programs

The primary activity of the Laser Teaching Center is the collaborative development of individual projects. The student collaborators come from a variety of sources, and in some cases are carefully selected from a pool of applicants. The types of projects also vary, and depend in part on the time available and the student's background. The busiest period of the year is summer, roughly mid-June to mid-August, when a total of about eight high school and undergraduate students work together full-time. The summer program includes weekly lunch seminars by guest speakers and optics classes prepared by the undergraduates. Another hectic period is fall, when high school students work holidays, evenings and weekends with the director to complete and write papers on projects for the national science competitions. The focus of the spring semester is the more even-paced college WISE course (see below).

The main secondary activity of the Center is an academic year program for small groups of high school junior girls in a separate WISE program. They spend an afternoon about once a month in the laboratory seeing demonstrations, learning basic optics, and doing group activities such as focusing sunlight, comparing waveforms of musical instruments, or measuring hair sizes by diffraction. They may develop a group presentation, but do not work individually. These activities are well documented on the LTC web site with numerous pictures. Other secondary LTC activities include giving lab tours, often with optics demonstrations, and some outreach and recruiting.

Most of the individual projects carried out fall into one of the following three categories:

1. Fairly standard tutorial exercises that acquaint a student with a topic, technique, or field of optics. These can be similar to the experiments "performed" in regular teaching laboratories, with the key difference that our students spend much more time, several weeks or even a full semester. There are no written instructions, although sometimes a published article or a previous student's report is a guide. The topic studied is typically suggested by the mentor as something related to the student's specific interests, once these have been determined through conversations. The final product could be a web-page report, a poster, an oral presentation, or some combination of these. Past project topics have included: Fourier optics, microwave Bragg scattering, laser beam propagation and focusing, elliptically-polarized light, interferometry, fiber optics, and photo-refractive optics. The set-ups for most of these projects are created from scratch by the students.
2. Experiments related in some way to relatively advanced topics of current research interest. Many high school students write 20-page reports for science research competitions, and some research has been presented at optics meetings such as OSA/DLS and DAMOP. Topics of particular interest include: optical vortices and singular optics, optical tweezers, and acousto-optics. Although the topics are advanced the actual project need not be

complex. One high school student studied vortex-phenomena in flowing soap films with a very simple apparatus [17]. This project was recognized as one of the top 40 in the nation in the 2003 Intel competition.

3. Projects that are simple yet creative explorations or demonstrations of everyday devices or phenomena related to light, optics, or sound, as described further in a separate paper [18]. Often the topic is suggested by something the student is just curious about or wants to "invent," or by a chance observation or news article. These projects are typically summarized in web-page reports that may include numerous pictures and hand-drawn diagrams.

All of our students are given the opportunity and challenge to suggest any feasible project they wish. Those new to research soon learn that finding a suitable project topic is itself a research problem, a valuable lesson. A few have a good idea almost immediately, others may come up with one on their own after a few weeks, but the majority of students require some sort of guidance. We often hear "I give up, tell me what my project is!" and respond "let's see what we can come up with together." Such projects are typically modest in scope initially but can be very open-ended. Graduate students typically prefer to base a project on a specific suggestion or published article.

The LTC student community has several components:

- <u>High school students (age 16-18)</u>. Many of these students have been accepted into the Simons summer research program [6] and are looking for a research opportunity related to optics; others contact us directly. All of our final candidates come in for lengthy interviews. A peculiarity of high school education on Long Island is that a significant and growing number of schools support in-school "science research" programs, often with a dedicated teacher. These programs present research as a methodology and emphasize achieving success in organized science competitions. In our interviews we look for students who can demonstrate a working knowledge of subjects they've "taken" in school, and who are motivated primarily by natural curiosity. A few high school students are accepted in their sophomore year, and thus have a possibility for an extended experience over two summers and (if they are within commuting distance) the intervening year. Our high school students who live relatively close by often take Stony Brook college courses through the Young Scholars program [19].
- <u>WISE program freshmen (age 18 or 19)</u>. The Women in Science and Engineering (WISE) program includes an *Introduction to Research* course (WSE187) in the spring semester of freshman year. We have taught a section of this class since 2001, with typically 4-6 students. The course is normally arranged as a three-cycle rotation, but our students can elect to stay for the entire semester, and most do. We encourage all potential physics and astronomy majors to participate. These young women have generally turned out to be excellent LTC students, very receptive to learning and appreciative of this opportunity. Several past students are now committed to careers in physics or astronomy research or teaching; one of these is now a graduate student of quantum optics.
- <u>Other Stony Brook undergraduates</u>. The Center is open to any undergraduate in our department with an interest in optics. They can enroll for course credit, or not. Some students continue work started in the WSE187 course.
- <u>Summer undergraduates</u>. These students have received an NSF-REU fellowship to a 7-week summer research program. We review the applications and select a few of the admitted students with a strong interest in optics but as yet limited experience, who would be willing to work with high school students. Some past REU Fellows have been from Stony Brook, including three young women who had just completed the freshman WISE course.
- <u>Graduate students in an Optics Rotation course</u>. Optics Rotation (OR) gives new physics graduate students an exposure to optics research in the department. Students carry out two projects a semester with a mentor of their choice; some enroll for two semesters. Enrollments fluctuate, and we have had as many as nine OR students in one calendar year. Many are quite experienced already, but for others this is their first opportunity for significant hands-on work. The OR students tend to work (or want to work) very independently, rather than collaboratively.
- <u>High school teachers</u>. There is just one example to date, a physics teacher in training who collaborated on a project about soap film colors in spring 2004 [20]. It was rewarding experience for both student and mentor, and we look forward to having more such highly-motivated adult students in the future.

While the primary LTC mentor is its full-time director, there is a growing community of other mentors. These include Marty Cohen, a retired optical physicist, and Anand Sivaramakrishnan, a Stony Brook adjunct professor of astronomy. Their specialized expertise has been invaluable for projects related to acousto-optics and wavefront sensing respectively. Regular summer visitors include Kiko Galvez of Colgate University and Sam Goldwasser, creator of "Sam's Laser FAQ." Graduate and undergraduate students also serve as mentors and laboratory assistants.

6. Educational philosophy and pedagogy

We are not professional educators [21]. We have been guided solely by instinct and intuition, and personal experience with the power of engaged active learning. The proven Suzuki method of violin instruction and the more recent One Laptop Per Child (OLPC) initiative [22] are based on the premise that young children, given appropriate tools and placed in a supportive environment, have an unlimited potential to learn. We seek to create a similarly supportive environment for a wider range of students in the context of optics. It is widely recognized that optics is an ideal vehicle for teaching more general lessons about science and research, for a variety of excellent reasons. But we must not forget that we are educating students *using* optics, not just teaching *about* optics. We are not trying to develop or transmit any particular skills (train), but rather nurture a state of informed curiosity that makes self-directed learning possible. We want our students to "learn how to learn" for themselves. Mark P. Silverman has written extensively and eloquently about self-directed learning, which he terms a "heretical experiment" [23,24]. Our educational philosophy has much in common with Silverman's ideas and is no less heretical.

<u>Writing</u> is a very important part of our pedagogy. Every student receives a bound notebook, and is encouraged to use it well and often; some eventually need more than one. Notebooks complement keyboard writing by encouraging drawing and visual thinking. The internet journals that students create often express the excitement and frustration of research in refreshingly honest and original terms. We encourage them to also write "Answers and Questions." Answers are just things that are now personally understood, facts or observations; Questions are things that one doesn't understand or are just curious about. Questions are for the future and may never have a matching Answer [25]. Writing more formal reports well is often a challenge that can only be met by writing collaboratively with a mentor, and we often provide students with their first such experience. We insist on precise language, and a logical and consistent technical style. Sometimes getting a few sentences right can take hours! Through such carefully crafted writing, eventually students come to appreciate how every word and phrase is important in a scientific paper. Writing web pages in hand-coded html, and printed reports in LaTeX, develops computer literacy and with this a further appreciation of precise syntax and logical structure in writing. Writing emails well is important too; without this there can't be meaningful collaboration with mentors at a distance, or letters addressed to relevant scientists.

Even more important than writing is <u>speaking</u>, trying to communicate or explain something extemporaneously to another person while on one's feet. Our students get lots of practice at this in all sorts of contexts. Prepared talks are valuable too, but not as much so. Realizing that one doesn't really understand something when one goes to explain it is a powerful motivator! In short, this Yogi tea tag has it right – "To learn, read. To know, write. To master, teach."

Our approach to <u>mentoring</u> has been called "getting into kids' heads" by someone who knows the author well. Getting into kids' heads means asking questions about students' interests, gauging their reactions to new ideas and experiences, sensing their concerns, and just generally customizing the interaction. This type of mentoring is about far more than giving advice, or even knowing when NOT to give advice. It involves building a personal relationship based on trust, which can only be developed over a period of time from shared experiences and challenges. (Sharing disappointments and misunderstandings is even better.) Students will only absorb and accept advice if they feel comfortable discussing and even disagreeing with it. It's far better in the long run for the student to have the mentor say "I don't know. / I'm confused. / Let's figure it out. / You tell me." than to be just "given the answer." Especially during the busy summer program there is also <u>peer mentoring</u>, where students from disparate backgrounds learn from each other and thereby gain a further appreciation of the importance of collaboration.

The term <u>holistic learning</u> is used in a variety of ways, for example to describe learning that involves feeling, imagination, thinking, and acting. We think of it as simply meaning educating the whole person, or educating by involving the whole person. In the lab the optical table is steps from the whiteboard and sofa (for discussions and just pondering), the computer terminals (for writing), and the reference library. A student can move without hesitation from handling an optical element or seeing a curious effect to making a drawing on the board, or delving into a book. It is a fertile setting for learning that engages equally well the mind, the imagination and the senses.

In contrast to currently popular trends, with beginning students we minimize the use of <u>technology</u>, both computer and optics-related, and improvise whenever possible. It is far preferable initially to record a few hundred data points by hand and carefully match them (by manually altering parameters) to a theoretical function in a simple spreadsheet than to see a result pop up on the screen with no effort. One beauty of optics is that with a few simple tools one can get data (the intensity profile of a laser beam, for example) that match a theory astoundingly well.

These and other lessons that we hope our students will absorb can be summarized as follows:

- Knowledge has endless layers of complexity that are revealed through inquiry and research.
- Real science can be exciting and fun, but it requires much hard work and is often frustrating.
- Don't accept "black boxes" – strive to "look under the hood" to learn how things work.
- Scientists are real people, and most often very willing to help an informed student.
- Collaboration enriches, but honest competition is valuable too.
- Humility and thoughtful curiosity are essential states of mind.

7. Results and recognition

We can only meaningfully evaluate the lasting impact of what we do on a person-by-person basis, over a time frame even longer than the nine-year lifetime of the Center. It is hard to judge the long-term impact of any educational experience, but for a significant number of our students their LTC experience has clearly been a very important or decisive influence that opened the door to further opportunities and/or stimulated a continuing interest in research, physics or optics. (The defining moment could be achieving success in a challenging project, or maybe just a brief conversation with a famous scientist.) As mentioned in the introduction, many others have benefited in a variety of more subtle ways that are hard to assess.

We can, however, make two general observations about outcomes based on specific student experiences:

- A significant fraction of our former undergraduates, from both Stony Brook and elsewhere, and even some of our earliest high school students, are now in optics-related PhD programs at prestigious universities (three are at Harvard alone). In several cases there is a clear connection between the early interest nurtured through the LTC student project and the eventual research specialty. For numerous others among our still-current undergrads and former high school students, such an academic career path is a strong possibility.
- Several of our Stony Brook undergraduate students have gone directly to work in a local laser company. It will not surprise the ETOP community that there is a large and growing demand for employees with some optics experience who can "think on their feet and work with their hands." The new optics specialization in the undergraduate physics program will hopefully help create a pathway to the local optics industry for others.

Visitors to the Center, especially those who meet our students, have invariably been impressed. Our distinguished visitors include former OSA head Anthony Johnson, Professor Sir Michael Berry, and 1997 Nobel Laureates William Phillips and Claude Cohen-Tannoudji. The LTC has been featured in various campus publications and cited in Physics Today [26]. Our high school students have been recognized by numerous awards in national and international competitions, and several of our former undergraduate students have received prestigious fellowships for graduate study. Significantly, much recognition has also come *from* our students, who frequently express their appreciation of the LTC experience in notes, emails and web journal comments.

8. Conclusions

Some of the conclusions we can reach from nine years experience with this unusual experiment in optics education may seem obvious. First and foremost is that the most enduring teaching and learning takes much time and patience, and a relaxed trusting relationship between mentor and student. A corollary is that it's quite possible to "do a lot with a little" and this may well teach more than using expensive equipment that's not well understood. Writing is clearly important, and giving students a way to write for the web is empowering. Letting students teach others and make mistakes is even more so. Finally, every student is different and has to be related to in a unique way. Personalized learning is indeed time consuming and often frustrating, but it opens doors to unbounded growth and success.

An important question for the future is how to sustain and further develop such a labor-intensive undertaking, while maximizing its effectiveness. One possibility is to offer the LTC experience to more high school teachers, who could in time assume a leadership role in training further teachers, as well as their students, in our approach.

Acknowledgments

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Last but not least, I would like to thank our many enthusiastic and hard-working students, without whom the LTC would not have been possible.

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A Complete Ray-trace Analysis of the 'Mirage' Toy

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Abstract: The 'Mirage' (Opti-Gone International) is a well-known optics demonstration (PIRA index number 6A20.35) that uses two opposed concave mirrors to project a real image of a small object into space. We studied image formation in the Mirage by standard 2x2 matrix methods and by exact ray tracing, with particular attention to additional real images that can be observed when the mirror separation is increased beyond one focal length. We find that the three readily observed secondary images correspond to 4, 6, or 8 reflections, respectively, contrary to previous reports.

Keywords: optics demonstrations, ray trace analysis

1. Introduction

The 'Mirage' [1] is a well known optics demonstration [2] that is very popular in our laboratory and at open house events. It consists of two horizontal concave mirrors that work together to project a real image of a small object placed on the lower mirror through an aperture in the upper one. Visitors are fascinated by the realistic image that "floats in space" and are challenged and involved when they are asked what will happen when it is viewed through a magnifying glass or mirror, or illuminated by a laser beam.

A little-known feature of the Mirage is the appearance of additional real images when the distance between the two mirrors is uniformly increased by carefully raising the upper mirror without tilting it. Three such secondary images (which are alternately inverted or not inverted compared to the primary image) are clearly visible at additional mirror distances of 3.1, 4.5, and 5.3 cm [3]. While the first secondary image is nearly as clear as the primary one, the subsequent secondary images are increasingly dim, distorted and hard to discern.

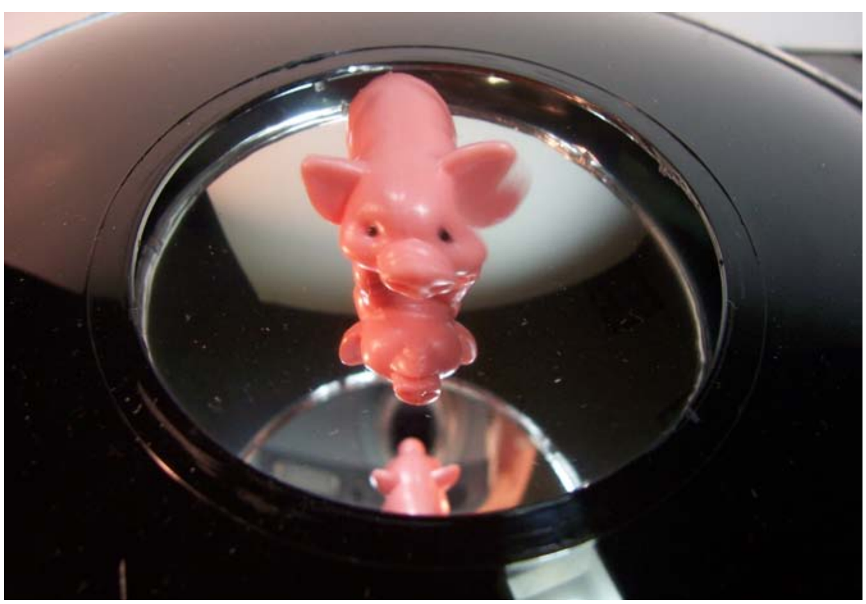

Fig.1. Photograph of the Mirage toy in our laboratory showing, from top to bottom, the projected real image, the projected reflection, and the actual object. The two images appear larger than the actual object primarily because the camera is close to the device. The opening in the upper mirror is 6.25 cm in diameter.

We have studied the formation of these secondary images in the Mirage toy by both 2x2 matrix ray-optics methods in Mathematica [4] and by exact ray tracing with the BEAM2 program [5]. The problem provides a very good introduction to geometrical optics and to these two very useful and pedagogically valuable software tools. The project is typical of those used to introduce high school and young university students to optics at the Stony Brook Laser Teaching Center, as discussed elsewhere at this conference [6,7].

2. Description

The Mirage toy is readily available from various suppliers of science education products for about US $35. Its two parts are made from a durable black plastic by injection molding. The mirror surfaces appear to be optically quite accurate except for an irregular portion ~2 mm in diameter at the center of the lower mirror. This imperfection is of no consequence as it is normally covered by the object placed there. The optical surfaces are protected from tarnishing by a durable over-coating, but are quite sensitive to damage from fingerprints or scratches. We have found that cleaning is best done by wetting the surface with dilute household detergent and flushing with a copious stream of hot water; residual water droplets can be blotted dry with a paper towel, but the surface must never be wiped or rubbed. Now that the original Mirage patent has expired similar devices are being produced and sold by companies other than Opti-Gone. The ones we have seen are of significantly lower optical quality than the authentic Mirage and don't clearly show the secondary images.

The description of the Mirage on its packaging and elsewhere is misleading in several ways. The trade-marked name Mirage has of course no relation to the refraction phenomenon by that name, and the term "3-D reflection hologram" is not accurate either. The packaging further states that "optical surfaces are crafted to 5/1,000,000,000 of an inch." This figure (which corresponds to only about one Angstrom) was intended to be indicative of the extreme thinness of the aluminum reflective coating [8].

3. History

The Mirage has an interesting history [8] that begins with a chance observation by a custodial worker, Caliste Landry, in the physics department at the University of California, Santa Barbara some four decades ago. One day Landry happened to be cleaning a stack of large World War II surplus searchlight mirrors that had been stored away in a closet. (Such mirrors have a central aperture for the arc lamp support.) Landry was startled and fascinated to see a realistic illusion of "dust that couldn't be cleaned." He reported his observation to a young faculty member in the department, Virgil Elings [9], who quickly recognized the optical principles involved and the novelty and potential utility of devices of this type for displaying jewelry, etc.

Elings and Landry filed for a patent for an ``Optical Display Device" in 1970, and it was granted two years later [10,11]. The patent is interesting for what it does and does not say about the optics of the device. For example, Figures 3 and 4 in the patent show the second solution for two reflections and the non-inverted secondary image after four reflections, respectively. (See discussion in Section 5 below.) The accuracy of the images is not discussed, and the drawings show only one symmetrical pair of rays. The patent also mentions without any further discussion the possibility of using mirrors of unequal curvature or a mirror which isn't convex.

Michael Levin first became aware of the Elings device when he came across an expensive glass version of it (made by Elings and a son) at a San Francisco gift shop. Levin had prior experience with commercial ventures related to optics, having been involved with the Laserium shows [12] in the 1970's, and could see the potential of marketing a more affordable version to a wider audience. By 1977 he had acquired the rights to the Elings invention and founded Opti-Gone International, whose sole products remain the standard Mirage studied here (Model 2000) and a much larger version (Model 22) used for dramatic displays at museums and the like [1].

4. Geometry

We decided to study the geometry of the Mirage with no prior assumptions other than that the mirrors are surfaces of revolution. We first used a caliper and steel ruler to measure the active (coated) diameter of the lower mirror c and the perpendicular distance (sagitta) from the midpoint of that chord to the mirror surface h, taking care to account for the lip at the mirror's edge. From the relationship $r = c^2/(8h) + h/2$ we deduced a radius of curvature r =18.0 cm. A circular template of this radius cut out from paper did not match the mirror surface, so it was apparent that this was not spherical. By trial and error it was determined that a smaller circular template (r = 16.13 cm) matched the surface well near its center, but deviated from it at the edges. Finally, a parabolic template with the same curvature at the vertex was constructed. It matched the entire surface well. Additional measurements confirmed that the vertices of the two mirrors in the Mirage are separated by one focal length (8.06 cm), as expected. The sagitta method was used to account for the large (6.25 cm diameter) opening in the upper mirror.

It is of course clear why parabolic mirrors would be desirable, if not essential, in this device. A parabolic upper mirror placed one focal length above the lower mirror will direct all rays originating from the vertex of the lower mirror directly downwards, regardless of their angle with respect to the axis. When these precisely vertical rays reflect from parabolic lower mirror they will converge to an image point that lies at the vertex of the upper mirror, as shown in the following sketch taken from the Opti-Gone International web site [1].

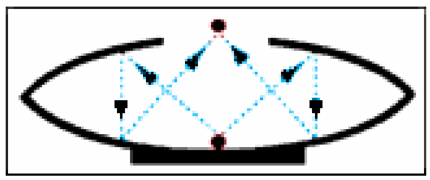

Fig. 2. Ray paths between parabolic mirrors [1].

5. Matrix Analysis

The 2x2 or ABCD matrix technique for ray tracing is well known [13,14]. The (r,θ) form we used applies to spherical optical elements on a common axis, where the ray angle θ is sufficiently small that the paraxial approximation $\sin(\theta) \sim \tan(\theta) \sim \theta$ applies. This approximation is certainly not justified in the present situation, and in fact all rays close to the axis are lost through the opening of the upper mirror. The mirrors are also not spherical. Nevertheless it is an interesting and useful exercise to carry out the analysis and study the solutions obtained.

Our matrix analysis had two parts. First we studied the magnification and displacement of the primary image as a function of the displacement of the object above the lower mirror. Then we studied the secondary images by finding all mirror separations d/f at which an image forms at the upper surface, after 2, 4, 6, 8, or 10 reflections.

The two optical elements represented by 2x2 matrices are the two mirrors of focal length f = 8.06 cm and the varying drift distance d between them. A product matrix with elements ABCD is formed by multiplying the appropriate element matrices in sequence, from right to left. For the primary image formed by two reflections the sequence would be: drift (D), reflect (R), drift (D), reflect (R), drift (D). For four reflections the product matrix would include an additional RDR sequence, etc. The condition for the formation of a real image is that matrix element B = 0. When B = 0, the matrix element A gives the magnification.

The calculations were carried out with the popular Mathematica software tool [4], which was available to us at no cost through a campus license. (The free open-source program Scilab [15] would have been equally effective.) To locate the secondary images the product matrix for a particular case was written out and the values of drift distance d that make element B of this matrix zero were obtained. For n reflections there are n solutions, but many of these are for mirror separations less than the focal length, or occur at relatively large separations. The first solution for 2 reflections (d = f) is the primary image normally observed; a second solution occurs at d = 3f. This second solution has been discussed before by other authors [16,17], who erroneously associated it with the first secondary image.

Figures 2 and 3 and their accompanying captions summarize the results. The steadily increasing magnification and upwards shift of the primary image as the object is raised above the lower mirror surface is responsible for the slightly “muscular” appearance of the pig image. If one small pig is placed atop another, then the image of the upper one clearly appears larger than the lower. The plot of image locations shows interesting mathematical patterns. As the number of reflections increases to infinity a multitude of images will converge at the confocal distance d/f = 2.0.

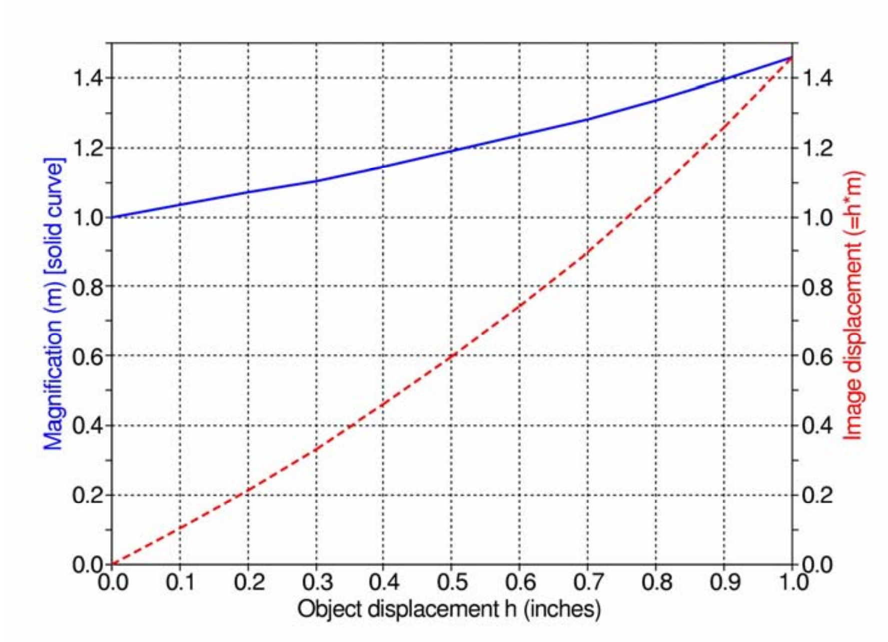

Fig. 3. Position and magnification of the primary image as a function of the object position relative to the lower mirror. As the object is displaced upwards its image expands and is displaced upwards by an amount that increasingly exceeds the shift in the object position.

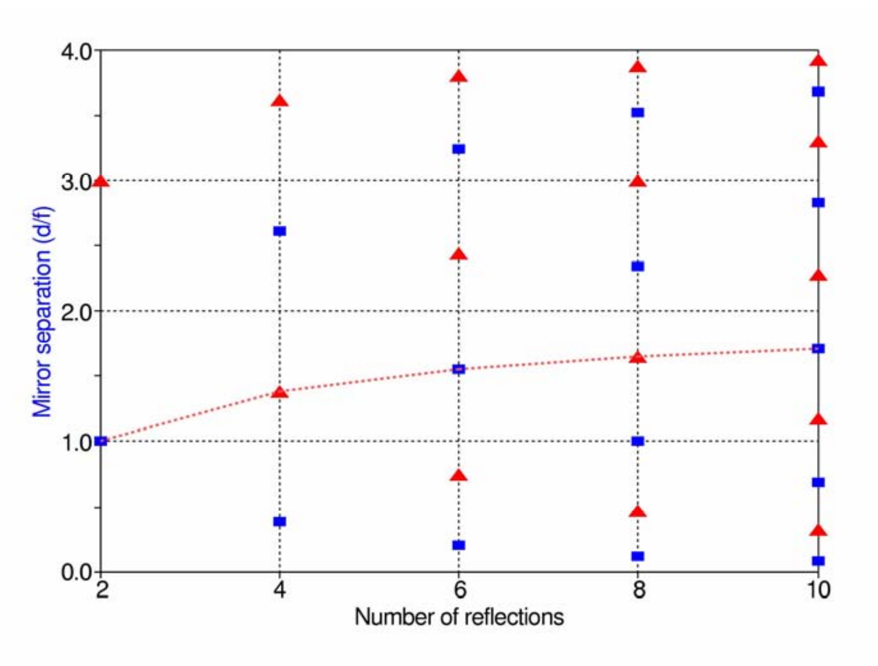

Fig. 4. This plot shows the locations of all images predicted by matrix analysis as a function of the mirror separation *d* in units of the focal length *f*. The number of images is equal to the number of reflections, and the predicted images are either inverted (squares) or not (triangles). The dashed line shows the primary image and the observed sequence of secondary images.

6. Exact Ray Trace Analysis

The BEAM2 software [5] proved to be an excellent tool for the exact ray trace studies, with limited yet quite adequate features for this study. (It only handles surfaces of revolution, but these can be formed by an arbitrary conic section.) It was quite easy to learn, especially with the detailed examples published by Atneosen and Feinberg [18]. Finally, it was quite affordable, just US $89 for a single user copy, unchanged from 1991 [18].

We started by confirming that the primary image formed by parabolic mirrors one focal length apart is perfect, with no geometrical aberrations. The spherical aberrations produced by spherical mirrors are strikingly large, and even a few percent deviation from the optimum parabolic shape gives a noticeable imperfection in the calculated image.

We next studied the first and clearest secondary image, produced by four reflections. Parabolic surfaces were assumed. As shown in Figure 5, a secondary image is formed, in agreement with the matrix analysis and observation, but it is clearly distorted by spherical aberration. Rays emerging from the object at relatively large angles cross the optical axis further from the object than do rays close to the axis. If only highly paraxial rays are considered the location of the image agrees precisely with the prediction of the matrix model (Figure 4), as it should. Not illustrated here, spherical aberration increases significantly with each additional pair of reflections,

We also looked at the two-reflection image predicted by the matrix model at a large mirror separation $d = 3f$. Once again, for rays nearly parallel to the axis (within a degree or less), an image is formed at the upper mirror, in agreement with the matrix model. However, as strikingly illustrated in Figure 6, realistic rays fail to converge, and may even remain parallel to the axis. Thus the exact BEAM2 calculation is in agreement with the easily done experiment – there simply is no observable two-reflection secondary image, as previously claimed [16,17].

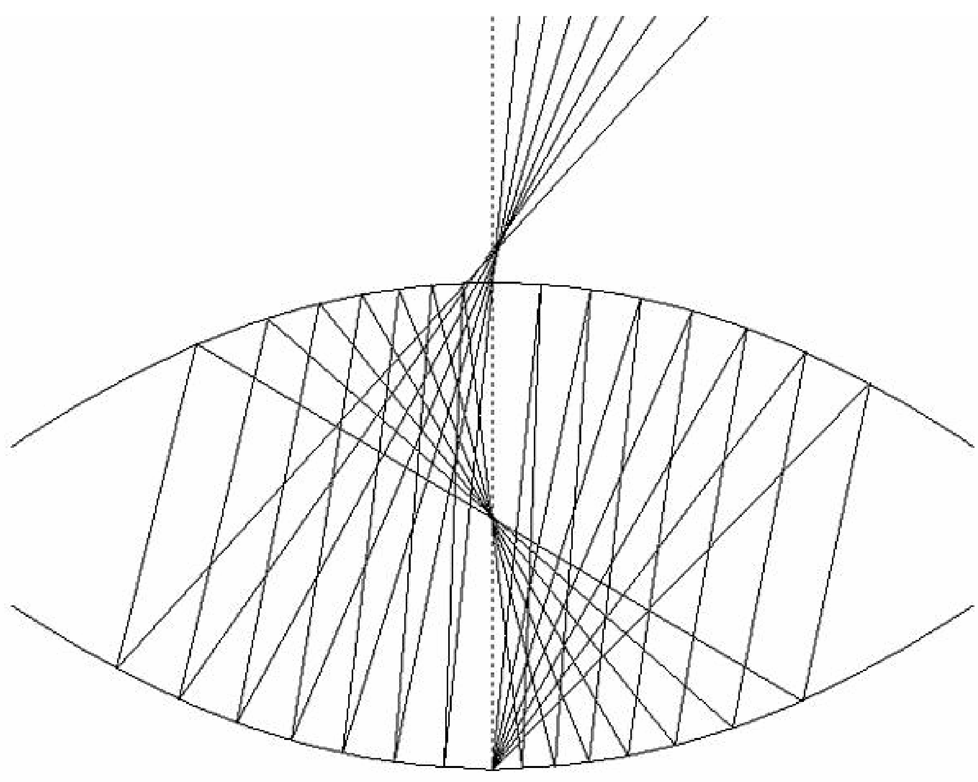

Fig.5. Exact ray trace for the first secondary image, calculated with BEAM2. An image is formed at the surface of the second mirror, but it is distorted by spherical aberration. The opening in the upper mirror is not shown, and some of the rays drawn would escape through it and not be reflected.

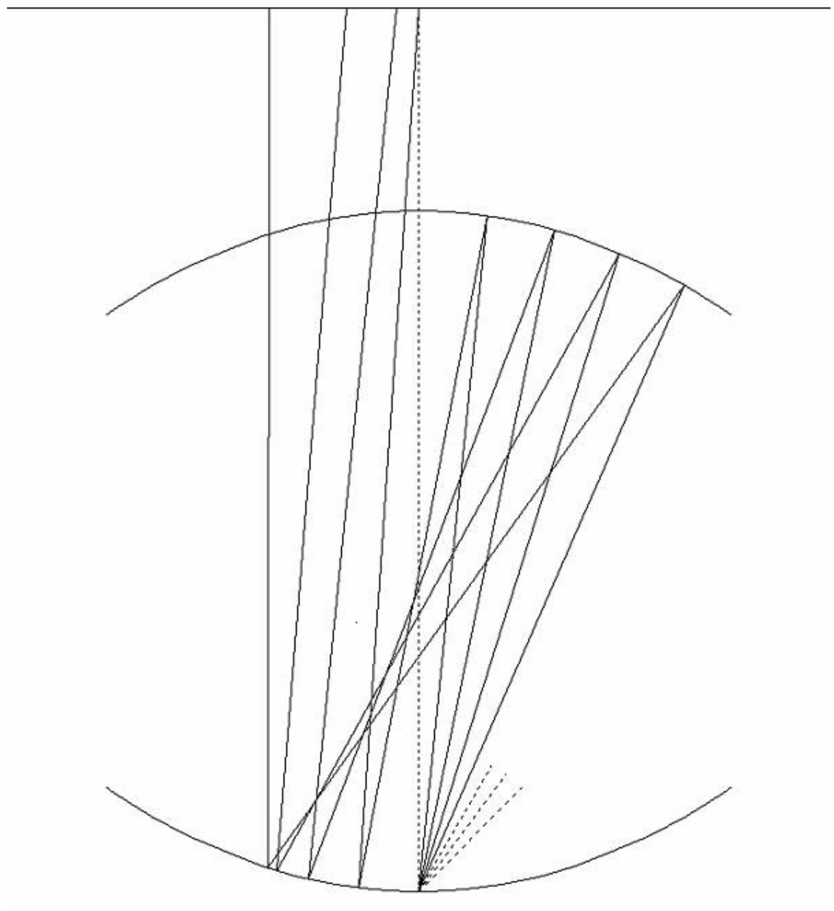

Fig. 6. Exact ray trace for a mirror separation d = 3f. The emerging rays do not come to a focus and there is no visible image. The horizontal line at the top is a "screen" that must be included when setting up the program.

7. Discussion

This turned out to be an excellent student project for a variety of reasons. The easily observed and interesting phenomena of the Mirage device provided a strong motivation for mastering new analytical tools. The mathematics and computer skills involved are relatively simple and well-suited to self study. Learning about the history of the Mirage and the people involved was an adventure, as was finding that published information was incorrect.

As with all good Laser Teaching Center projects [6,7], there is much more to learn and explore, through both simulations and hands-on measurements and experiments. As suggested in the patent filing there are many more optical configurations for image projectors that could easily be explored by the methods described here, including having mirrors of different shapes and unequal curvature (focal length). It would be interesting as well to apply the realistic analysis to the eight-reflection image that is predicted to coincide with the primary image at d/f = 1.0, as shown in Figure 4. Hands-on experiments could involve placing a small light source at the object position to more precisely track the images, or even creating a reflecting telescope with one of the mirrors and studying its properties. (An even easier experiment is to use one of the mirrors to focus sunlight, with dramatic results!) In short, the Mirage toy provides a rich playground for exploring image formation and geometrical optics.

Finally, a recent paper in The Physics Teacher gives instructions for making a cylindrical device that produces a somewhat similar effect [19]. The device is simple, effective, and very inexpensive to construct, but it could not be analyzed in the same elegant and informative way that the Mirage toy was analyzed here.

Acknowledgments

We would like to thank Michael Levin (Opti-Gone International) and Michael Lampton (Stellar Software) for interesting and informative discussions. We are also indebted to Azure Hansen for the excellent picture of our Mirage toy, and for her invaluable help with the manuscript. This work was supported in part by the Women in Science and Engineering (WISE) program and the Department of Physics and Astronomy at Stony Brook.

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Simple Creative Projects from an Optics Teaching Laboratory

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Abstract: The core educational program of the Stony Brook Laser Teaching Center is learning through the collaborative development of individualized projects. Many of these projects, especially with students new to research, are simple explorations or demonstrations of everyday devices or phenomena related to light, optics, or sound that have some creative component. Often the topic is suggested by something the student is just curious about or 'invents,' or by a chance observation or news article. This paper will describe a number of these 'simple, creative' projects, and relate the discovery process by which each came about and the results obtained.

Keywords: Active learning, project-based learning, collaborative learning, individualized research experience

1. Introduction

As described in a separate paper at this conference [1], the core educational activity of the Stony Brook Laser Teaching Center (LTC) is learning through the development of individualized hands-on projects; one such project was discussed in detail in a second separate paper [2]. Some of these projects can be described as fairly standard exercises explored in greater-than-usual depth over weeks or months [1]. Other projects relate to topics of current research interest, such as optical tweezers or optical vortices, and can be quite involved and open-ended. A third project category, which is described and illustrated through the various examples presented in this paper, consists of mostly simple explorations or demonstrations of everyday devices or phenomena related to light, optics, or sound that have some novel or creative component. This component could be related for example to the way the project topic was picked, or how the project was carried out with the simple tools and materials on hand in the laboratory or readily available. In some projects there is a 'Eureka!' moment of discovery when the student working alone has a significant insight, makes an unexpected observation, or invents something. More often the creativity arises in some way from the special chemistry between student and mentor that gradually develops as they communicate about and collaborate on the project over an extended period of time.

The students involved in these 'simple, creative' projects are mostly new to research and generally have had at most a very limited exposure to optics in a high school physics course. When they enter the LTC they are introduced to various optics phenomena and concepts through seeing demonstrations and participating in informal discussions. Except during the full-time summer program there are no classes or lectures and the unstructured discussions all take place in the small laboratory discussion area. The detailed optics knowledge and laboratory skills needed for each project are acquired on a need-to-know basis, through self-study and informal discussions with mentor(s) and more experienced students. The main requirement for success on the part of the student is ample interest and curiosity and an ability and willingness to collaborate with the mentor. Students and mentors become in effect partners in a unique shared experience, and the synergy of their interaction leads to the new ideas and insights not otherwise possible. The student-mentor partnership extends to the all-important writing process that concludes the project, as the mentor guides the student as closely as necessary to create a thorough and convincing written description of the project.

The projects described are not meant to be duplicated, although some of the ideas and 'tricks' might be useful to others. They are presented simply to provide examples of what's possible through relaxed one-on-one student-mentor interactions in a supportive learning environment. We hope that others will be inspired by these stories to explore opportunities to incorporate such unstructured project-based learning into their own educational programs.

2. Representative Projects

In the following I will describe eight representative projects of the type described above. Most of the students involved were university freshmen (age 18 or 19) from the Introduction to Research course (WSE187) in the Women in Science and Engineering (WISE) program [3]. Several others were high school students, and one was a high school physics teacher in training. In many cases the creative component was the idea for the project, how it came about, or what was studied. In another case a simple but very effective technique for nanometer motion control was invented in the course of a much more involved project. Several projects involved interesting or unusual optical properties of everyday objects. Studies of this type have a grand history and can be very open-ended indeed, see for example Michael Berry's "Reflections on a Christmas-Tree Bauble." [4]

The duration of the projects ranged from a few weeks to a full semester. Those by WISE students are documented in straight-forward (hand-coded) web reports that are freely available on the WISE Programs portion of the Laser Teaching Center web site [5]. Learning to create such hand-coded html reports is an essential part of the WSE187 course, and the collaborative writing involved reinforces understanding as well as writing skills. The project by the prospective high school teacher is also described in a web report. Other projects are documented on the web site in pictures, abstracts, Powerpoint slides and full-length written reports prepared in LaTeX. Web reports typically include many photos, drawings and graphs. The drawings could be done on a computer (we use the Linux program xfig) or could simply be a photo of a hand-drawn sketch on the white board or in the student's notebook. Graphs and numerical simulations are typically made using the 1980's era DOS spreadsheet program QuattroPro, the ultimate simplicity of which is a valuable feature to students new to this type of analysis.

2.1 Light decay of 'Glow in the Dark' materials

My partner in this project was Jill Chen, a mechanical engineering major who was one of six students in my spring 2002 WISE class [6]. Jill was the unusual student who not only had an excellent idea for a project ("can we study those glow-in-the-dark stars?") but also suggested it almost immediately. As a young child, Jill had enjoyed the comfort of falling asleep in a room with a light on, and had also enjoyed seeing stars in the sky at night. At some point she had been introduced to glow-in-the-dark decorative stars and had ever since displayed these in her room at home and later in her college dormitory. This turned out to be an excellent project: one that could be effectively performed with very simple equipment already on hand, but which was also very open-ended. The following summarizes the shared adventure that is better described in Jill's own words on her project web page [6].

We started with some internet research about glow-in-the-dark (phosphorescent) materials, and soon learned about a company (Shannon Luminous Materials) that markets such materials for a range of applications [7]. A person at the company was interested to hear about the project and quite willing to help. He provided samples of Shannon's state-of-the-art 'Super Phosphorescent' material based on rare-earth-activated strontium aluminate (SRA) [8] as well as a more traditional zinc sulfide (ZnS) screen. Although a photomultiplier was available, one of our standard Thorlabs silicon photodetectors (model DET-210) proved to be adequate for observing the light decay for several hours, and had the advantage of simplicity and stability. No amplifier was used, but a high value resistor (10^5 to 10^6 ohms) was placed across the output of the detector to convert the small current signal to a voltage in the 0.1 - 100 mV range.

In projects that involve taking a modest series of readings I typically guide students to record readings by hand in their notebook and then type these data into a spreadsheet program for plotting. This manual technique has worked well for numerous laser beam profile measurements and the like, but in this case a very simple automated method based on the serial interface port in the Radio Shack Model 22-805 digital multimeter was employed instead. The software provided with the meter transferred one reading per second into a text file, which could then be imported into our QuattroPro DOS spreadsheet environment for plotting. This scheme was very simple, effective and economical (US $50 for the meter), and also pedagogically more transparent than using a less familiar device for an interface. To record data the materials were 'charged' by exposure to a bright desk light, the detector was set on top, and this package was quickly placed in a dark environment.

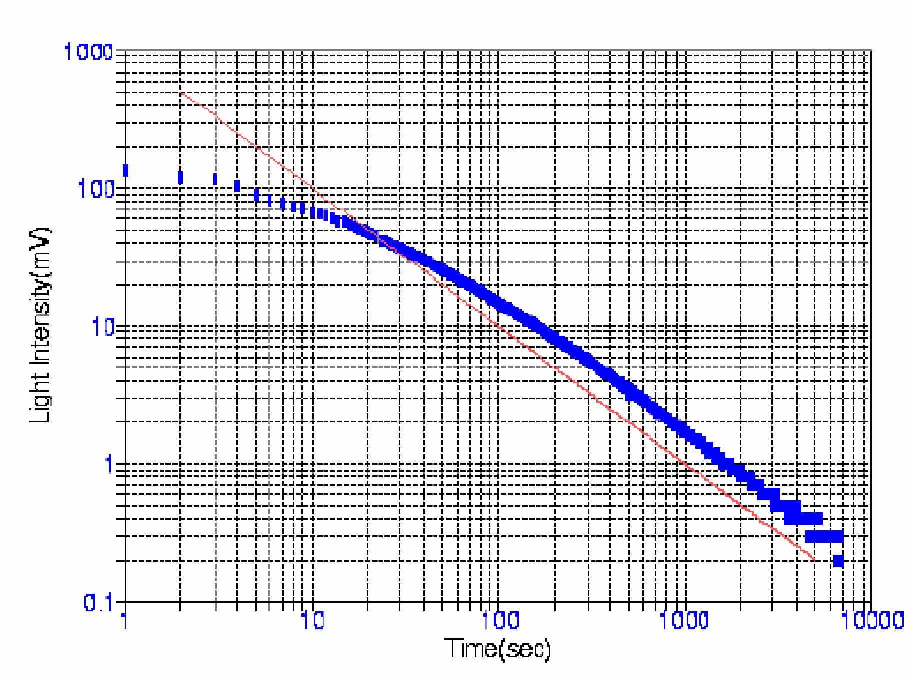

Fig. 1. Light decay curve for a sample of a commercial ‘glow-in-the-dark’ (SRA) material. The >6000 solid points (blue) are light intensity readings at 1-second intervals. The red line with slope -1 illustrates a power law of the form $I \sim t^{(-1)}$.

Our expectation was that the light decay curve would be exponential in form, and thus characterized by a ‘half-life.’ Such data, when plotted on a semi-log plot, would appear as a straight line. Much to our surprise, when we plotted the two hours of useful data obtained we did not obtain a straight line at all! By chance the data were then plotted on a full log-log plot, and this revealed the astounding result shown above. The recorded light intensity drops relatively slowly at first, but at a gradually increasing rate. Then from about 100 seconds on the intensity I drops steadily in inverse proportion to the elapsed time, $I \sim t^{(-1)}$. This type of behavior is known as a ‘power law’ (the exponent can be any constant) and turns out to be quite common in nature and statistics [9]. Familiar examples from physics are the inverse-square law for optical radiation or gravitation, and the `1/f law’ that describes the intensity distribution of random noise. It was a surprise to learn that power laws also describe seemingly-unrelated phenomena such as the frequency of occurrence of words in a book (Zipf’s law).

While this project went on for more than a full semester the key result (the figure above) came early on and many questions (such as how the decay curve varies with temperature) were left unexplored. We were however able to confirm by more sensitive measurements that the power law decay continues for at least ten hours. We also learned from reading and conversations with others that delayed light emissions arise from triplet spin states, and that a random distribution of the triplet state lifetimes can explain the power law behavior of the composite decay curve.

2.2 Multiple reflections in a decorative lamp

A decorative glass candle lamp with interesting optical properties was the topic of two similar but independent student projects five years apart. The lamp was a table decoration at a local Indian restaurant [10], which was happy to donate one to our lab. The flame in the candle lamp is surrounded by four tinted glass panels whose inside surfaces have a partially reflective coating; these panels are arranged in the form of a rectangular prism, with opposite faces parallel to each other. When the flame is viewed from outside the lamp at eye level a sequence of flame images of gradually diminishing luminosity is seen. These are clearly due to multiple reflections and 12 or more images can be counted in a darkened room (see figure below). The goal of the measurements and analysis performed was to determine the relative luminosity of the images. This is interesting in part because the luminosity ratio between the first image and the last visible image is a direct measure of the visual sensitivity range of the eye.

Fig. 2. Multiple reflections of the flame in a decorative lamp. The eye can perceive several even weaker reflections that the camera can't register.

After seeing a demonstration of the lamp Victoria Bonvento (WISE program, 2001) decided to study it for her project. She found the 'one way mirror' aspect of the lamp's metallized partially-reflecting surfaces especially appealing [11]. Hamsa Sridhar, a sophomore high school student, returned to this topic in spring 2006 for her initial research experience in optics. She was not aware of the earlier project at the time and made an independent and more complete analysis based on new and more careful measurements [12].

Victoria and I soon realized that the high reflectivity surface was the inner one, and that the luminosity ratio between successive images was simply equal to the reflectance r of this surface. We measured r directly by reflecting a HeNe laser beam against the inner surface on to a photodetector. While this direct method involved little analysis the geometry was awkward and our result r = 36 ± 4 % had a relatively large uncertainty.

The subsequent experiments with Hamsa involved more analysis but gave more information and a more certain result for r by two different methods. Since Hamsa was quite comfortable with math, but had not yet studied physics or optics, this was a pedagogically quite appropriate project for her. In the first experiment the He-Ne beam was directed toward the glass lamp from the outside at a slight angle. Using a photodetector, the intensity of the initial beam and the three beams that either reflected from one of the two surfaces of one glass panel, or passed completely through it, were measured. These values were analyzed through a series of equations to obtain the reflectance values of the inner and outer surfaces and the absorption in the tinted glass between. In the second experiment, the laser beam was allowed to travel through the glass lamp to a screen. Five spots of decreasing intensity were visible when the lamp was rotated slightly; they were consecutively isolated by an iris and their relative intensities measured using the photodetector. In this case the ratio between the spot intensities is r^2, and this value could be accurately determined by a graphical analysis, as shown in the figure below.

The reflectance results from the two experiments were in good agreement and we took their average, 43.0 ± 0.5 % as the final result. It follows that the nth visible image must be $(0.43)^{(n-1)}$ times as bright as the first (unreflected) image, or 1/4,627 times as bright for n = 11. Thus the human eye can perceive an intensity range of about 5,000 – 10,000 at a single instant. (The eye can of course adapt to a much wider brightness range given time to adjust.)

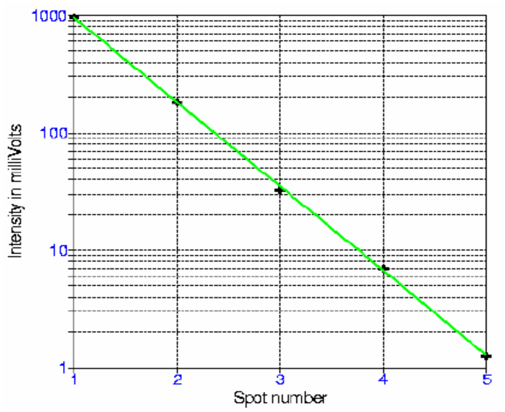

Fig. 3. Measurements and analysis on multiple reflections in the decorative lamp [12]. Left: measured intensities of multiply reflected laser beams. Right: predicted relative luminosity of the flame images.

2.3 Frequency response of the eye

The creative aspect of Meruba Anwar's project [13] derived from her strong native curiosity and ability as an observer. This was a short project for the WISE Introduction to Research course, about a third of a semester. The actual observations took just an afternoon or two, while learning html and writing a web report took a few days longer. Unlike Jill Chen (Section 2.1 above) Meruba struggled at first to find a suitable topic. I encouraged her to just pay attention to things around her that she was curious about and that seemed interesting. After several weeks she reported that while shopping at the mall that weekend she'd seen an unusual clock in which numbers and letters appeared to float in space [14]. She soon learned that the operating principle of the clock is the persistence of vision effect. By chance Meruba had stumbled upon a topic that was an excellent match to her interest in neuroscience.

I gave Meruba an assortment of LED's (purchased from the local Radio Shack store) and set up a square-wave generator to pulse them at any desired frequency. My intention was for her to explore how the threshold for visually detecting flicker (the Critical Fusion Frequency or CFF) depends on parameters such as the LED brightness and color [15]. After a few hours of investigation Meruba reported with great excitement an observation that was obvious in retrospect but which neither of us had anticipated – the threshold for detecting flickering depends significantly on whether one is looking directly at the LED (direct vision) or looking to the side (peripheral vision). By chance Meruba had discovered an essential feature of vision, the two types of cells (rods and cones) in the retina! An understanding developed in this way through self-discovery will certainly endure. Meruba went on to carefully record a variety of CFF observations and write an excellent web report that includes these [13].

Fig. 4. Demonstrating the principle of the Fantezein clock.

2.4 A variable water drop lens

Scott Huang was a high school student in summer 2006 [16]. After some exploration of possible project topics he developed an interest in techniques or devices that measure or correct for wavefront aberrations, and we worked together to find a project related to this interest. One such device, the Shack-Hartmann wavefront sensor, is based on an array of small lenses ('lenslets') that create a corresponding array of focal spots on a CCD-detector. While discussing this idea I showed Scott an image I knew of that depicted droplets of water trapped in the openings of a window screen (see figure below). We considered making a lenslet array of fluid droplets, but it was soon evident that it would be difficult to make the lenses sufficiently small and uniform enough to create a useful lenslet array. While playing with water-drop lenses Scott happened to place a droplet of water into the opening of an iris diaphragm, a common object in our lab. He was fascinated by the way the focal properties of the lens could be varied simply by varying the opening, and decided to investigate this 'variable water-drop lens.' Scott soon learned that variable fluid lenses are a topic of considerable recent interest, with important potential applications [18].

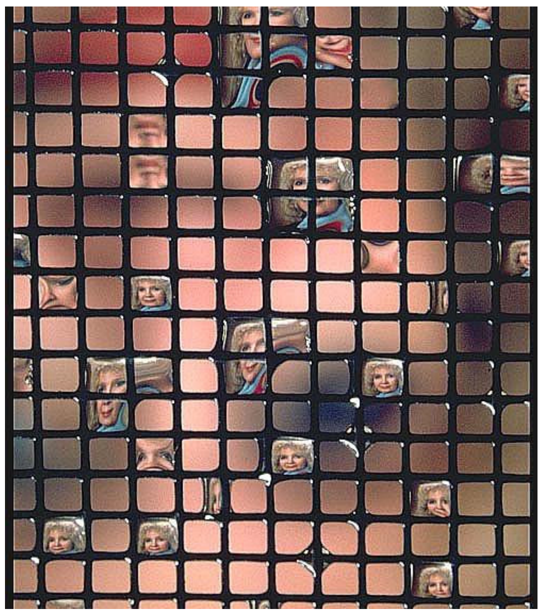

Fig. 5. Face viewed through water drop lenses in a screen [17].

Using a simple setup he devised, Scott measured the focal length of various water-drop lenses. These varied over a wide range (5 to 80 mm) as the droplet diameter varied from about 3 to 8 mm, and the droplet deviated more and more from a spherical shape [16]. Scott also made a simple microscope from the water-drop lens and recorded the image below and others with our Electrim 1000N CCD detector [1].

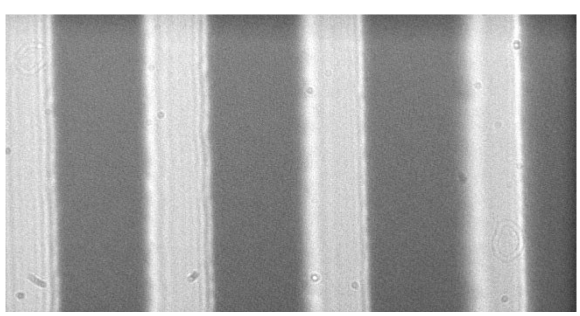

Fig. 6. Partial image of a Ronchi grating (pitch 150 μm) recorded through the water drop lens.

2.5 Color patterns in soap films

My student partner in this project, Eric Tompkins, was just completing an MAT (Master of Arts in Teaching) program at Stony Brook to be certified as a high school physics teacher [19]. He needed a course credit to complete his degree and so undertook a semester-long project. Eric and I started by looking at various simple demonstrations of optical phenomena. One of these was the demonstration of colors in soap bubble films illustrated in Figure 7 below. The small bottle holds a mixture of roughly of equal parts water, glycerin, and Dawn dishwasher detergent. (The bottle originally held the glycerin.) When the bottle is tipped over with its cap in place, and the cap is then removed, a soap film can be seen across the mouth of the bottle. If the bottle is held in a nearly horizontal position as shown for a few minutes the film is affected by gravity and develops a distinct black band at the top. In a location free of air currents a white area and horizontal colored bands form below this. The colors on the soap film are most distinct in an area well lit by diffuse bright light, preferably indirect sunlight. Coincidentally, the opaque container does more than provide a convenient way of creating the film – it keeps the back side of the film in darkness and thus allows the black area to show up distinctly.

Fig. 7. Interference patterns of reflected light in soap films. Note the 'black' film at the top, and the white area and horizontal colored bands in the right-most picture.

Eric was familiar with the way soap film colors arise from interference of light, but he had never seen a black soap film before. It was apparent to him immediately that this effect and the horizontal colored lines must be somehow related to the way film thickness must vary due to gravity, with the thinnest film at the top. We decided to focus the project on developing a mathematical model of the way the film colors vary with thickness. As described in Eric's research journal and report [19], the key concept is that a 180° phase shift occurs at the front surface of the film but not at the rear. Light reflected from the rear surface is however phase-shifted by its passage (twice) across the film. If the film is very thin, much thinner than a wavelength of light, the latter phase shift is negligible and one has purely destructive interference. To quantify this Eric derived an expression for the intensity of the reflected light, which was in turn used to create the graphs of intensity versus wavelength or film thickness shown in these figures.

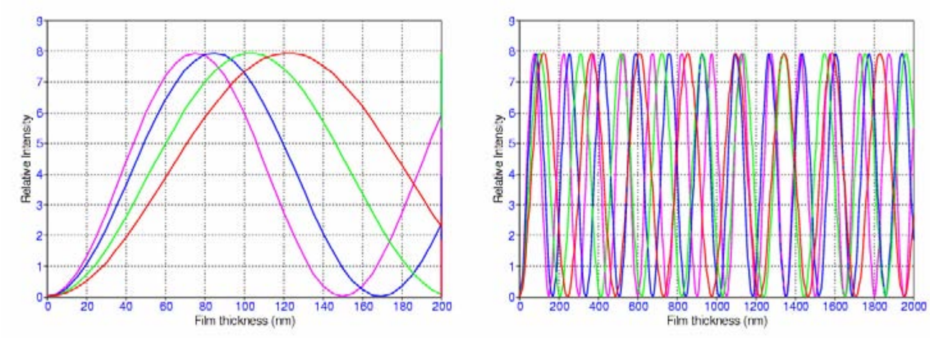

Fig. 8a. Calculated relative intensities of four colors (violet, blue, green and red) as a function of soap film thickness [19]. The plot at the left is just an enlarged view of the one at the right. It is apparent that the black soap film must be no more than about 10 nm thick. The fact that intensities for all colors peak around 90 nm explains the white region below the black band. Using these predictions reflectance measurements for monochromatic light could be used to map the film thickness as a function of position.

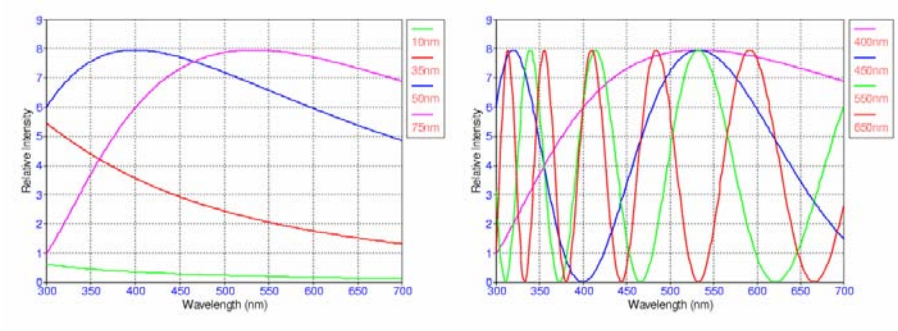

Fig. 8b. Calculated relative intensities of reflected light as a function of wavelength, for eight different film thicknesses. Note that the colors of the lines in this case relate to thickness, not wavelength. These predictions could be compared to spectrometer measurements of reflected white light to uniquely determine the film thickness.

2.6 Point spread function (PSF) of a consumer CCD camera

Marissa MacDonald (WISE program, 2007) carried out the first astronomy-related student project in the LTC [20]. It was one of several projects over the last decade that utilized the lab's simple Sony Mavica FD73 camera as a quantitative tool, not just for documentation. An important concept in observational astronomy is the point spread function or PSF. This can be described as the response of an imaging system to the light from a point source such as a star. The figure below shows the setup we used to create and photograph a simulated star. The angular size of the pinhole at the camera (2.2 arc seconds) was not nearly as small as even the 'largest' star Betelgeuse (0.045 arcsec), but it was comparable to the diffraction limit of the camera and therefore adequate.

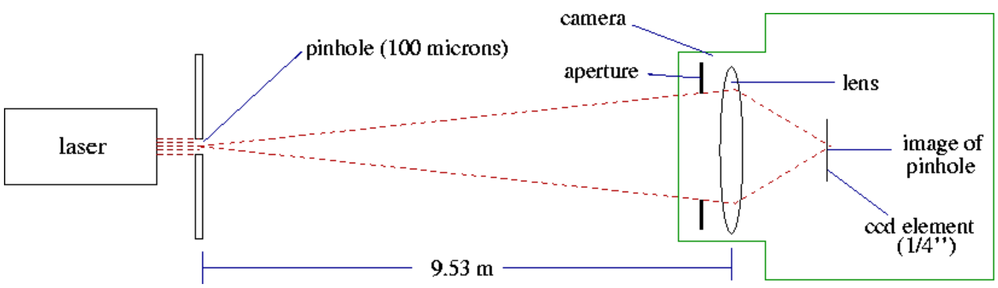

Fig. 9. Setup for the point spread function experiment.

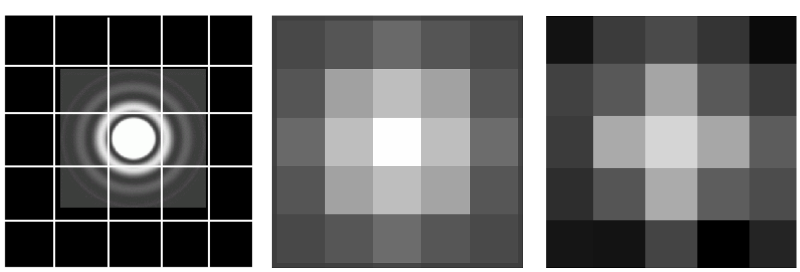

Fig. 10. Simulated (left and center) and observed (right) PSFs for the Mavica camera. The image at the far left shows the predicted Airy pattern corresponding to the camera's aperture superimposed on a grid of 5.6 μm square camera pixels. In the center image the same Airy pattern has been 'pixelated' in the xv program. Far right, the observed PSF is compact and comparable in size to the diffraction limited spot.

2.7 Noise cancellation and the velocity of sound

Yu Fen (Jen) Hwang (freshman WISE course, 2004) was inspired to this project by late-night noise in her dorm room [21]. She had seen my demonstration of two tuning forks 'beating' against one another, and thus knew that one sound could cancel another. She wondered whether arbitrary sounds could be canceled in a similar way. (Jen was not aware at the time that noise cancellation was already an off-the-shelf consumer technology.) An important consideration in noise cancellation is the wavelength of sound. We decided to try to visualize the wave properties of sound with a small handheld loudspeaker and microphone. A 2.00 kHz sine wave was fed to the loudspeaker and also to one channel of our dual-channel oscilloscope, which controlled the oscilloscope trigger. The microphone signal was fed into the second channel. Figure 11 below shows 9 consecutive images recorded over 3 seconds as the microphone and speaker were steadily moved apart. The phase shift of the received wave (fuzzier trace) is apparent, as well as its diminishing intensity. After this we established the distance corresponding to a 2π phase shift as 17.8 ± 0.5 cm. This wavelength value together with the known frequency implies a sound velocity of 356 m/s, in good agreement with the accepted value at 25 C. Even more interesting was the result when both loudspeaker and microphone were pointed at the adjacent wall. Now moving the microphone caused no phase shift, but did cause a periodic intensity modulation. We had inadvertently created a standing wave! All in all, this simple impromptu project, which took just part of an afternoon, was quite successful at making sound waves a familiar entity.

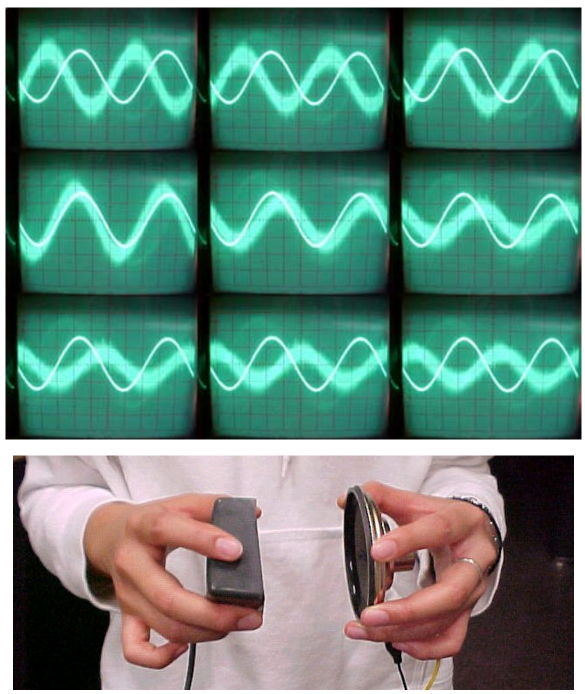

Fig. 11. Demonstrating the wavelength of sound (see text).

2.8 Nanometer motion control with a rubber band

The most creative aspect of Jon Wu's project [22] was a very simple yet quite effective technique for ultra-high-resolution motion control in a scanning optical interferometer. The path that led to this novel development was long and complicated. Jon was a high school participant in our 2004 full-time summer program. He expressed an interest in medical optics, so we looked at possible project ideas in this area. After considering various possibilities we focused on optical-coherence tomography (OCT), a technique for achieving micron-scale depth resolution within turbid media such as tissue by utilizing the limited coherence length of an broadband light source [23]. The idea gradually emerged of demonstrating the concept of OCT by observing interference fringe visibility as a function of path length difference. Similar to Fourier Transform Spectroscopy (FTS) the interferogram contains information on the wavelength components (spectrum) of the light, or in this case the spectral width of the broadband light source.

It was soon apparent from preliminary experiments in an interferometer that Jon put together that the challenge of the project was to achieve sub-micron resolution in the mirror movement over a range of thousands of fringes. (The difficulty of doing this is why FTS is rarely done at wavelengths shorter than the IR.) Jon experimented for some time with levers and the like that would scale down the motion of the mechanical translators available to us, which are graduated in relatively coarse 25.4 micron steps. His devices worked but were plagued with mechanical noise and backlash. While pondering these difficulties the idea came up of simply pulling on the mirror mount in a controlled way to gently deflect it . When an ordinary rubber band was used as the coupling device the result was amazingly successful (Figs. 12 & 13). Of course the range of mirror motion is quite limited, but the precise motion control provided by this simple trick has proven very useful for demonstrations and some other experiments.

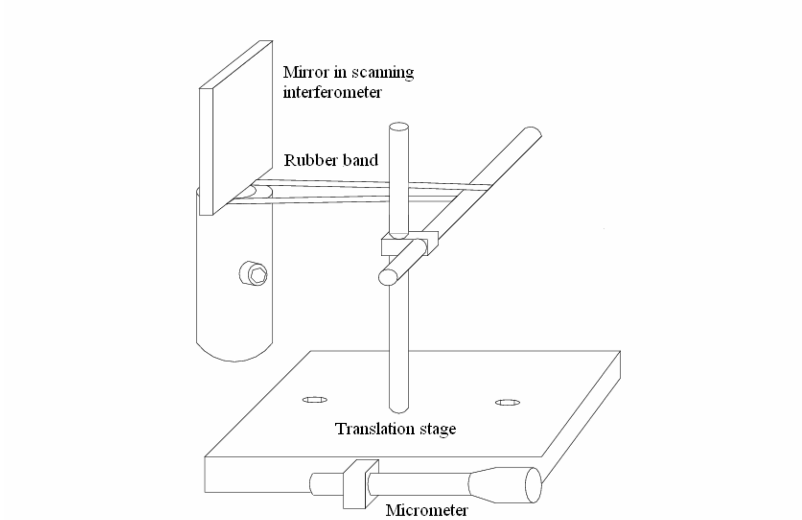

Fig. 12. A rubber band attached to the 25.4 mm translation stage pulls on the Thorlabs mirror mount to create reproducible nanometer-scale deflections.

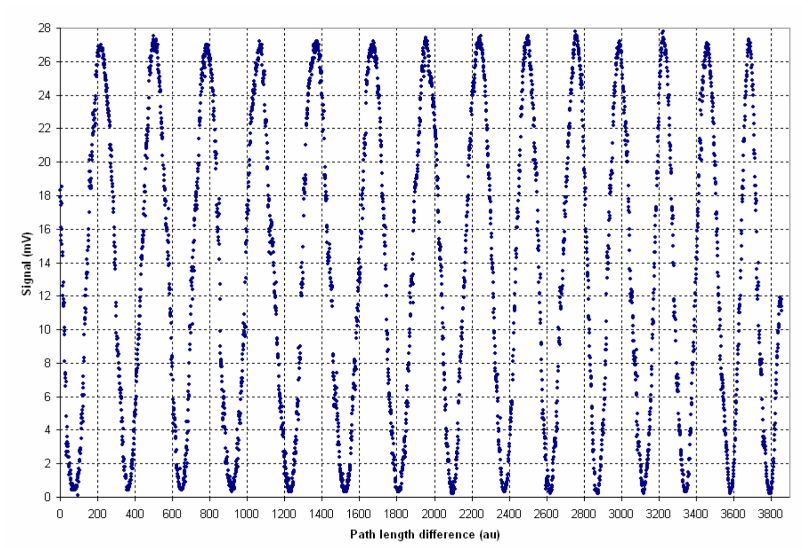

Fig. 13. Interference fringes from a HeNe laser recorded with the rubber-band translator as the micrometer was turned by a stepping motor. The step size is approximately 1.2 nm.

3. Conclusion

The response of the many students involved in these projects has been overwhelmingly positive, and the creative educational approach illustrated here has been enthusiastically endorsed by our university and many visitors. A great deal of time and effort is required to work individually with each student, but the resulting projects and educational experiences are often quite original and invariably of significant and lasting value.

Acknowledgments

I deeply appreciate the willingness of my students to collaborate with me so enthusiastically on the projects described in this paper and many others. I would also like to thank the many companies and individuals who provided information, materials and assistance in support of the projects. This work was supported in part by the Women in Science and Engineering program and the Department of Physics and Astronomy at Stony Brook.

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I.

Introducing and Engaging Diverse High School Students to Biophotonics Through Multi-Year Courses

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Abstract: The National Science Foundation (NSF) funded Center for Biophotonics Science and Technology (CBST) has created various high school biophotonics research academies for both students and teachers from diverse socioeconomic backgrounds. These academies engage diverse students for 10 hours to over 350 hours per year for multiple years with an emphasis on learning the basics of biophotonics and then conducting original, team-based research. We have developed three versions of the academy, one focused on biology and biophotonics, one on cancer and biophotonics, and a third on plants and biophotonics. A fourth emphasis on biomedical engineering and biophotonics is planned. We have conducted one of these academies for three years and have had very good student retention and science fair winners. As part of our program we also have a summer academy for training teachers. Challenges have arisen amongst the various levels of Academies, chief among them sustainability. In the future, more extensive evaluation, curriculum consolidation, and widespread dissemination are critical.

1. Introduction

The Education and Human Resources Program of the Center for Biophotonics Science and Technology (CBST) is committed to the goal of increasing the quality and quantity of science education experiences available to a diverse population of students, educators, and the public. We are accomplishing this by developing and implementing an innovative program that establishes pathways to careers in the emerging field of biophotonics. Applications of biophotonics range from using light to image or selectively treat tumors, to sequencing DNA and identifying single biomolecules within cells.[1] The CBST educational program is a comprehensive educational package that links *"the learning years to the earning years."*

The inauguration of the Science and Technology Center (STC) program at the National Science Foundation in 1987 represented a fundamental shift in scientific funding policy in the United States,[2] viz., a move from individual principal investigators to large, multi-investigator, multi-institutional centers. Well established by 2002, the STC program added six new centers, including CBST for which the University of California, Davis was the lead campus. Partner institutions include Lawrence Livermore National Laboratory, UC Berkeley, UC San Francisco, Alabama A&M University, Stanford University, University of Texas at San Antonio, Fisk University and Mills College. Roughly 100 researchers, including physical scientists, life scientists, physicians and engineers, are collaborating in this rapidly developing area of research.

CBST is now nearing the end of its fifth year of operation. Science and Technology Centers have typically operated for a ten-year period. Although the earliest STC's have now finished their NSF funding cycles, many have been institutionalized as permanent research centers. There are currently 17 STC's funded by NSF. A benefit of the community of STC's is networking and collaboration among different centers. The Center for Adaptive Optics, started in 2000 and headquartered at the University of California, Santa Cruz, has been an especially useful collaboration for CBST. Similarly, the annual meeting of the NSF Research Center Educators Network (NRCEN), a gathering of educational specialists from the various STC's and similar NSF-funded centers such as Engineering Research Centers

(ERC) and Materials Research Science and Engineering Centers (MRSEC), is a highly effective forum for sharing best practices for educational programs.

CBST currently provides educational opportunities from a middle school summer camp to advanced graduate courses. Pre-college courses tend to provide a stimulating access to the sciences (evenly balanced between the physical and biological sciences) while undergraduate courses provide a general introduction to the field of biophotonics and graduate courses give advanced training in specific topics within the field. This paper focuses on the CBST efforts with the high school audience, students ages 14-18 and their teachers, that have been carried out since Center inception.

2. Program Description

The High School Biophotonics Research Academy (HSRAB) is a high school enrichment program that demonstrates the relevance of Biophotonics in medicine, industry, and research and that challenges students' ideas about careers in science. This program engages students in inquiry-oriented activities and research projects. The curriculum is steered by emerging conceptual models of biophotonics, emphasizes information technology, scientific inquiry and biology/physics/chemistry concepts through studying the applied field of Biophotonics. Program designs from simplest to most involved include (1) integration as a module or unit into an existing course; (2) 200+ hour/year after school programs; (3) in school elective courses and/or college preparatory laboratory courses. Over thirty, 1 to 10 hour long, activities have been created through collaborations between CBST education and research staff and local high school teachers since program inception. These activities come in several variations depending on the particular focus of the HSRAB implementation. In the last three years there have been HSRAB implementations focused on biophotonics, plant biology and biophotonics, and cancer science and biophotonics. In the coming years, a biomedical engineering focused set of activities/curriculum is planned.

2.1. Program Design 1: Integration as Modules

By far the simplest manner in which biophotonics has been included in high school curricula has been through interested teachers incorporating one or more activities into an existing biology or physics course. As teachers complete the first two levels of the CBST Summer Biophotonics Research Academy Professional Development series (Level I – 3 days, Level II – 5 days) they are given copies of our basic biophotonics activities and are automatically eligible to check out specialized equipment. This equipment includes items such as: pulse oxymeters, lasers, light sources, basic USB microscopes, PASCO GLX data loggers, and Ocean Optics Fiber-based spectrophotometers. Most often the teachers report back using 3 to 4 activities which they modify to fit on-site needs. The activities have been incorporated as 1-2 week units in a course, as a "Science Friday" set of activities during a semester, and as the last 2-3 weeks of a school year once the Advanced Placement (AP) exams have been completed (for advanced placement biology usually mid May).

Fig. 1. Teachers attending the Level I and II training workshops at CBST in Sacramento.

2.2. Program Design 2: After-School Elective

The after-school elective design was the first design implemented back in 2004 at Center High School in Antelope, California, just north of Sacramento. A competitive application process targets highly motivated and responsible students but de-emphasizes their grades as long as it is above a “C”. The Center High School population is highly diverse and socioeconomically disadvantaged. Many students attending the school need to supplement their family’s income through after-school work. To attract these students to the program, a basic stipend for their participation is offered. The lead teacher, a 20+ year veteran of high school biology teaching, runs the program that regularly meets from 5-7:30 pm, 2 days a week. He is assisted by CBST education staff on a weekly basis and conducts various hands-on activities and field-trips. Three undergraduate students from UC Davis also participate as student mentors starting in the second semester. The mentors act as role models and help student teams with their individual research projects.

Fig. 2. Center High School students engaged in research and visiting CBST headquarters.

During the first year of this 200+ hour academy, students (1) engage in inquiry-oriented activities; (2) work in small research teams to design a systematic Biophotonics investigation; and (3) are introduced to research and industry opportunities through field-study trips and interaction with CBST research scientists. The year culminates with a research symposium. Students who successfully completed the first year are eligible to continue their study for a second year during which they can continue their research and prepare a competitive biophotonics science fair project. After the second year, they may also apply for internships as they become available.

In the last two years, numerous second year Academy students (Associates) successfully competed in regional science fairs. In 2006, six students competed in the Sacramento Regional Science and Engineering Fair and won first and second place in the team science event, three went on to compete in the California State Science Fair. In 2007, two teams won awards at the Sacramento Science and Engineering Fair; first place in the Molecular and Cellular Biology Category, and an award from the Society for In-Vitro Biologists. These student research teams were supported by four undergraduate mentors, three of which have mentored for over 2 years.

Fig. 3. Two teams of Center High School winners from the Sacramento Regional Science and Engineering Fair.

2.3. Program Design 3: Multi-Year Course

The year-round elective course was first attempted in the 2005-2006 school year at East Oakland Community High School (EOCHS, a community charter school). EOCHS is a school serving a primarily underrepresented population in the inner city. Local CBST researcher, Susan Spiller, from Mills College, along with several of her post-baccalaureate students have acted, and continue to act as program mentors working in collaboration with the current science teacher at the school. The Academy focuses on biophotonics and plants, reflecting the expertise of Susan Spiller and matching with the school focus on community and environment. Due to heavy teacher turnover and the 90 mile distance to the CBST main headquarters, the program is having some difficulties becoming fully established. Pictured at right is mentor Stephanie Lane working in the laboratory with one of the students in the course.

In an effort to establish a more local, multi-year course, a partnership with the UC Davis Cancer Center and the local St. Hope Academy at inner city Sacramento High School was developed. The resulting program, the CURE High School Research Academy, is funded through a combination of CBST funds and the "P30 Supplement" to the UC Davis Cancer Center NIH Grant. Per the "P30 Supplement" grant, the aims of the CURE program are to: (1) offer a two-year cancer science curriculum consisting of didactic and experiential learning in basic, clinical and population sciences for three successive cohorts of 20 high school students from Sacramento High School; (2) attract, recruit and enroll these students during the second semester of their ninth or tenth grade; (3) document and measure progress; (4) help prepare these students for entry into four-year institutions with a greater aptitude for and probability of selecting cancer-relevant majors; (5) track and longitudinally report the achievements of CURE students and alumni; and (6) document and disseminate lessons learned.

Figure 4: CURE students engaged in various basic biophotonics and biology laboratory experiments.

The CURE Academy is implemented as a regular science course offering at the Science, Math, Engineering and Health Academy at Sacramento High School, a St. Hope Academy Public Charter school. To ensure that the courses have relevance in college applications, we have applied for approval of the CURE course to be an A-G college preparatory laboratory science course. A-G approval would show University of California recognition of the biophotonics course as fulfilling the laboratory requirement for students applying for University of California admittance. During spring, 2006, 20 students were selected from a pool of 30 applicants through competitive application reviews and interviews. All 20 students selected for the first student cohort participated in the first semester of the program; however, two left the program during the second semester (one because she moved, and the other because he was unable to fulfill the requirements and expectations of the program). Thus, 18 students completed the first year of CURE (15 from underrepresented groups as defined by the National Science Foundation). The average cumulative GPA of the cohort is 3.43.

The lead teacher for the CURE program is Angela Jones, a UCD graduate who worked for four years as a laboratory assistant at the Cancer Center. The curriculum emphasis during the first year was basic science, see Table 1. The basic science faculty team included Drs. Marco Molinaro, Ana Corbacho, Pam Castori, and Frank Chuang. This first cohort spent 270 hours of classroom instruction (a class period is 90 minutes long and there are 180 days of instruction); they spent at least 40 hours participating in after school laboratory and field trip experiences, another 6 hours in a summer orientation, and will spend 80 hours in their first summer research experience (June 4 – 21). Total learning time for Cohort I of Year I of the CURE program is estimated to be 396 hours, a substantial commitment by both students and faculty. Of this time, approximately 40% is didactic teaching and 60% is hands-on laboratory activity.

	Year 1 Modules	**Topics**
Basic Science	**Module 1**: Introduction to Cancer Biology, Biophotonics, Scientific Investigation, Information Technologies	What is cancer? What technologies are useful in studying cancer? How does cancer science happen? What kinds of work do cancer scientists do? What tools, techniques, and skills will we use to study cancer?
	Module II: Experiences in Light Basics for Biophtonics	electromagnetic spectrum, nature of light, light and color, absorption, transmission, reflection, optics, light sources, light/tissue interaction, spectroscopy
	Module III: Experiences in Biology Basics for Oncology	cell biology, gene expression, cell cycle, cellular differentiation, cell signaling, life and death of a cell, cancer biomedicine, causes of cancer, diagnosis, treatment, goals in cancer medicine
Clinical Science	**Module IV:** Cancer detection, diagnosis and treatment using Biophotonics:	optical methods, tumor imaging, photodynamic therapies, image-guided surgery, cell and bacteria diagnostics, non-invasive optical diagnostics, confocal laser scanning techniques
	Year 2 Modules	**Topics**
Basic Science	**Module I:** Molecular and Cell Biology of Cancer (Basic cancer science)	Characteristics of cancer, understanding cancer as a disease, classification, diagnostic procedures, carcinogenesis, cellular differentiation and progressions of malignant behavior, oncogenes, cell cycle regulators, gene transcription/transduction, cancer therapies
Clinical Science	**Module II:** Clinical Science	Cancer diagnosis and treatment: cancer of different tissues (e.g. lung, breast, prostate, skin, blood, etc.), cancer typing and staging, clinical tests, radiological imaging, surgical biopsy, treatments (surgery, radiation and chemotherapy); life as an MD, clinical duties, careers in clinical cancer science
Population Science	**Module III**: Population Science	Cancer prevention and control in human populations: role and controversies associated with nutrition and obesity; health communication and consumer health education, environmental influences, cancer screening, role of culture and behavior, and research topics.
	Module IV: Lab skills for Cancer Science (INTEGRATED INTO OTHER MODULES)	gel electrophoresis, PCR, microscopy, spectroscopy, advanced imaging techniques, bioinformatics

Table. 1. High School Biophotonics Research Academy Biophotonics and Cancer Science Curriculum.

3. Program Assessment and Evaluation

The High School Research Academy in Biophotonics, no matter which program design is utilized, involves substantial effort from students, educators, and researchers, as well as substantial financial resources that increase based on design complexity. In an effort to improve the program and provide concrete data as to its effectiveness, a substantial evaluation effort has been undertaken at the formative and summative levels. The various instruments created for the purpose of assessing student gains in a pre/post fashion are listed in Table 2 below.

Partial evaluation outcomes from the last 2 years indicate (1) significant changes in students' understanding of the processes, skills and values of science; (2) significant change in students' understanding of the discipline of biophotonics; (3) changes in students' course choices for math/science (increase in AP course choices); and (4) change in students' interests in pursuing STEM-related majors and careers. More extensive data collection and analysis efforts are currently underway.

CBST Education Evaluation Efforts		
Program Domains	**Area of Assessment**	**Instruments***
HS Research Academy: Students	Knowledge of Biophotonics Concepts and Scientific Inquiry Creativity/Scientific Inquiry Skills Attitudes about science, scientists, scientific careers, and self as a scientist	• CBST SciInquiry • CBST BPConcepts • CBST SciAttitudes • CBST SICA • CBST Q-sort • CARS survey • Whiteboard and journal data • Interviews • Inquiry assessment (Hot House) • final research reports and PPT presentations • CBST PERC
HS Research Academy: Teachers	Knowledge of Biophotonics Concepts	• CBST BPConcepts • CBST PERC • Teacher lessons or units

*Participation numbers and demographics, continued participation over time, educational choices, and career choices, are followed throughout our program domains by use of our participant database which is constantly being improved to provide data of higher impact and analyses of the information.

ABBREVIATIONS

CBST BPConcepts = Knowledge of Biophotonics Concepts
CBST SciInquiry = Meta - Knowledge of Scientific Inquiry Concepts
CBST SICA (Science Inquiry and Creativity Assessment) = Performance of Scientific Inquiry Skills
CBST SciAttitudes = Attitudes about Science, Scientists, Scientific Careers, Science Education, and Self as a Scientist
CBST PERC = Participant Event Report Card
CBST Q-Sort = Process of Science card sort

Table. 2. High School Biophotonics Research Academy Evaluation Efforts and Instruments.

4. Program Challenges and Surprises

In the last three years of working with the High School Research Academy in Biophotonics design, various challenges and surprises have arisen. A few of the main challenges and surprises are presented here in bulleted form.

- Teacher experience and turnover –Many schools in the United States are undergoing frequent teacher turnover as more capable teachers seek better opportunities in wealthier districts. In poorer, inner city districts, younger, less experienced teachers appear to be the norm. Starting teachers usually bring with them high motivation but lack experience in maintaining classroom discipline, a substantial drawback in a team-based, less structured, non-rote based experiences such as that presented by the Biophotonics Academy.
- Large support structure needed – To successfully engage high school students in doing authentic research related

to biophotonics requires a substantial and diverse team. The teacher involved has to be open to being less of a "sage on the stage" and more of a "guide on the side" and be willing to take risks in an area of expertise usually foreign to them. Researchers with an educational background or interest need to be present to provide a real connection to the current research, acting both as an expert in the topic and an open and willing communicator that is able to simplify very complex ideas. More often than not the last role mentioned is fulfilled by 2 or more persons, usually a scientist turned educator acts as a translator for one or more researchers. Undergraduate mentors act as a very helpful, and less formal, bridge between the world of high school and that of university, especially when the student population is from a disadvantaged socioeconomic background and has little to no experience with the collegiate world. Lastly, a willing principal and school administration needs to understand the value of the program and support out of class activities such as field-trips and visits to laboratories for more extensive research experiences.

- <u>The course or courses need to matter academically</u> – Biophotonics Academies can be the equivalent of two full courses plus require substantial time outside of the classroom and in the summer. In all cases when a student choses biophotonics they are having to remove another class from their schedule. While we all tend to believe that experiential learning and authentic research are invaluable experiences, the students still need to graduate on time and be on track for college/university admission. Making the experience count towards college entrance can be the critical factor for making the experience sufficiently valuable academically. This also means that the course needs to be rigorous and contain enough assessments to accurately reflect the students' performances.
- <u>Long term sustainability</u> – While our programs are not yet self sustained it is clear that substantial funding and training over several years are needed to have a chance at sustainability. Simpler program designs such as the in-course modules are likely much easier to sustain but a range of levels will hopefully lead to the greatest student exposure over time.

5. Future Plans and Conclusions

We are intending to continue the high school program at various local high schools for as long as possible. Current focus is on long-term sustainability. No new full year commitments with new high schools are added unless they come with the funds necessary to fund CBST educational staff (part-time), teacher development time, and base equipment for multiple years. Towards that end, in Fall 2006, a grant proposal was submitted to the Howard Hughes Medical Association for a HSRAB program with an emphasis in Biomedical Sciences to be created in collaboration with the West Sacramento School District/River City High School. This proposal would fund the training of middle and high school teachers to implement program designs 1 and 3 (in-course modules and full courses) over the span of 5 years with equipment funds to create stations to support up to two simultaneous classes. The equipment envisioned, an upgrade to the CBST teacher kit mentioned in Section 2.1, would serve the school in biophotonics related experiments that could arise in biophotonics, biology, chemistry, environmental science, and physics related classes. Our long term hope is that by incorporating biophotonics concepts and techniques throughout the science curriculum, many more students can enter college and university better prepared to comprehend and conduct research in biophotonics and science in general.

6. ACKNOWLEDGEMENTS

The Center for Biophotonics Science and Technology (CBST) is funded by the National Science Foundation and is managed by the University of California, Davis under Cooperative Agreement No. PHY 0120999.
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II.

Integrating Nanophotonic Concepts and Topics into Optics Curricula

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Abstract: Nanophotonics has emerged as a new and important field of study, not only in research, but also in undergraduate optics and photonics education and training. Beyond the study of classical and quantum optics, it is important for students to learn about how the flow of light can be manipulated on a nanoscale level, and used in applications such as telecommunications, imaging, and medicine. This paper reports on our work to integrate basic nanophotonic concepts and topics into existing optics and optical electronics courses, as well as independent study projects, at the undergraduate level. Through classroom lectures, topical readings, computer modeling exercises, and laboratory experiments, students are introduced to nanophotonic concepts subsequent to a study of physical and geometrical optics. A compare and contrast methodology is employed to help students identify similarities and differences that exist in the optical behavior of bulk and nanostructured media. Training is further developed through engineering design and simulation exercises that use advanced, vector-diffraction-based, modeling software for simulating the performance of various materials and structures. To date, the addition of a nanophotonics component to the optics curriculum has proven successful, been enthusiastically received by students, and should serve as a basis for further course development efforts that emphasize the combined capabilities of nanotechnology and photonics.

OCIS codes: (000.2060) Education, (999.9999) Nanophotonics, (160.0160) Materials, (290.0270) Scattering, (050.0050) Diffraction and gratings, (060.0060) Fiber optics, (300.0300) Spectroscopy.

1. Introduction

In recent years, education in nanotechnology [1] has accelerated, in part, due to the creation of programs such as the National Nanotechnology Initiative (NNI) that have promoted and supported research and development in this area. Nanophotonics [2,3], which combines the capabilities of nanoscience and technology with photonics [4], has emerged as a new and important field of study in its own right, encompassing the study of new optical interactions, materials, fabrication techniques, and architectures, including the exploration of natural and synthetic, or artificially engineered, structures [5] such as photonic crystals [6], holey fibers [7], quantum dots [8], sub-wavelength structures [9,10], and plasmonics. With these developments come new and exciting opportunities for students at the undergraduate level to learn about how the flow of light can be manipulated on a nanoscale level, and used in critical applications that range from telecommunications and imaging, to medicine, healthcare, and environmental sensing. Such an exposure can provide breadth in the overall educational experience, as well as a heightened awareness of the pervasive role that this interdisciplinary field plays in today's society [11,12]. Herein, we report on our efforts to bring nanophotonics into the classroom by integrating basic concepts and topics into an existing optics curriculum.

2. Background

Many universities and colleges now have programs and centers dedicated to the pursuit of research and education in nanotechnology and nanophotonics. By comparison, Merrimack College, a small regional college with an Augustinian heritage that primarily serves the local Merrimack Valley communities of northern Massachusetts and southern New Hampshire, has only one course in optics within its Electrical Engineering curriculum. The Electrical Engineering Department, which has ABET accredited full- and part-time programs, has an enrollment of approximately 80 students, as well as a thriving Continuing Education program that draws part-time students from local industry, with primary employers in the military electronics, telecommunications, semiconductor, and instrumentation test and measurement markets. As part of its core curriculum, classes in electronics, VLSI, microprocessors, and senior project design provide students with extensive hands-on laboratory training, both in hardware, software, design, and test and measurement. There is also a keen interest within the college's Division of

Science and Engineering to promote STEM (Science, Technology, Engineering, and Math) education [13] to non-science and -engineering majors. The interdisciplinary nature of nanophotonics makes it an attractive candidate to facilitate this process, as well as to address the needs of local industry that have a need for well-trained students, and who utilize photonics in some form as part of their core business or product lines.

3. Educational Goals and Objectives

Based on the above, the challenge of bringing nanophotonics into the classroom at Merrimack College is one of taking a senior elective one-semester course entitled "*Optical Electronics*" and successfully integrating new concepts and topics into it that build upon existing course content, without initially creating an entirely new course. The course materials could, however, form the basis for a new course or multi-course sequence in the future. The overall goals of this effort are therefore threefold:

- Build upon existing course content in optoelectronics and photonics
- Leverage on-going faculty research activities in the field of nanophotonics
- Stimulate student self-discovery and exploration of nanophotonics through in- and out-of-class activities

At the end of the course, students are expected not only to have a working knowledge of basic photonic concepts, but also be able to articulate various aspects of nanophotonics from their classroom and experimental exercises. They should also have some idea about what approaches and tools can be used to design and engineer devices (or products) based on this technology. Seniors, and some advanced juniors, typically enter *Optical Electronics* with a solid background in fields and waves, but having prior sophomore-level physics classes as the only exposure to geometrical and wave optics.

Following the development of topics as presented in the text by Kasap [14], the course presents a detailed discussion of the wave nature of light (including polarization), and proceeds to develop the ideas of optical materials, light confinement and optical waveguiding, basic semiconductor principles, and the design and operation of semiconductor lasers and LEDs. It is within this framework that elements of nanotechnology and nanophotonics are introduced as extensions of existing course content.

The author's involvement in the design and development of specific nanophotonic structures and interactions provides a means to engage students and to show the relevance of the material to real-world devices and applications. Designs, fabrication methods, and test results on structures such as photonic crystal (PC) waveguides, sub-wavelength (SWS) anti-reflection structures, and quantum dots are presented to show photonic engineering in practice, rather than in abstract form. It is here that students acquire some hands-on training in lab experiments that involve the measurement of reflection, transmission, and polarization properties of various research-grade optical structures, including holographically-patterned SWS and PC structures.

Lastly, students are encouraged to explore the field of nanophotonics on their own through weekly readings and presentations of technical, trade journal, and web articles using, for example *Photonics Spectra*, *Biophotonics*, *OPN*, and *Optics Express* [15] as resources for topical materials that reinforce class concepts.

4. General Course Structure and Development

The challenge of presenting new concepts within a one-semester optical electronics course means that only a select number of topics can be covered. To this end, we have integrated nanophotonic concepts into a couple of key areas, those of which are outlined in Table I. These specific areas were chosen because they can be seamlessly integrated into the existing curriculum, are representative of key concepts, and can help students clearly identify the similarities and differences that exist between the optical behaviors of bulk and nanostructured media and devices. Such a compare- and contrast- methodology is used to help students distinguish nanoscale processes and interactions from those that occur on a much larger scale.

Beginning with a general introduction to photonics and its capabilities, the course quickly proceeds to a discussion of the wave nature of light and the scale of interactions, including light localization and cooperative electronic interactions. This is followed by the study of wave propagation and the optical properties of materials. It is here that ideas relating to the transmission, reflection, and coherent scattering by natural and artificially engineered materials, including quantum dot and periodic nanostructures like woodpiles and photonic crystals, are presented. The ability of these structures to confine and localize light are further addressed when the topic of optical waveguiding is introduced. Here, software simulation packages like *BeamProp* and *GSolver* can be used by students to design bulk- and nano-scale devices, simulate wave propagation, and analyze optical performance by interpreting spectral transmittance and reflectance curves, or observing the propagation, confinement, and light localization effects within nanostructures.

TABLE I. *Outline of topics integrating nanophotonics into an existing Optical Electronics course.*

- **Photonics as an Enabling and Pervasive Technology**
  - Generation, transmission, detection, manipulation, and processing of light
  - Role of nanophotonics within the photonics and optical electronics fields
- **Wave Nature of Light and Scale of Interactions**
  - Characteristics of ray, wave, and quantum optics
  - EM spectrum, size and scale, nanoscale interactions and light localization
- **Wave Propagation and Optical Properties of Materials**
  - Refractive index, absorption, effective index, negative index
  - Bulk and structured materials (dots, microspheres, woodpile, photonic crystal)
  - Reflection, refraction, and Fresnel equations
  - Interference, diffraction, and Bragg scattering as forms of coherent scattering
  - Design and simulation of optical structures using BeamProp and GSolver
- **Light Confinement and Optical Waveguiding**
  - Properties of dielectric slab and optical fiber waveguides
  - New waveguide types: photonic crystal, holey fiber, close-packed opal
  - Refractive index profile, bandgap absorption, light localization
- **Semiconductor Lasers, LEDs, and Detectors**
  - Semiconductor statistics and energy band diagrams
  - Modified density of states in dimensional structures
  - Nanocavity lasers, thermal emitters, surface-enhanced emitters, IR detectors
- **Applications**
  - Spectroscopy of quantum dots and biomedical applications
  - SWS structures for antireflection coatings, polarization control, and resonant reflection
  - Photonic crystal devices for PICs, biosensing platforms, optical backplanes

The last two topics covered in the course include semiconductors, lasers and LEDs, and specific applications having nanophotonic solutions that are currently being addressed by industry. The section on semiconductors provides an opportunity to examine semiconductor statistics, band diagrams, and density of state functions in the case of bulk, thin film, periodic, and nanostructured media. These modified properties form the basis for discussion of new devices, as well as applications that range from the use of quantum dots in biomedical imaging and the design of antireflective and hydrophobic surfaces, to the development of photonic integrated circuits, high-speed optical backplanes, and biosensors, to name a few. The applications chosen for discussion tend to be focused on those that address semiconductor, telecommunication, or product engineering solutions, commensurate with the industries being served by the engineering program of the college and the interests of the part-time student body.

5. Examples and Illustrations

Many of the concepts introduced throughout the course are illustrated using examples drawn from laboratory simulations, the fabrication and testing of real devices, or the results from current research and development activities in the field. An example of different nano-optical structures presented to students is shown in Fig. 1. These examples, which include quantum dots, holey fibers, and sub-wavelength structured surfaces (SWS) [9,10] illustrate the diverse nature of structures and scales over which optical interactions can occur. Photonic structures in biology, such as the brittlestar arm, moth eye, or exoskeleton of the diatom *Thalassia*, are also nice examples that show how nature employs nanophotonics to manipulate the flow of light

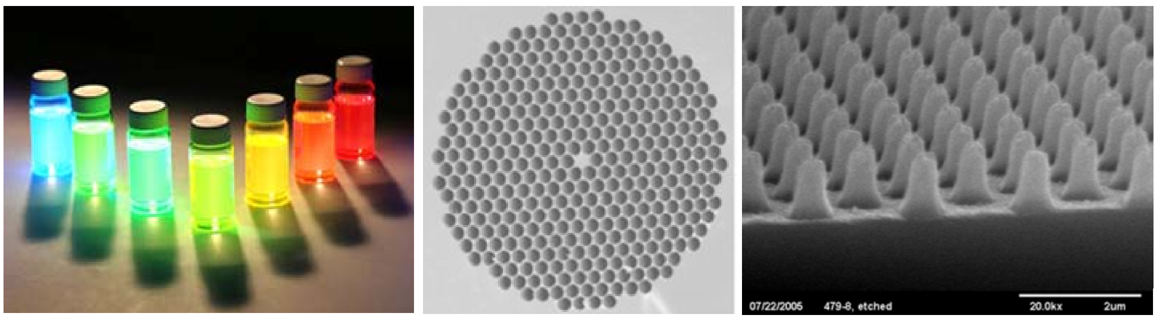

Fig. 1. Examples of nanophotonic materials and devices. These include quantum dots solutions (left), holey fibers (center), and diffractive sub-wavelength structures (right) designed and fabricated by the author.

Critical to any engineering course is design and simulation. Here, tools such as GSolver and BeamProp may be used to study the optical properties of different materials, geometries, and device configurations. An example of these tools and results that are demonstrated to students, and used by them in the class, are shown in Figs. 2 and 3. Fig. 2 shows one of the menus that is used in GSolver, a vector-diffraction software simulation tool, to enter optical material, wavelength, and geometric parameters prior to running a simulation of spectral transmittance and reflectance. Such a tool allows students to see the effects that parametric changes have on device performance.

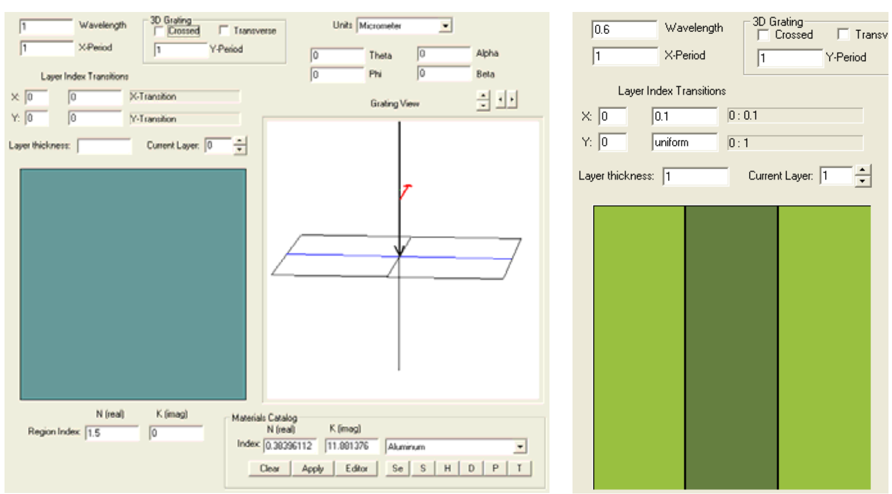

Fig. 2. GSOLVER editor (left) and Wavelength/Layer setting (right) menus used for simulating the optical properties of bulk and structured materials.

Optical waveguiding and the effects of light localization can be illustrated using a model for a photonic crystal slab waveguide, as shown in Fig. 3. These results, generated using finite-difference time domain techniques, show how an optical waveguide can be created using a linear array of air holes that have been patterned into a thin slab of silicon containing a periodic array of smaller-sized air holes. The example also provides a basis for the discussion of coherent scattering, including the dramatic visual and optical effects it can produce.

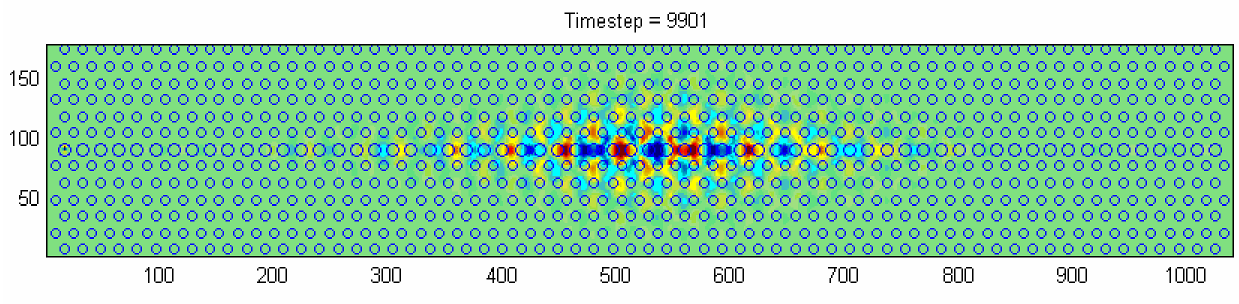

Fig. 3. Wave propagation in a slab photonic crystal waveguide. This example illustrates the concepts of optical waveguiding, light localization, and the process of coherent scattering in a photonic nanostructure.

No engineering class would be complete without showing the results from some real devices or products, or by giving students the opportunity to make sample measurements for themselves. For this purpose, an Ocean Optics high-resolution spectrometer is used to make spectral measurements in the visible wavelength range, while the services of a local vendor are used for FTIR measurements in the near- to mid-infrared spectral range. An example of the latter is shown in Fig. 4 for a silicon-based SWS structure that was designed and fabricated by the author to operate as an antireflection (AR) coating in the 2 – 6 μm spectral range. This result emphasizes how the effective index properties of photonic nanostructures can be used to manipulate the spectral and polarization properties of light.

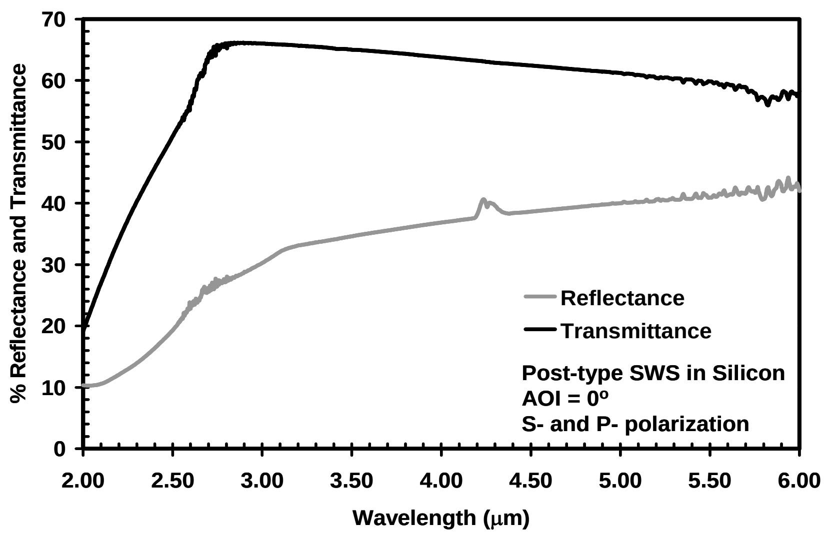

Fig. 4. Reflectance and transmittance spectra for a two-dimensional SWS structure designed for broadband antireflection (AR) operation in the 2 – 6 μm MWIR wavelength range.

An example that demonstrates the use of a photonic nanostructure in a critical application is that of the chemical or molecular biosensor, as shown in Fig. 5. Here, a resonant reflecting structure is used as a biosensing platform for sensitive protein detection. Though this device has yet to be realized in our lab, it provides students with an opportunity to consider various design requirements, material choices, and the possible advantages of exploiting nanoscale optical interactions for the high resolution detection of molecules that, themselves, are nanoscale in dimension.

Lastly, to foster the continued discovery and exploration of nanophotonics outside of the classroom, students are encouraged, and required, to find, read, and present, articles found in the various technical and trade journals. The cover pages of several such trade magazines are shown in Fig. 6. These magazines are most instrumental in showing students the relevance of their studies in optical electronics, and the new developments that are rapidly emerging in the nanophotonics field.

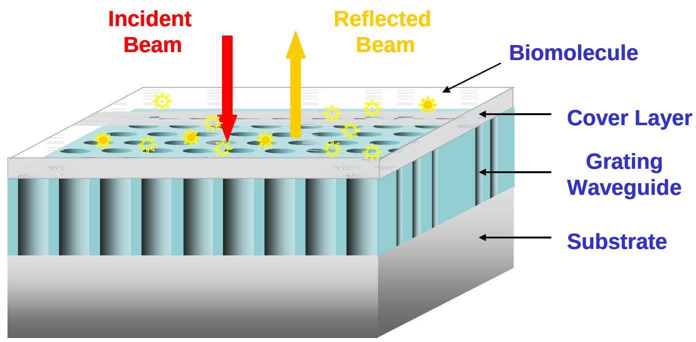

Fig. 5. Resonant reflecting structure used to illustrate the research and development of a new biosensing platform for protein detection using nanophotonic structures.

Fig. 6. Cover pages from the journals of Photonics, OPN, and Biophotonics. These magazines are used to get students engaged and excited about their studies in optical electronics and nanophotonics.

6. Conclusion

Nanophotonics is rapidly becoming a pervasive technology, with applications that range from optical and fiber optic communications to imaging, medicine, and healthcare. In this paper, we have described an approach for introducing nanophotonics to undergraduate students in a small liberal arts college engineering program, and bringing these basic concepts into the classroom. Through trade-journal and on-line readings, weekly discussions, and a limited number of laboratory experiments, students are able to learn about nanophotonics and its many facets, including optical interactions, materials, fabrication techniques, and uses. While limited in scope, this work should serve as a basis for further course development efforts that emphasize the capabilities of nanotechnology and photonics combined.

Acknowledgements

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III.

Biophotonics Master studies: teaching and training experience at University of Latvia

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ABSTRACT: Two-year program for Master's studies on Biophotonics (Biomedical Optics) has been originally developed and carried out at University of Latvia since 1995. The Curriculum contains basic subjects like Fundamentals of Biomedical Optics, Medical Lightguides, Anatomy and Physiology, Lasers and Non-coherent Light Sources, Basic Physics, etc. Student laboratories, special English Terminology and Laboratory-Clinical Praxis are also involved as the training components, and Master project is the final step for the degree award. Life-long learning is supported by several E-courses and an extensive short course for medical laser users "Lasers and Bio-optics in Medicine". Recently a new inter-university European Social Fund project was started to adapt the program accordingly to the Bologna Declaration guidelines.

Keywords: biophotonics Master's study programs, biomedical optics education, lasers in medicine.

1. INTRODUCTION

Biophotonics is a subject related to photonic phenomena in biological media, e.g. living tissues; it can be regarded as a parallel term to "Biomedical Optics" or "Bio-optics", also frequently used in scientific community. A Master level sub-program "Biomedical Optics" was originally developed at University of Latvia and started in Faculty of Physics and Mathematics in year 1995. The Curriculum (total 80 credits) includes the main special subjects "Biomedical Optics – 1" (tissue optics and optical bio-sensing), "Biomedical Optics – 2" (lasers in medicine), "Medical Lightguides", "Anatomy", "Physiology", "English Terminology of Biomedical Optics" etc., as well as selected chapters of Basic Physics, laboratory training (2 general physics lab-sets and 5 special student labs) and Laboratory-Clinical Praxis. The studies take four semesters – three for lectures and practical training, and one for the Master project.

This paper presents details of the Curriculum and shares the 12-year experience regarding its implementation. Some novelties of the teaching and training approaches in addition to those reported previously [1-3] are regarded, as well.

2. THE CURRICULUM

The actual Curriculum for the two-year/four-semester Master's studies in Riga is presented in Table 1. There are two main parts – part A is compulsory for all physics Master students, and part B is specific for the students specialized in Biophotonics (Biomedical Optics). The corresponding semesters and credits for each course are given, as well. Total number of credits to be collected is 80. The credits awarded at University of Latvia may be transferred by means of the European Credit Transfer (ECT) system: 1 UL credit is equal to 1.5 European credits. One credit corresponds to 16-20 contact hours plus 20 hours of individual studies. Bachelor degree in natural sciences or engineering is a prerequisite to be enrolled as a Master student in this sub-program without entrance exams; candidates with medical background have to pass entrance exam in General Physics. The courses are presented in Latvian language; however, individual studies in English are also possible under agreement with the International Department [4]. Visiting students from Canada, Sweden and Bangladesh have been taught in English so far.

Brief descriptions of the main courses are given below.

Table 1. Curriculum of the Biophotonics Master studies at University of Latvia

No.	***Subject***	***Semester***	***Credits***	***Part***
1.	Modern Physics - 1	1	5	A
2.	Selected Chapters of Basic Physics	1	4	B
3.	English Terminology of Biomedical Optics	1	3	B
4.	Physics Laboratories – 1	1	4	A
5.	Fundamentals of Biomedical Optics – 1	2	4	B
6.	Modern Physics - 2	2	5	A
7.	Human Anatomy	2	4	B
8.	Physics Laboratories – 2	2	4	A
9.	Lasers and Non-Coherent Light Sources	2	2	B
10.	Fundamentals of Biomedical Optics – 2	3	4	B
11.	Medical Lightguides	3	4	B
12.	Physiology	3	4	B
13.	Laboratory-Clinical Praxis	3	3	B
14.	Master Project	4	30	A

Fundamentals of Biomedical Optics [1] as the largest course (8 credits) is divided into two parts. The first part includes Tissue Optics (propagation of optical radiation in tissues, skin optics, blood optics, eye optics and optics of the hard tissues) and Optical Sensing for Diagnostics and Monitoring (photoplethysmography, pulse oximetry, laser-Doppler blood flowmetry, NIR monitoring of cerebral oxygenation, optical sensors of physical and biochemical parameters, spectrometric sensors and fluorosensors). The second part covers laser-tissue interactions and laser treatment (medical lasers, laser safety, laser bio-stimulation, laser photodynamic therapy - PDT, laser applications in cosmetology, surgery, dentistry and other medical specialties).

Anatomy and Physiology courses are addressed mainly to the students with physics and engineering background. Its anatomy part regards the composition of human body, structure of brain, heart, kidneys and other organs, as well as the neural, respiratory, reproductive and other essential living systems. The physiology part includes homeostasis, blood supply, muscle dynamics, cellular structures and physiological functions of the basic human organs.

Lasers and Non-coherent Light Sources is a course explaining basic physical principles of non-coherent and coherent light emission. It regards specific features of various laser types (gas, solid state, semi-conductor, excimer, etc.) and their applications in non-linear optics, spectroscopy, environmental studies and medicine. Non-coherent sources like halogen lamps and discharge tubes are regarded, as well.

Medical Lightguides is a course concerning basics of fiber optics and applications of fiber lightguides in various medical devices – fibroendoscopes, "cold light" and non-shadow illuminators, medical laser delivery systems, phototherapy units, bio-optical sensors, etc.

Acquisition of practical skills is a very important aspect of the teaching/training process. Laboratory-Clinical Praxis is included in the study plan at the 3rd semester. During this praxis students spend certain time (at least 6 full days) in real laboratory or clinical environment dealing independently with some particular problem. If this work is successful, it is usually extended at the Master's project. A further step to increase the role of practical activities is development of the specialized student's laboratory. Student practicals concerning optical properties of tissues (laser light scattering from tissue phantoms with subsequent Monte-Carlo modelling), laser-excited skin fluorescence and non-invasive optical diagnostics (photoplethysmography, pulse oximetry and laser-Doppler blood flowmetry) are to be completed in parallel with lectures on Biomedical Optics.

E-learning is a useful tool for the enrolled Master students as well as for those studying independently (so-called "life-long learning"). Four specialized Biophotics e-courses in the WebCT environment are offered by University of Latvia – both Biomedical Optics courses, Medical Lightguides and the Laser course. The contents of e-courses are permanently updated and supplemented with PPT files that are prepared and presented by students during acquisition of those courses.

In frame of the Swedish-Baltic VISBY project, a short course for medical laser users ***"Lasers and Bio-optics in Medicine"*** in English was created in the PowerPoint file format (see details in Chapter 4). This course is formally recognized by the Medical Laser Centre of Lund University and has been approbated internationally in Latvia, Lithuania and Sweden. It may serve as additional contribution to the life-long learning in Biophotonics.

Existence of the specialized Biophotonics library and the specific student's laboratories at University of Latvia proved to be very useful. It became possible thanks to financial support from the European Commission in frame of the TEMPUS project [5] incorporating five Baltic universities and two from the EU countries (Linkoping University, Sweden, and King's College London, UK). University of Latvia has been recognized as the regional center of excellence on Biomedical Optics teaching in frame of this project. Fruitful international collaboration has been developed also with other European universities, e. g. Lund University (Sweden), University College London (UK), University of Patras (Greece). EU *Leonardo da Vinci* project on biomedical physics vocational training (including chapters on tissue optics, clinical applications of lasers and medical lightguides) was completed few years ago in collaboration with our Lithuanian, Polish and German colleagues.

3. SOME PRACTICAL ASPECTS OF THE BIOPHOTONICS TEACHING

One of the main practical problems was and still is the lack of suitable textbooks in the profile topics. The field is emerging very dynamically, and regular studies of the periodicals - first of all, the journals "Biophotonics" and "Biomedical Optics" - are always necessary. A lot of proved and established knowledge on the topic is available in the review articles, but only few specialized books can be recommended for students. Our Biomedical Optics library now consists of more than 200 units – books (or copies of their chapters), conference proceedings, specialized CDs, periodicals and copies of selected papers. Several most appropriate books for Biophotonics teaching are cited here [6-26], and selected chapters of them we find quite suitable for the students as basic literature sources. In parallel, Internet resources in the Biophotonics field are growing rapidly, and part of them also might be used as teaching materials. However, some of the topics are presented there incompletely or even totally wrong, so certain web-pages can be recommended to students only after very careful revision by experts of the field.

Biophotonics as emerging inter-disciplinary subject attracts people with different backgrounds. Entrance criteria for enrollment of Biophotonics Master students are very substantial in this respect. At the first years of this program, we enrolled students with Bachelor level diploma in natural sciences, engineering and/or medicine. Further experience led to some limitations – students with medical background were enrolled only after passing the entrance exam in General Physics. That proved to be necessary due to serious differences in physics knowledge if compared with those with natural science (physics, biology, chemistry, geology) or engineering backgrounds.

Generally, several practical problems in the Biomedical Optics teaching area have been identified:

- substantial differences in student's background knowledge levels, especially on physics; medical graduates sometime have difficulties to follow the lectures on special subjects, even after passing the Basic Physics course at the 1st semester;
- the Curriculum does not cover all main aspects of the area; in particular, Medical Imaging, Photosynthesis, Cell Optics and probably some more subjects ought to be added in future, thus changing the existing balance of subjects;
- the Master's study program is time-consuming (2 years), and many students cannot afford to spend all their time for studies; therefore the mean successful output rate for this sub-program has been only about 50 %;
- the research activities on the subject would promote teaching quality and therefore should be developed more actively, by attracting additional research resources (human potential and funding);
- the program offers only academic degree without any professional certificate which sometimes can be of value, e. g. for the young clinicians;
- the social need for this kind of specialists is relatively low, and the program has weak support by the local clinical and medical institutions so far;
- harmonization of European education system (in order to meet the Bologna Declaration goals) create some problems – transfer from 4-year to 3-year physics Bachelor program "compresses" the 2-year Master program since some subjects from the 4th Bachelor year are to be moved to the Master program leaving less space there for the specific Biophotonics courses.

4. THE SHORT COURSE "LASERS AND BIO-OPTICS IN MEDICINE"

To avoid laser accidents in hospitals and clinics, all medical laser users should have basic core knowledge on laser principles, laser-tissue interactions, laser safety matters and related items. Obviously, special certified short course is needed for that, preferably not exceeding 4-8 hours. There is a lack of European standards and internationally recognized course programs of this kind. Therefore a special attempt was taken to work out such course titled "Lasers and Bio-optics in Medicine", targeted to medical professionals with little or no background regarding lasers and their clinical applications. This work was done in collaboration with Lund University Medical Laser Centre in frame of the Baltic-Swedish VISBY project. The elaborated program (see below) can be presented more or less detailed, as one of three options - extensive 8-hour course with 180 color slides (26 MB), basic 4-hour course with 140 slides (22 MB), or brief 2-hour course with 95 slides (15 MB). All materials are in English and are intended for modern presentation technology – computer projection, using the MS PowerPoint format files.

The proposed certification program for medical laser users

1. Introduction
2. Laser principles, designs and parameters.
   - How the laser works
   - Basic types of lasers and their designs
     - Gas discharge lasers
     - Solid state lasers
     - Diode lasers
   - The most important laser parameters
3. Basics of tissue optics
   - Light absorption and scattering in tissues
   - Wavelength effects, the therapeutic window
   - Light penetration in tissues
   - Absorbing agents in tissues and blood, their spectra
   - Skin optics, response to the UV radiation
   - Optical parameters of tissues
4. Laser-tissue interactions.
   - Photo-thermal effects; examples
   - Photo-mechanical effects; examples
   - Photo-chemical effects; examples
5. Medical laser systems
   - The medical lasers
   - Beam delivery systems
   - Auxiliary sub-systems
6. Laser and UV safety regulations
   - Harmful effects of laser and UV radiation
   - Laser safety classes
   - The caution and warning signs
   - Protective goggles and shields
7. Clinical aspects of laser applications (invited MD's)
   - Lasers in therapy and surgery
   - Lasers in dermatology and cosmetology
   - Lasers in oncology
8. Laboratory training with lasers and tissue samples or phantoms.
9. Certification test/exam.

5. DISCUSSION AND CONCLUSIONS

The significance of Biophotonics as educational subject undoubtedly is growing, and the experience gained over 12 years in University of Latvia may appear useful for development of new or updating the existing teaching methodologies in other universities and colleges. The above-discussed Curriculum has been quite significantly modified during this period, and further amendments are expected in future. One reason is transfer to the Bologna 3+2 scheme with subsequent changes in physics Master program at University of Latvia. It is proposed that the developed Biophotonics topics will be further integrated in two courses of the new academic Master program and two courses of the professional Master program, all to be developed over the next couple of years.

As a new initiative, an inter-university Master study module on Medical Physics is being developed under support of European Social Fund. It represents a set of 16 courses selected in accordance with recommendations of international experts for obtaining professional certificate in Medical Physics. 8 courses are prepared by Riga Technical University and 8 courses – by University of Latvia, including three of those related to Biophotonics – "Radiation Physics", "Lasers and Optical Methods in Medicine" and "Medical Imaging". Presumably, the gained experience in Master teaching on Biomedical Optics will be helpful in creation of those courses.

The main conclusions are:

- Biophotonics is a rapidly emerging area, therefore every-year updates of the program content are necessary;
- The students are enthusiastic about their studies, but the lack of textbooks in this field makes studies difficult; considerable self-efforts of the students are requested;
- Specialized Biophotonics library and student's laboratory are essential parts of the study process. Student laboratories are very helpful, but expensive; a professionally agreed inter-university methodology is needed;
- Internet resources may be useful in many cases; however, some of the Biophotonics items are presented there incompletely or even totally wrong; how to get rid of them?
- WebCT has proved to be a useful tool for Biophotonics e-studies;
- Further international collaboration on Biophotonics education at all levels should be strengthened by regular meetings and inter-university exchanges of students and teachers;
- Development of specialized regional or international centers seems to be a future trend of providing Master's education on inter-disciplinary subjects like Biophotonics, and University of Latvia is ambitious to become a Baltic regional center in the field of Biophotonics education in future.

ACKNOWLEDGMENTS

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IV.

Teaching Optics in a Multi-Disciplinary Curriculum: Experience From Optometry Programs

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Abstract

The Optometry program in Schools and Colleges of Optometry leads to a Doctor of Optometry (OD) degree in north America and is usually a post-baccalaureate course of study of four years duration. Historically Optometry developed out of Physics and/or applied optics programs. Optics, and more specifically, geometric optics and it's applications to the human eye plays a significant role in the education of an optometrist. In addition, optometrists are trained in physical optics as well as in radiometry/photometry. Considering the fact that most optometry students come to the program with a biological sciences background implies that educating these students require elucidation of "real-world" applications and clinical relevance to hold their interest. Even though the trend in optometric education in the past few years is to put more emphasis on biological sciences due to the increased scope of practice of the optometrist, optics still continues to play a major role in the training and career of an optometrist, especially with the advent of new technologies in treating low vision, measurement and correction of aberrations of the eye, etc.

Introduction

The field of Optometry probably began at the time when the first spectacles appeared. It is known that around 1300 there were spectacle manufacturing businesses in Italy, Germany and the Netherlands. The first bifocals were devised by Benjamin Franklin in the 18th century in Philadelphia. See Rosen (1956) for a discussion of the historical origins of spectacles and optometry.

The first use of the term optometrist is thought to have been used by Landolt, a German, who contributed much to our knowledge of visual acuity (and devised a chart which is still in use) in 1886, to describe the fitting of glasses. This term became popular in the first two decades of the 20th century. Before that optometrists were usually referred to as Opticians (a term that is still used today to describe people who make spectacles and dispense spectacles). In the 19th century, there came a distinction between refracting opticians (the ones who test the eye and determine the correct spectacle prescription) and dispensing opticians. The refracting opticians became known as optometrists (Gregg, 1965).

Legal cases in the first half of the 20th century ruled that optometry was separate from medicine. The origins of the fields differ both in the sciences from which they developed and in the shift of tradesmen into the professions. The scientific origins of optometry are in the optical sciences while medicine has its roots in the biological sciences. The professions developed amongst tradesmen – jewelers in the case of optometry (because they had the tools to work on spectacles) and barbers in the case of medicine (since they had the tools with which to do surgery!). The first American optometric licensing law was passed in the state of Minnesota in 1901, but by 1924 all states and the District of Columbia had optometry licensure laws. By comparison, the first medical licensure law in the US was passed in the late 1700s. However, it was not until 1895 that almost all states had their medical licensure boards. In addition, the diagnostic pharmaceutical agent law which allowed optometrists to use pharmacological methods to diagnose diseases of the eye was passed in Rhode Island in 1971 and the first therapeutic pharmaceutical agent law which allowed optometrists to prescribe certain medications for treatment of specific eye diseases was passed by West Virginia in 1976. Currently all fifty states have some form of DPA and TPA (including treatment of glaucoma). In Canada, the province of Ontario is currently in the process of approving a TPA law. Other laws being considered include the approval for optometrists to do refractive surgery procedures such as LASIK using a laser (in Oklahoma).

Optometric Education

Some of the first optometric schools were private schools. Amongst the existing optometric schools in the US, the Illinois College of Optometry can trace its roots to 1872 (predecessor schools; Northern Illinois College of Optometry and Otology, Needles Institute, Monroe College of Optometry and Chicago College of Optometry), while the New England College of Optometry can trace its roots to 1894 as the Kelin School of Optometry. Amongst university based schools, the oldest is the Ohio State University College of Optometry (Columbus, established in 1914), followed by the University of California at Berkeley. The first university based optometry program was established at Columbia University (New York) which opened in 1910 and closed in 1954. These university based optometry programs in general originated as a part of the Physics or Applied Physics curriculum. This is still true in many European optometry programs such as those in Portugal, Spain, Italy, etc. The first Canadian optometry program was established at the University of Waterloo in 1967. There are currently 17 schools and colleges of optometry in north America. The newest program in the US is the Optometry school at Western University of Health Sciences in Pomona, California which is to admit its first students in the fall of 2009.

Doctoral degrees for optometrists were awarded by various schools and the first Doctor of Optics degree was given by the Philadelphia Optics College (precursor to today's Pennsylvania College of Optometry) to optometry graduates in 1885. Before the nineteen twenties, optometrists generally avoided using the term "doctor' but this gradually changed in the ensuing decades. Currently all north American institutions award an OD (Doctor of Optometry) degree while in other countries such as the UK, India, Australia, New Zealand and south Africa, only a bachelor's degree is given (B.Sc. in Optometry). In 1950, all ten of the optometry schools in existence at that time in the US required five years of study past high school. All private schools offered the OD degree. The Ohio State University, University of California and Indiana University (Bloomington), did not offer the OD degree until switching to a six year pre-optometry and optometry curriculum. Berkeley, for example, did not graduate its first OD class until 1970. A more comprehensive review can be found in Woodruff (2001; see also Borish, 2001).

Currently, most students admitted to optometry programs in the US have an undergraduate (bachelor's) degree usually majoring in the biological sciences. Pre-requirements for admission include at least one year of college biology, general chemistry, general physics (with laboratories), as well as a year of college math for all optometric institutions. Other requirements vary depending on the school. Specific information about student profiles, enrollment, pre-requirements, etc. can be found in the Association of Schools and Colleges of Optometry web site (ASCO 2007).

Optics in the Optometric Curriculum

As noted earlier, optics being the historical basis of optometry, plays a major role in the education of an optometrist. The student of optometry is trained in various aspects of optics. These can be classified as : geometric, physical, ophthalmic and visual optics. This classification was done using the optics content outline for the National Board of Examiners in Optometry (NBEO), the major licensing exam for the optometrists (NBEO 2007). The website for NBEO gives a detailed listing of the areas covered in the optics section of the exam. This exam tests the minimum required knowledge/proficiency of a new entrant to the field. Sheedy et al (2006) has head of a special interest group of optometric educators at ASCO surveyed and analyzed the curriculum content. Figures 1 and 2 are from their survey. Because of difficulties in equating credit hours across institutions and differences between quarter and semester hours, actual instructional clock hours were used as the unit of measure. The mean (plus/minus SD) number of clock hours for lecture and laboratory are 202.7(27.0) and 102.7(33.7). Although there is variance in the number of lecture hours and how they are allocated across the institutions, it is small relative to the variance in laboratory hours. The number of laboratory hours of instructions in total and by optics category is quite small at several institutions. For example, at the University of Waterloo, there is no laboratory requirement for Physical Optics. Here, the results of the survey for clinical rotations (optical dispensing) is not included.

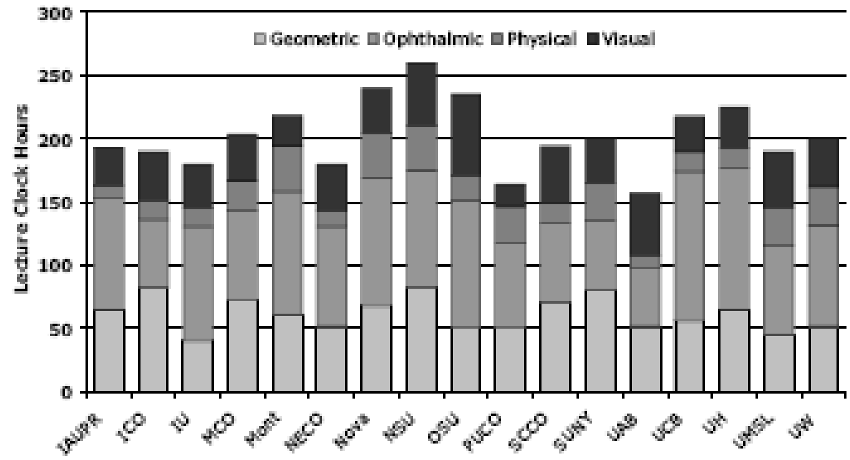

Figure 1. Clock hours of lecture in 4 areas of optics at 17 schools and colleges of optometry.

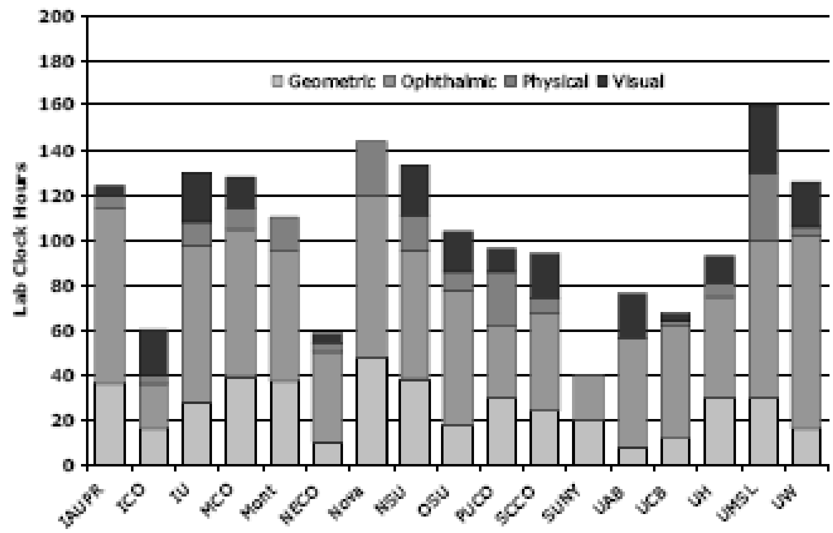

Figure 2. Clock hours of laboratory instruction in 4 areas of optics at 17 schools and colleges of optometry.

Given the amount of optics in the curriculum and the fact that the students are squeezed for time due to completing needs in the biological sciences curriculum, as a result of the expanding scope of clinical practice of the optometrist, students question the need for learning, for example, physical optics. It should be noted that in addition to biological sciences (including histology, microbiology, biochemistry, pharmacology, disease, etc), students also have to learn optometric jurisprudence, perceptual science, statistics and epidemiology, medical ethics, environmental vision and so forth. This brings about the question of importance of the quality and quantity of optics which is taught in the first year of the OD curriculum. In order to address this, there is the need to address the question of relevance. This brings out the requirement that the instructor has to show why the students need to understand basic optical principles by bringing up examples from the clinic –i.e., real world examples. Unfortunately there aren't many good text books that addresses this issue. The book by Pedrotti and Pedrotti (1998) attempts to deal with this by giving some examples, but far more is required. Mention should also be made of the book by Keating (2002) who is a professor in an Optometry school and was educated as a physicist. However, this book is considered "hard" and is used in only one school to the best of my knowledge. In my own teaching over the years, I have tried to do so. Examples will include in a discussion of say, total internal reflection, how it is used in gonioscopy in viewing the so-called angle of the anterior chamber, in fiber optics the fact that the incident light is trapped and sent to the sites of absorption by the pigment molecules in the photoreceptor as a waveguide, how chromatic aberration is used in the bichrome/duochrome test, resolution criteria applied to vision test charts, modulation transfer functions to the contrast sensitivity function of the human eye and its imaging performance, telescopes as applied to low-vision observers, thin film interference applied to anti-reflection coatings in spectacles, lasers and their applications in ophthalmic surgery etc..

Recent advances in technology such as aberration correction using Hartmann-Schack aberrometry and the use of adaptive optics(Porter et al 2007), excimer laser use in refractive surgery (Macrae et al 2001), polarimetric methods to examine the retina (Weinreb et al., 2002), etc. require that the future optometrist be intellectually equipped with the necessary optical physics and engineering knowledge to better utilize these advances for both diagnostic and therapeutic use. As optics educators it is up to us to not only deliver that information, but also do it in such a manner as to make it relevant and interesting to the studies and concerns of student optometrists.

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Teaching thin optical coating and optics education in developing country – a scenario in Bangladesh

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Abstract: Optics education is an essential ingredient in building modern science and technology. As the rate of technological change accelerates, continuing optics education becomes more important than other. This talk is an account of a successfully continuing professional-education course on optics and optical coatings in the Department of Applied Physics & Electronic Engineering, University of Rajshahi, - a scenario of optics education in Bangladesh. The foundation course on optics emphasizes in understanding of the basic principles of geometrical and physical optics through formal lectures and its practice through laboratory demonstrations. The Department of Applied Physics & Electronic Engineering usually do local fabrication/ assembling of optics laboratory teaching aids. Students and technical staffs under the guidance of a Faculty staff member do equipment fabrication and assembling. This article describes some of the project-type set ups for performing experiments on (i) wavelengths of various spectral lines determination (ii) determination of unknown solution concentration (iii) determination of thickness of thin optical coating as well as (iv) determination of various optical parameters such as refractive index, optical band gap through the measurement of transmission and reflection spectra.

OCIS codes: (000.2060) Education, (080.2740) Geometrical optics, optical design, 310.6860) Thin Films, Optical Properties

1. Introduction

Science and technology have a major role in the development of today's society and civilization. The science of optics includes light emission, transmission, absorption, reflection, detection and amplification of light by optical devices and instruments, laser, fiber optics, optoelectronic devices and related optoelectronics system of hardware and software [1]. In recent years, optics plays a significant role in the growth and development of high tech industry such as energy generation, telecommunications, information technology, detection & ranging, medical diagnostics and treatment, structure of health monitoring, quality control of products as well as in the environment control of our ambience [1].

Bangladesh is a country of about 140 million people and it has 16 public Universities and more than 50 private Universities. Most of these Universities have undergraduate and graduate programs in disciplines of Humanities, Social Sciences, Business Studies as well as Science & Engineering programs. In response to the growing importance of optics, education institute across Bangladesh including the Rajshahi University (RU), a very old University in the country established in 1952, has been offering optics course in the Department of Applied Physics & Electronic Engineering from the inception of the Department. The Department of Applied Physics & Electronic Engineering at RU was established in 1966 and initially it had started to offer a Master of Science education program. The Department had late offered an undergraduate program in 1973. Optics and optoelectronics courses at RU are part of a 4-year Bachelor of Science Honors in Applied Physics & Electronic Engineering degree program. A 2-credit project course is compulsory for all attending Honors graduate.

The main courses include Applied Optics, Basic and Advanced Electronics, Quantum Mechanics, Atomic & Nuclear Physics, Pulse & Switching, Instrumentation & Control Systems, Non Conventional Energy, Integrated Circuits (IC) Fabrication & Communication Electronics, Solid State Physics, Communication Engineering, Applied Geophysics, Medical Physics, Computer Architecture & Organization, Radio & TV Engineering, Telecommunication, Microprocessor & Microcomputer, Materials Science and Advanced Solid State Physics. The Honors degree program is 4 years duration, comprising 160 credits, where 128 credits are allocated for theory courses and 32 credits for practical classes with project works. The education of RU contains a formal lecture of 50 minutes duration and a laboratory session of 2 hours. The department offers a basic course of Applied Optics for the first year Honors students to have a fundamental knowledge in optics.

Optics and optoelectronic courses are embedded in Instrumentation & Control Systems, Non Conventional Energy, IC Fabrication & Communication Electronics, Solid State Physics, Communication Engineering, Materials Science and Medical Physics. In laser and fiber optics, students learn various aspect of laser such as principles of laser generation, laser resonator, beam properties, application in interferometry & holography and application in medical physics. Light guiding properties of optical fibers, dispersion, attenuation, applications of fiber optics in telecommunication and in Satellite Communication as well as laser in various sensor applications. Besides, basic optics principles and their use in optical equipments as well as in technical applications are taught through lectures and practices. Discussed topics include interfrometry, diffraction, polarization and their applications through a number of demonstration classes.

2. Project

The main concern in the undergraduate project work is the syntheses of the knowledge from all lectures that have been in the classroom and its application to solve real problems in practice. Components and instrumentations are needed to construct the necessary project to carry out its measurements and to exhibit its performance to the audience present. The following two typical illustrations are among 50-project work usually done in every year by the Honors students at the end of their 4th year degree program. The project was based on electronics & optoelectronics with hardware and software design.

Design and construction of a microprocessor control four-way traffic signal system: Electronic auto traffic signal system is very useful for developing country like Bangladesh. It has very important role to make discipline in vehicle communication in a busy road. A microprocessor-based system is controlled by software; therefore it controls the duration of light ON/OFF to make order of the traffic systems.

Carbon dioxide gas detector: Whenever CO_2 gas is passed through a fresh colorless lime water $Ca(OH)_2$, it is turned milky in color due to its white precipitation of calcium carbonate ($CaCO_3$).

Colorless limewater + Carbon dioxide gas ↔White precipitated of Calcium Carbonate + Water.

Therefore, CO_2 gas changes the optical transparency of the limewater. Their changes in transparency can be measured by using optoelectronic circuit and detect the presence of CO_2.

3. Examples of experiment for basic understanding

The objective of running optics laboratory class is a provision of practical experience to supplement and illustrate concepts developed and discussed during formal lectures. With this in mind, various laboratory works are organized for the first, second, third and fourth year students. In the first year level, the courses are not very specialized so that the laboratory experiments involve certain common components and instruments. Exchange and reallocation of the equipments are possible during the execution of the yearly program. The motivating factors for local fabrication/assembling of optics experiments are: (i) to have fundamental knowledge in education (ii) cost-effectiveness (iii) easy maintenance and (iv) easy duplication, upgrading or modification. The exercise involves teaching staff members, technical staff members and the students also. Five sets of optics experiments are illustrated below which have been set for demonstration for students from the first year level to 4th years.

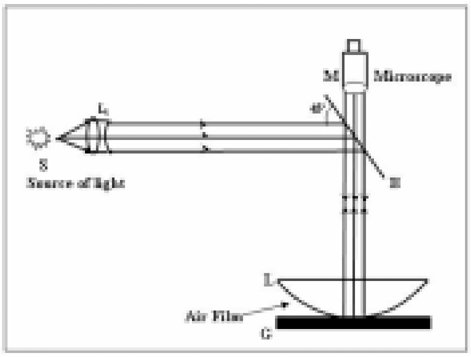
3.1 Phenomena of interference of light.

Measurements of radius of curvature of a lens by Newton's ring: The set up is developed in the laboratory and is depicted in Figure 1(a). When a plano-convex lens L of large radius of curvature is placed on a glass plate G, a thin air film of progressingly increasing thickness in all direction from the point of contact between the lens and glass plate is formed. The air film thus possesses a radial symmetry about the point of contact. When it is illuminated normally with monochromatic light, an interference pattern consisting of a series of alternate dark and bright circular rings concentric with the point of contact is obtained.[2, 3, 4] and it is shown in Figure 1(b).

Students usually measure the diameter of the lens and calculate the diameter, D, of dark and bright rings by using of microscope. By plotting a graph of the square of the diameter as the ordinate and number of rings as abscissa, the calculated result gives a straight line and it then determines the radius of the curvature of the lens by using the following equation

$$R = \frac{\left(D_{n+m}^2\right) - D_n^2}{4m\lambda} \tag{1}$$

Where, λ is the monochromatic light wavelength n & m are the number of rings, respectively.



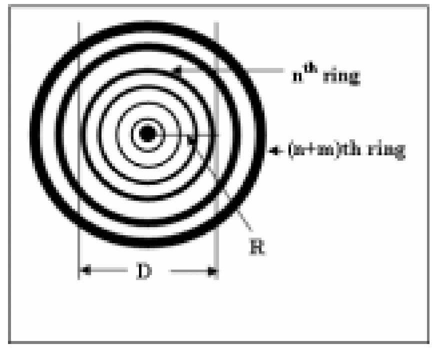


Fig. 1(a). Experimental set up of interference of light

Fig. 1(b). Interference pattern

3.2 The phenomena of diffraction of light

Determination of the wavelengths of various spectral lines by spectrometer using plane diffraction grating: The laboratory experiment is summarized schematically as in Figure 2. If a monochromatic light of wavelength λ falls normally on a plane diffraction grating placed vertically on a Prism Table, a series of diffracted image of the collimator slit will be seen on both sides of direct image [2, 3, 4]. Using the equation

$$N = \frac{\sin\theta}{n\lambda} \tag{2}$$

Where, N is grating constant, n is the number of the image and θ is the deviation angle of light.

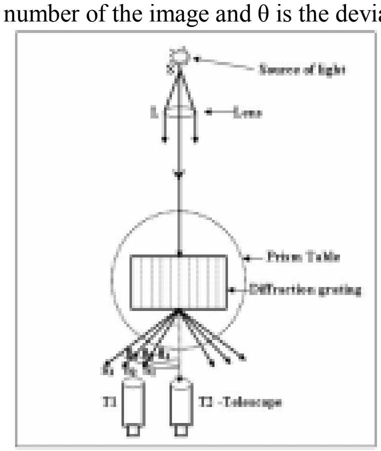


Fig. 2. Illustrates the diffraction phenomena of light.

The students usually do the experiment with sodium light of known wavelength and then the value of N is determined first. From the knowledge of N, the wavelength of any unknown light can be found with the help of Equation (2).

3.3 Phenomena of polarization of light

Determination of the specific rotation of a sugar solution by polarimeter: Figure 3 illustrates the schematic set up of the experiment to have a basic understanding of the polarization of light. The angle of rotation of the plane of vibration produced by a substance, in solution or otherwise, is proportional to (i) the thickness of medium (solution) (ii) the concentration of the solution or the density of the active substance in the solvent and (iii) the nature of the substance.

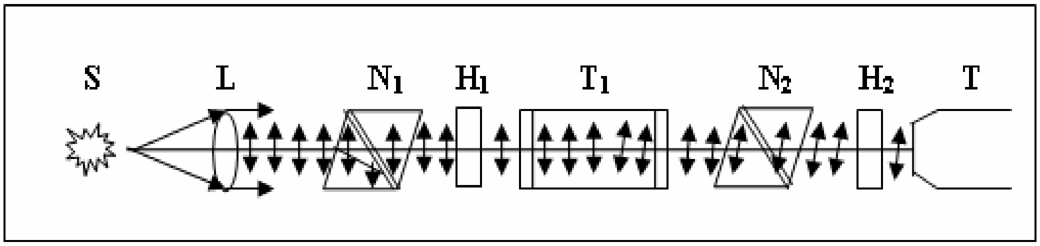


Fig. 3. Schematic diagram of the experiment of polarization of light

If l = 1 decimeter and c = 1gm/cm^3, then specific rotation may be defined as the rotation produced while traversing a path of one decimeter (10 cm) length in the solution containing 1 gm of the optically active substance per cm^3 of the solution.

The specific rotation = (rotation produced by 1 decimeter length of the solution)/(density of the solution in gm c.c.)

The amount of the rotation is usually determined from the experiment by the students and the rotation depends on the temperature as well as wavelength of the light used. The angle of rotation vs. their corresponding concentration of the solution yields a plot of straight line and it then determines the unknown concentration of the solution.

4. Thin optical coating

It is well known [5, 6] that one can improve the properties of the glass by use of very thin surface coatings. For example, one can diminish the inflow of solar energy to 50% (during the summer), without changing the visible appearance with one type of coating. Another type can be transparent to solar radiation but decrease the out flow of heat (during the winter) to 50% of the magnitude in a normal uncoated glass [5, 6].

In large parts of the world the climate is “Warm” during the summer and “Cold” during the winter. It is clear that to improve the quality of livings, to minimize the energy needs in the livelihood and to efficiently utilize the energy consumption, scientists all over the globe are engaged in research on selective surface coating and energy efficiency. The key concept of spectral selectivity is that the glass coatings should have qualitatively different optical properties in different wavelength ranges [5, 6, 7]. A low emittance coating is of particular importance in a cold climate where the coating has unity transmittance for luminous & solar radiation in the wavelength range $0.3<\lambda<3$ μm and unity reflectance or zero emittance in the $3<\lambda<50$ μm wavelength range [8, 9, 10]. The solar control coating is useful in hot climate and the ideal coating should be transparent for visible radiation in the wavelength range $0.4<\lambda<0.7$μm and have unity reflectance at wavelengths $0.7<\lambda<3.0$ μm. With this concept in mind, our group at RU is engaged in research on thin optical coating of metal, semiconductor or even insulating films to make of their use in selective surfaces and devices.

4.1 Specialized experiments on thin optical coatings

Determination of thickness for thin coatings: The objective of this particular experiment is to deposit thin metal or semiconducting thin films and to determine of their thickness as well as of their transmission & reflection coefficients. For deposition of thin films, a vacuum coating unit (Edwards Vacuum Ltd. England) was procured and it has the options to produce the thin films by thermal evaporation as well as by e-beam evaporation technique [11]. To measure the optical properties of the thin coating, our department obtained a Perkin-Elmer, Lambda-19 spectrophotometer as a generous donation by International Science Programs (ISP), Uppsala University, Sweden.

Student in the 4th year Honor’s level usually carry out their projects on thin optical coatings. The bench set-up for determination of the thickness of thin coatings is shown in Figure 4(a). The interference method for the determination of film thickness was done by a method developed by Tolansky [12] to a remarkable accuracy. When the interferometer is illuminated with a parallel beam of monochromatic light, a fringe system as shown in Figure 4(b) is produced. The displacement **I** of the fringes system across the film-substrate step is then measured to calculate the film thickness **t** using the relation

$$\mathbf{t} = \frac{\mathbf{I}}{\mathbf{h}} \times \frac{\lambda}{2} \qquad (3)$$

where, **h** is the fringe height. In this method, the thickness measurement of 3 to 2000 nm can be done with an accuracy of ±1nm.

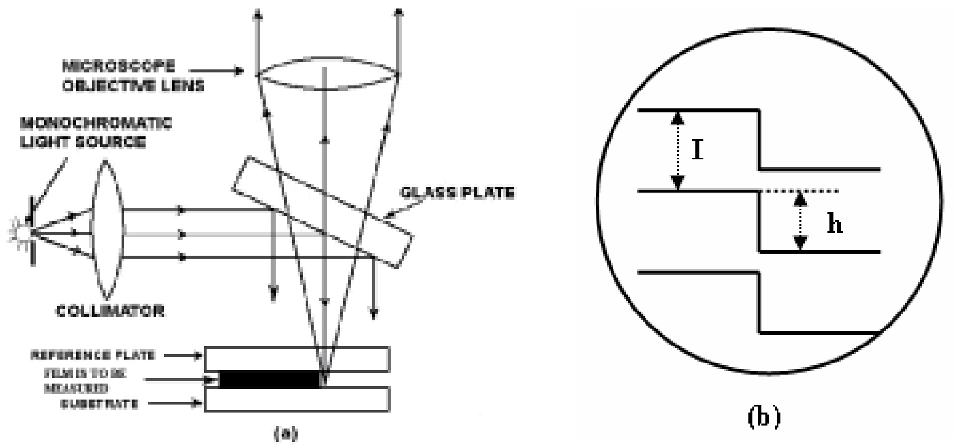


Fig. 4(a). Enlarge view of the interferometric arrangement for the measurement of film thickness; (b) The fringe pattern with step height ‘h’ and fringe spacing ‘I’.

Determination of optical band gap & refractive index: The objective of the experiment is to study the percentage of transmittance (T) and reflectance (R) of thin coatings obtained by its deposition of selected metal or semiconducting films in the selected wavelength range. From the obtained data of transmittance and reflectance spectra, the percentage of absorption (A) is to be calculated. Sample index of refraction is determined indirectly by measuring the transmittance as well as the thickness data by the conventional relation

$$\mathbf{n} = \frac{\mathbf{A n_o}}{\mathbf{T}} \times \frac{1}{\mathbf{ln}\left(\frac{1}{\mathbf{T}}\right)} \tag{4}$$

where, n_o refractive index of glass substrate (n_o = 1.5). From absorption data, the coefficient of absorption in the selected energy interval of the optical spectra helps to determine the optical band gap of the sample.

5. Conclusions

It is shown in our article that without using any sophisticated equipments, the optics education could be conducted in our laboratory and it helps to make understanding of the students the basic concept of optics The development of optics and photonics education requires a large number of well trained and motivated teachers and technicians who should discharge their experiences in teaching to the students efficiently. Most of the research and development in the area of photonics involves the use of optic fiber. We are now planning to revisit our experimental set-up by fiber optic based interferometer in addition of our conventional set-up. The science and teaching methods are truly international and this workshop provides a venue and opportunity for teaching and learning of the participants and has the capacity to bring people closer in both a professional and personal way.

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I.

Using a Research Laboratory for training Students

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Abstract. We present a way to use a Research Laboratory for training students to learn about simple measurements. In most cases, doing research and training students imply conflicting requirements, for instance in a Research Laboratory everything is aligned, some equipment cannot be moved and so on; therefore research and training laboratories are separated. Sometimes however, there is the possibility of using a part or the complete research equipment by the students, without "consequences". As an example, here we describe the way we used a research set up of wave propagation through atmospheric turbulence, devoted to long lasting statistical measurements, to train students in making position measurements and experiments at different levels, starting from beginners up to advanced and PhD students.

1 - Introduction

Typically, a Research Laboratory is equipped with sophisticated apparatuses devoted to specialized experiments and measurements, which are based on technologically advanced instrumentation, used for long-lasting measurements, with small or no flexibility. In most cases, these apparatuses cannot be used for simple experiments and measurements, like those needed for training students, for many reasons, such as the impossibility of removing the instruments from the experimental set up or the need of time to devote to the students and so on.

Training students, on the contrary, requires flexible instrumentation allowing simple and easy measurements and this is generally made in "on purpose" student laboratories. Therefore, there is the need of equipping training laboratories with suitable apparatuses, which in some cases duplicate some of the research instruments and also increases the financial need.

In the past, we set up an apparatus for "local" research on atmospheric turbulence, more precisely to measure lateral fluctuations of a number of "thin" parallel laser beams after a short (few meters) path in the atmosphere. "Thin beam" means a beam whose diameter is not larger than the smallest dimensions of the inhomogeneities of the turbulence. The use of good HeNe lasers, with small divergence, and the short path allow this requirement to be satisfied for what concerns this paper. The apparatus was made flexible to work both in the laboratory and in the open atmosphere. The need of making measurements in the laboratory also originated by the need of testing different propagation theories in controlled turbulence, to develop methods to characterize turbulence and to validate different methods to measure the parameters of turbulence. Without entering the details of this complex research, here I describe the apparatus and some characteristics which make it suitable for training students in the laboratory to learn how to make "static measurements" and also measurements of fluctuating quantities. One of the advantages for the students is also due to the fact that there are some periods along the year that generally coincide with the students training time, when outside measurements are not made. Training in this laboratory can be at different levels, starting from beginners, which can make simple laboratory experiments, up to PhD students, which learn how to make sophisticated experiments.

2 - Experimental set up

The basis of the experimental research is to send a number of parallel laser beams (up to four) through a region of natural, or heater produced, turbulence, to let each beam impinge on a position sensor and to measure a large number of subsequent "instantaneous" positions of each beam on its sensor surface. The data are subsequently elaborated by using statistical programs; the correlations between the fluctuations of the different beams are obtained, which are of interest for the research on turbulence.
The scheme for the horizontal measurements in the laboratory is sketched in Fig 1, where also the menu of different required operations appears.

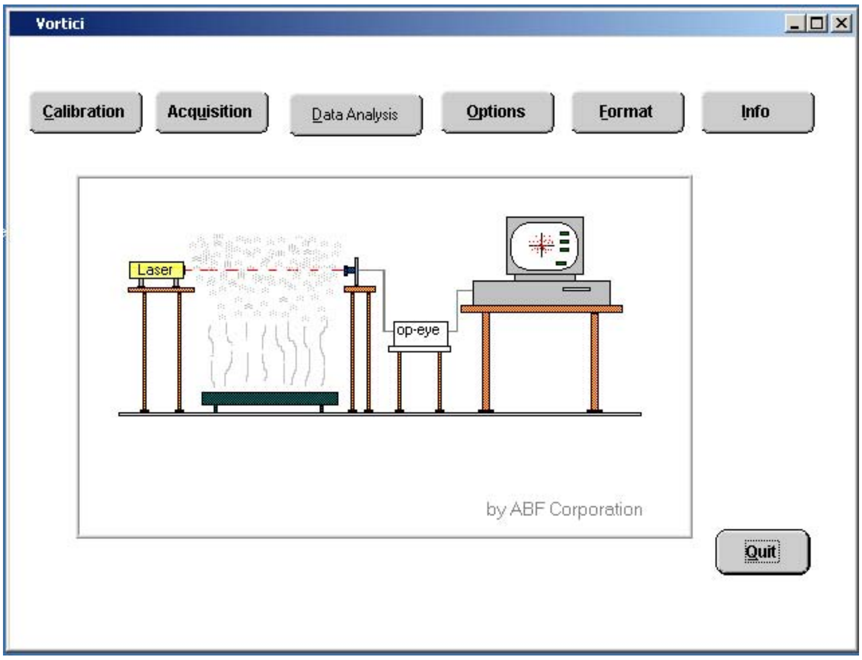

Fig 1 Scheme of the apparatus

The HeNe lasers are located on a movable support, tripod, heavy enough, but easy to carry. The lasers are fixed on a platform, which can be moved up and down and tilted (in the case of slant path) or adjusted to get a horizontal position.
The length of the path depends on the purposes, and in the Laboratory it can reach about 10 m, typical values are around few meters.
At the end of the path, a system of four sensors and amplifier (UDT OpEye) is located on a wood table which is heavy enough to prevent from vibrations. Each eye is located on a three axis micrometric table to allow centering of the beam. On its turn, the amplifier is connected to the acquisition system, which is located on a

wheel table, easy to move.

The possibility of easily moving the different parts of the apparatus is an important feature for the research activity in the laboratory and, mostly, in the open air, to allow different path lengths.

All the system is equipped to work with a maximum of four lasers and four receivers, while for training the students, and sometimes also for research, two lasers and the two corresponding sensors are only used. This is possible thanks to the flexibility of the apparatus and the corresponding acquisition and elaboration software. From now on, I will mostly refer to the two-beam version, in the case of horizontal propagation, which is the simplest configuration and is suitable for the students to make a number of training experiments.

The buttons in Fig 1 indicate the menu of the software and the different operations that can be performed with the apparatus: for the organization of the measurements, for the data acquisition, and to elaborate the data and present the results. The rate of data acquisition can be decided by the user. Here it is kept to a typical value, of 300 data/s, often used for turbulence measurements

3 – Calibration facility

The most useful procedure for training students is the first operation: Calibration. Calibration a is software that allows one to align each laser beam and to center it on the corresponding sensor surface.

With reference to Fig 2 t,he main features of this procedure are here described, with some detail, by also pointing out how they are used for the students.

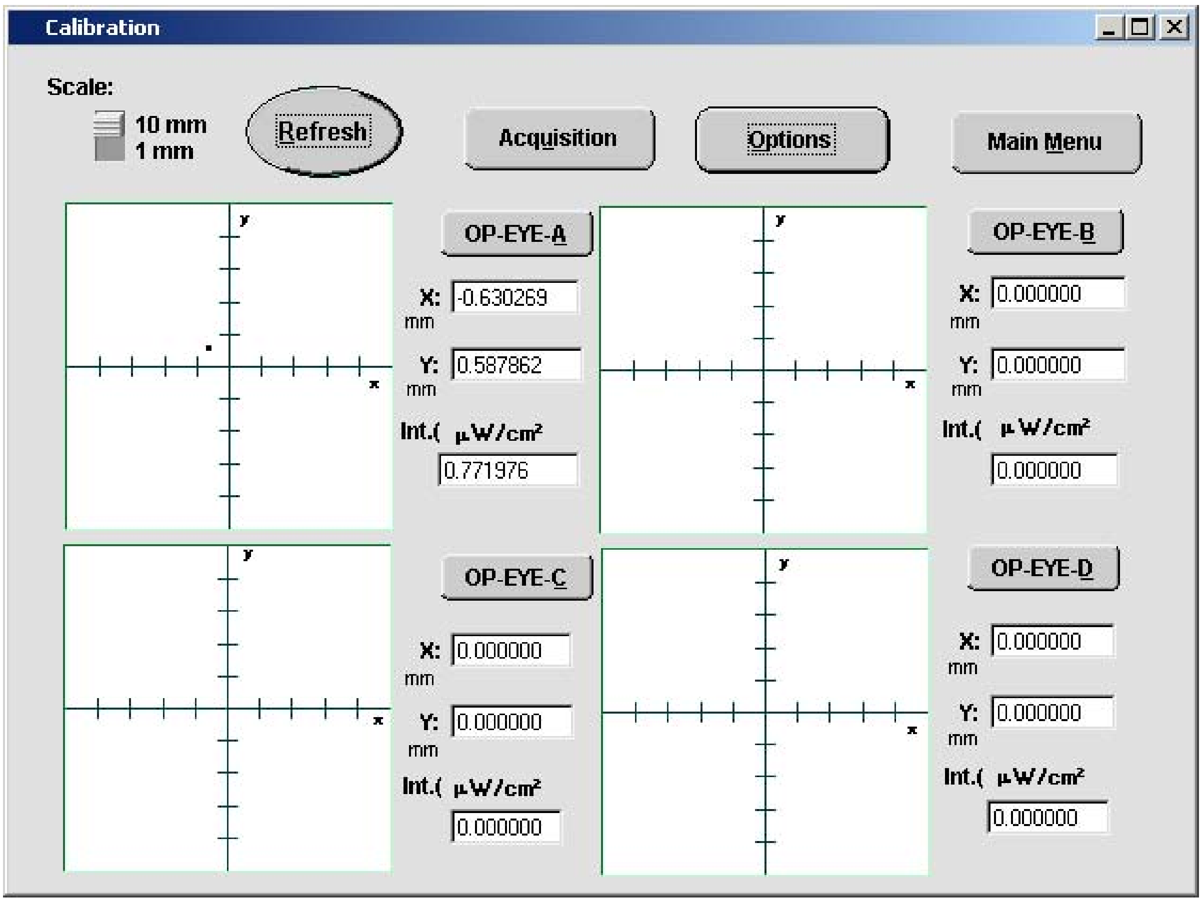

Fig 2 Screen presentation of the calibration of the four sensors

Each sensor, a so-called lateral effect sensor, has a surface of a square with 1 cm side. From each side a current is collected whose value depends on the distance of the "intensity baricenter" of the impinging beam from the side. The difference between the currents of the vertical sides, normalized to their sum, gives a quantity proportional to the horizontal coordinate which, in turn, after suitable normalization, gives the horizontal position, x, in mm, with respect to the center of the sensor which is taken as origin of the x and y axes.
Analogously the difference between the currents from the horizontal sides gives the vertical position, y, while the sum of all the currents allows one to obtain the intensity (more precisely the power density in $\mu W/cm^2$).

Fig. 2 is a representation of the main screen of the Calibration, where the 1 cm^2 surfaces of the four basic sensors appear. In this figure, one (low energy) laser is used and therefore one sensor only (OP-EYE A) is active. Here, for each sensor, the range of x and y is from –5 mm to 5 mm, corresponding to the entire sensor surface. The program also allows one to "zoom" the central mm^2, by using the lever at the left top of the screen, as will be seen in the next figure, where the scales will also be displayed on the axes.
The fact that all four sensors appear on the screen is the only not-flexible point of the software. However it is not a problem and is useful to show simultaneously the students the effect of the dark currents from the unused sensors. The numbers appearing near each EYE are values of positions and intensity "averaged" over a number of data, acquired at the decided rate, as will be seen in the next step.

Entering in one active OP-EYE, e.g. A, the program gives information on all the details of the measurement.
In Figure 3, where the surface of the sensor appears, only the central part (1 mm^2) is selected, as can be seen from the scales of the axes, from –0.5 mm to 0.5 mm. In addition to the averages, the corresponding variances are presented. From the intensity one can see that the power of the laser used here is about ten times higher than that of the previous figure.

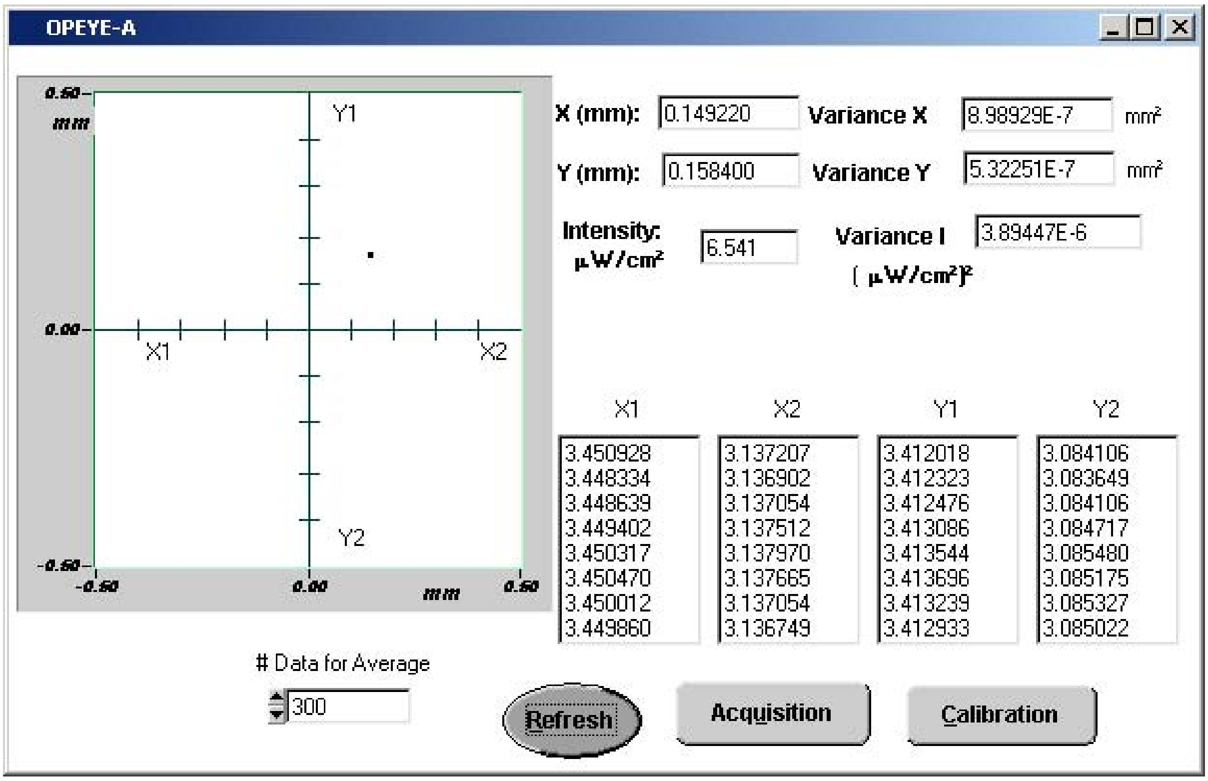

Fig 3 Screen presentation of one sensor calibration at the inner mm^2

As appears from the small box on the left of the figure, the number of data, used here for the averages, is 300 (it corresponds to one second duration of the measurement according to the decided rate). This number can be chosen starting from a minimum of 10. When calibrating the apparatus for research measurements, typical values are of some hundreds, while for the students, when they prepare "static" position measurements, 10 data or few tens are sufficient.

The details of the measurement can also be seen on the four bottom columns, each one giving eight subsequent values of the instantaneous currents from the four sides of the sensor surface. They are very useful to show the students how they vary when the laser spot moves on the sensor, for instance when moving the sensor for centering it, and how their difference vanishes when approaching the center.

It is interesting to note that, in the case of static position measurements made by the students, the variances give immediately the "errors" of the measurements to the students. In the research on turbulence, variances of fluctuations and correlation of fluctuations are of different interest and have different meaning because they are fluctuations produced by the turbulence and carry information on turbulence.

4 - Data Acquisition facility

When the procedure of alignment is completed, one can start the real measurement by using the Acquisition program. As one can see from Fig 4, the Acquisition program allows one to choose the active sensors, the acquisition rate, already mentioned, and the complete duration of the measurement, in seconds.

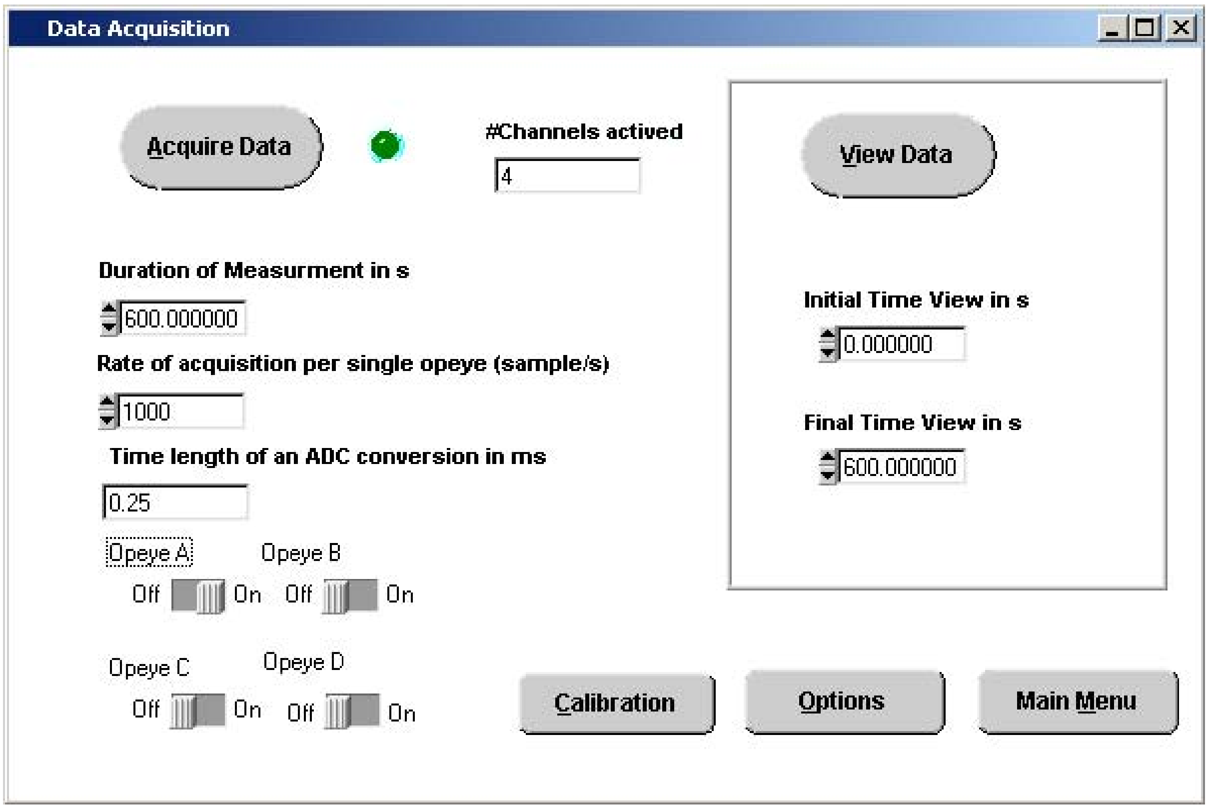

Fig 4 - Menu of the Acquisition Program

For research on turbulence, the duration of each file can go from a minimum of at least some minutes up to hours. The example in the Figure 4 refers to research measurements made with only one laser (at a rate of 1000

data/s) and lasting for 5 minutes (300 s). In static situations the duration can be as small as few tens of seconds or one or two minutes, just to give the students the possibility of dealing with a large amount of data. The information about the active sensors is given to the system by means of the four switches at the bottom left of the figure, and the program informs us about the active Channels: four channels for each sensor. It also informs us about the "Time length of an ACD conversion".
There is some other information required by the program, including comments.

The measurement starts by the button Acquire Data. At the beginning of the measurement, an initially green spot, near the button on the screen, becomes red and returns to green at the end. Waiting immobile and silent during one, two or even five minutes is an interesting experience for the students because they fill directly the time passing. At the end of each measurement, the system produces a file “dat”, labeled with eight numbers corresponding to month, day, hour and minute of the beginning of the measurement. For instance 11171708.dat is a file made on 11 November at 5:08 pm (17:08 in 24 Hours). No information is directly given about the year, which generally labels an external envelope. With the data file, another initial (.ini) file is produced with the same name containing all the information of the acquisition.

5 - Elaboration programs

There are several elaboration programs, which were developed along the years. The last and more complete one includes correction for the non-linearity of the sensors and allows one to split the entire duration in evaluation subintervals. For the students we generally use a good previous program, where the evaluation includes the entire measurement duration and the non-linearity is corrected.

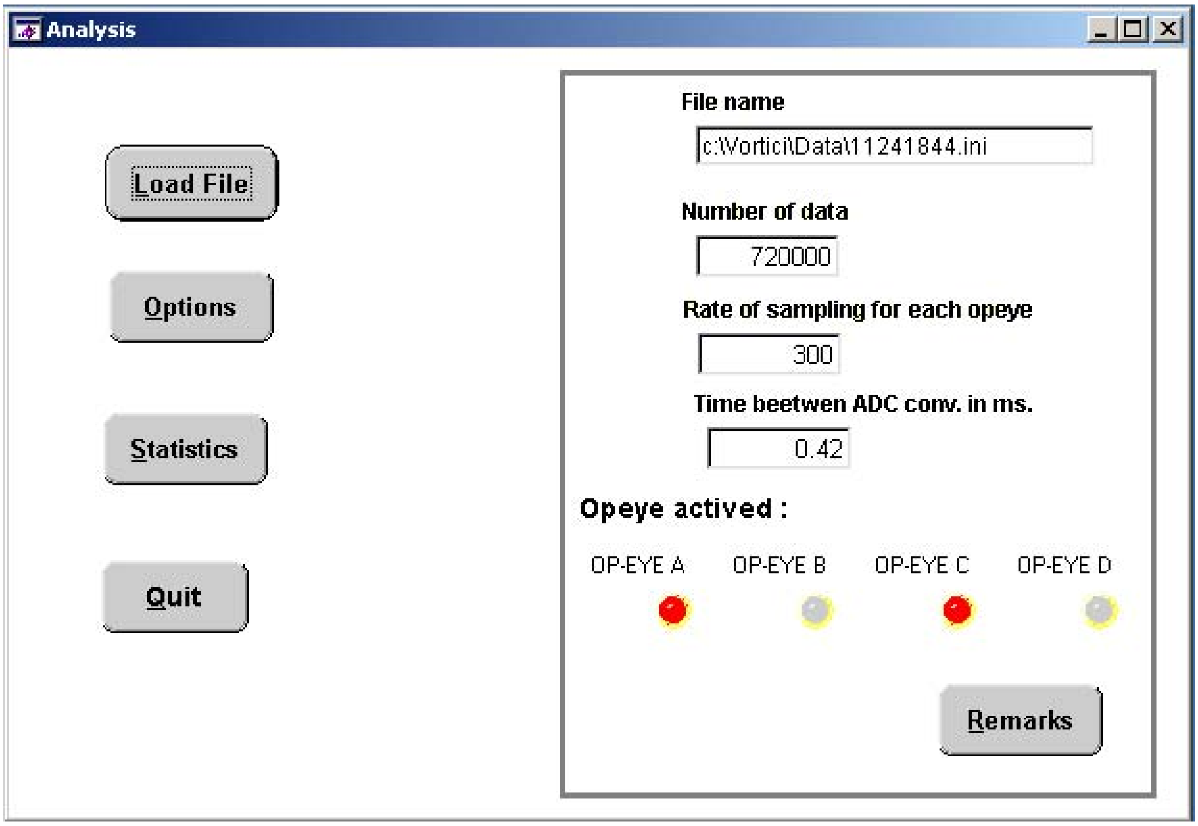

Fig 5 - Menu for the elaboration

As appears from Fig 5, the first step is to load the file one wants to elaborate: File name. The example is from laboratory training in 2006, when the students of an advanced course measured and elaborated the position fluctuations of two beams, due to turbulence, to the purpose of obtaining the correlation functions of the lateral fluctuations. On the right side of the figure, in addition to the name of the data file, the information from the initial file is represented. Here we know that the data were obtained with two laser beams, impinging on OP-EYE A and C respectively, on November 24 at a rate of 300 data/s at h 18:44 (h 6:44 pm). As in the data files the original four currents of each sensor are recorded, the number of data here (720 000) represent the total number of currents recorded from the sensors. The duration of the measurement was 300 s =720000:(300x4x2). Thinking about how to obtain this time is a very useful exercise for the students.
The Options button allows one to activate also the optional program of the correlations while the Statistics button starts the complete evaluation.

An example of elaboration results is given in Fig 6, which refers to the results of an advanced experiment of a student for her thesis degree (Laurea) in Physics, in 2004. She investigated the effect of wind and heating on an ensemble of four parallel beams in the laboratory, with the beams located at different distances from a system of heaters and fans.

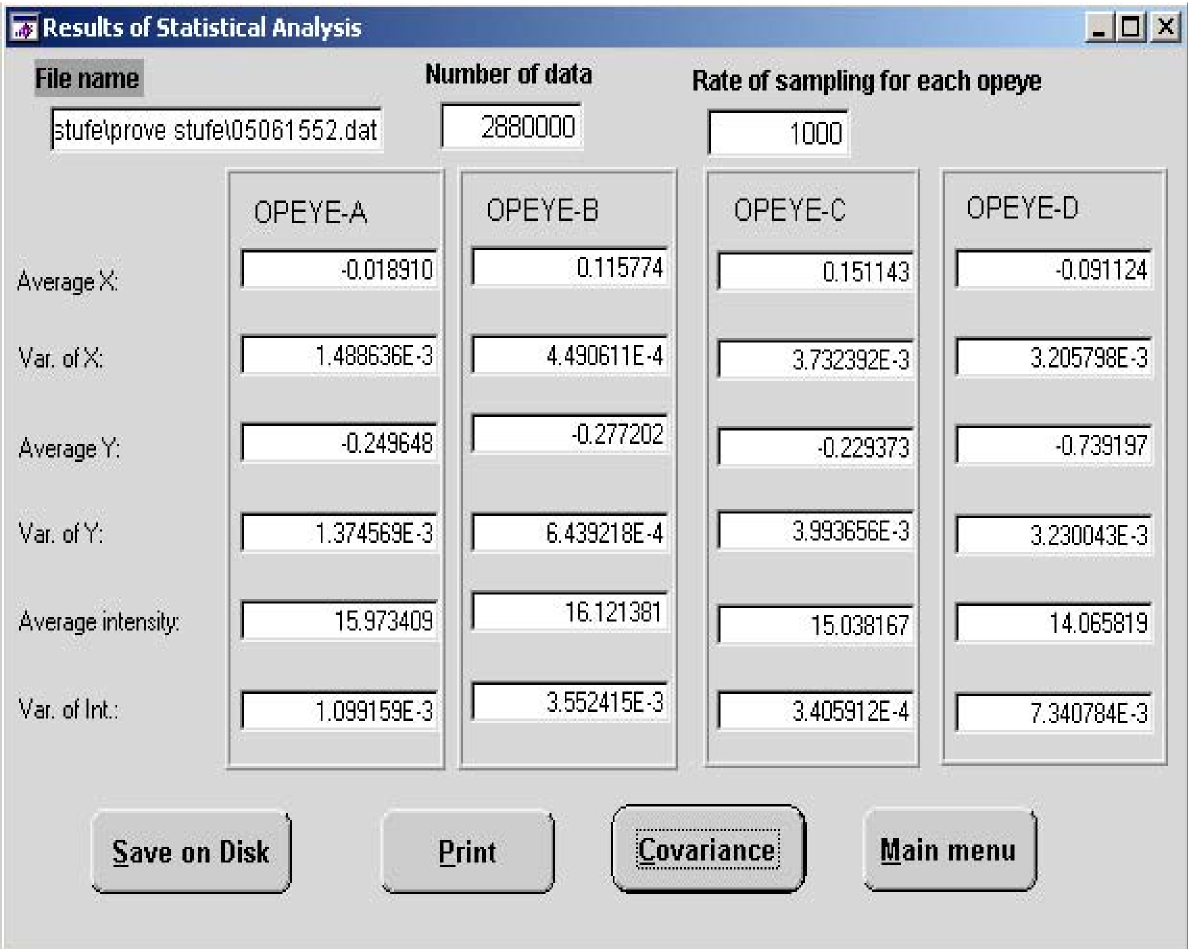

Fig 6 – Example of results

In the figure the first page of the obtained results, as they appear on the computer screen, is represented. A second page, accessible by the Covariance button and showing the correlations results, is not presented here.

First, information on the date of measurement, number of data and rate of sampling is given. Then a column for each sensor shows averages and variances. All coordinates are in mm, their variances in mm^2, the intensity is in $\mu W/cm^2$ and the intensity variances in ($\mu W/cm^2$). Although the order of the beams is not of concern here, it can be interesting to know that the beam impinging on OPEYE-C was the nearest to the heaters and fans, and then beams D, A and B followed at different spacing.
Another useful program, developed for our research, allows one to plot versus time the instantaneous values of the positions and intensity of the four OPEYEs, by choosing the percentage of data to use, typically 10%. This program is very useful for checking the quality of the measurement. For instance, once, in outside measurements, a fly crossed one of the beams and this was clearly seen on the plot.

6 - Experiments made in training students

Due to the flexibility of the apparatus, many different training experiments were made and many others are feasible, for students at the different levels. Here there is a list of some experiments already done several times, by using the apparatus:

-Simple position measurements of a "static" source at different source positions. For beginners.
-Measuring the pointing and intensity stability of a HeNe laser, in time, during several hours, typically 8 hours, by making samples at established intervals. For beginners.
-Profiling the Gaussian shape of a laser beam (this requires a pin hole in front of the sensor and, if the beam is not large enough, enlargement by a few meter propagation). Intermediate level.
-Measuring the "apparatus and room noise" on the position of a laser beam after one or two meters path. Intermediate level
-Verification of the effect of intensity instability on position measurements. Advanced level.
- Measuring the non linearity of the sensors outside the inner part, in the horizontal and vertical direction. Intermediate level. An improvement of this experiment, for higher level students, consisted in mapping the non linearity through the entire surface and comparing it with theoretical expectations.
-Measuring the M2 factor of a laser. Advanced level.
-Effect of the "room turbulence" on beam wandering of two parallel beams, when the path is relatively long, and correlation between the wandering of the beams as a function of their separation, to the purpose of deriving information on the dimensions of the turbulent eddies in the room. Very advanced level, PhD.
-Effect of a turbulent layer: measurement of wandering of a beam and comparison with that in the absence of turbulence. Intermediate level. A more advanced experiment consists in measuring the beam variances (and correlations) as a function of the distance of the layer from the sensor, and comparison with the theory.
-Enhancement of fluctuations by double passage of a beam through the same layer of turbulence. PhD level.

At the end, I would like to mention here that, in our research laboratory, students can also make a number of experiments and see a numer of demonstrations, for instance on diffraction and interference, without using the research apparatus. They were not described here.
For the sake of completeness some references on this research are listed here below.

Acknowledgement:

I would like to mention that all things that I described here are also the results of the work of a number of students, of different level, some of which also collaborated in the research, and whose interest stimulated me to do this training activity in the past years. In particular, the ABF Corporation of Fig 1 was a joke of three Post Doc students, Agabi, Bezzi, Fusco, who organized, on a PC, the acquisition, previously made by means of Apple Computers. Gianni Paoli, student, and my research collaborator, Claudia Innocenti, made many subsequent improvements in the analysis and elaboration programs. I thank all of them.

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II.

University of Toronto Institute for Optical Sciences Collaborative Program in Optics

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Abstract: We describe the activities of the Institute for Optical Sciences (IOS) at the University of Toronto towards the establishment of a Master's Program in Optics. The IOS was formed as a collaboration between faculty members interested in optics from the four departments of Physics, Chemistry, Electrical and Computer Engineering and Materials Science and Engineering. One of its goals is to serve as unifying entity for graduate and undergraduate programs in optical sciences. The details of the proposed graduate program will be discussed. It will be set up in the form of a collaborative university program, where students must satisfy the requirements of one of the four home departments, as well as a set of IOS-specific requirements of the program. IOS-specific activities include attending the Distinguished Visiting Scientist Series, participation in a best-research-practice mini-course, where essential research skills are discussed, as well as participation in an annual internal conference. The benefits of this interdisciplinary program, for students, faculty and relevant industries are discussed. The students will benefit from a wider exposure and a more coherent curriculum. The IOS will also serve as local community within the campus to which students could belong and network. Faculty, on the other hand, will benefit from a reduced teaching load, as redundancies among the departments will be removed.

1. Introduction

The understanding and practical use of optics and photonics is, by its very nature, a multi-disciplinary activity. Since there exists no single material that performs all necessary optical functions, as is the case in electronics, significant materials research is necessary, requiring expertise in chemistry and materials science. Understanding the various optical phenomena and the interaction of light and matter requires knowledge of optical physics, solid-state physics, electromagnetism and wave propagation. Finally, for the effective design of optical devices an engineering approach to the problem is best. Therefore, developments in optics benefit greatly from interdisciplinary collaborations. Faculty members with an interest in optics, and the corresponding research at the University of Toronto, were traditionally separated in several departments. The Institute for Optical Sciences at the University of Toronto was founded in order to provide a common home to professors with a shared interest in optics, and to encourage collaborations in this multidisciplinary field. The Institute is a network of 27 faculty members from two faculties and four departments, spanning the disciplines described above.

Along with the separation of optics research into several departments, student education in this field is also divided. As a result, students will try to receive an education in optics while registered in any of the four departments of Physics, Electrical and Computer Engineering, Chemistry or Materials Science and Engineering. Unfortunately, none of these departments offers a complete coverage of the field. Students with a strong interest in optics will try to find courses in other departments, in addition to those of their home department. This practice is not widely advertised, however.

The division of students into four departments, in addition to limiting their access to relevant courses, also limits their interaction with peers studying the same problems. Each department has a few yearly events meant to form a community among their graduate students. There are, however, no inter-departmental events fostering a community among students with similar academic interests. This lack is felt particularly strongly in multi-disciplinary fields such as optics, with students working on very similar topics who do not know about each other, due to the lack of communication between graduate students of different departments. Some students may learn about each other's work when taking courses together, but as mentioned above, this is not a common practice.

With a large number of expert faculty working in the general areas of optics and photonics, as well as many relevant courses, the University of Toronto has most of the resources needed to offer a graduate program in optics. For this purpose, it would only be necessary to combine these resources, which are presently scattered among the four departments. As a result, the most natural route is to set up a graduate program in optics as a collaborative program, combining courses already offered by the four departments.

2. Structure of a Collaborative Graduate Program at the University of Toronto

All graduate programs at the University of Toronto are administered by the School of Graduate Studies (SGS), which in turn is governed by the rules of the Ontario Council on Graduate Studies (OCGS). Fortunately, the SGS and the OCGS already have mechanisms in place for collaborative graduate programs combining courses and resources from multiple departments [1]. The main goal of a collaborative program is to offer an additional multidisciplinary experience for students, who are enrolled in one of the participating home programs. This added value is usually obtained from courses offered in the collaborating programs, or through a multi-disciplinary focus of the thesis.

Being a collaboration among several existing program or departments, such a program does not need significant new resources. In particular, students are admitted to, and registered in, one of the participating departments, and need to fulfill all requirements of that department. In addition to this, they are admitted to the collaborative program, which usually involves some additional requirements. In particular, a collaborative program must add value to what is normally available in a single department. It must also provide a common learning experience, which usually takes the form of a core course, or a seminar series. For programs with a thesis requirement, it is expected that participating students' thesis topics will be in the area of the collaboration. Since they fulfill all requirements of their home department and home program, students will receive a degree for that home program. The degree will carry, however, a mention that the student participated successfully in the collaborative program.

Each department or home program participating in the collaborative program must do so in a meaningful way. The departments should normally have faculty members whose research focus is in the area of the collaborative program, but participation can also be achieved if students of a department participate in the collaborative program, or if the program makes use of some shared facilities or courses from a given department. Finally, each participating department will have a number of *core faculty members* of the collaborative program. These are the members with an interest in the focus of the program.

A collaborative program is governed by a program committee, under the leadership of a director. The program must also be able to approve the granting of the degree designation to the graduate students. This is normally achieved by the presence of a collaborative program faculty member on the thesis examination committee, or by a collaborative program representative approving the recommendation for degree completion.

The structure of the collaborative program, as defined by SGS and OCGS make this a nature choice for the graduate program in optics, as most goals of the optics program align well with the requirements of a collaborative program.

3. The Collaborative Program in Optics

The Institute for Optical Sciences already fulfils many of the requirements for a collaborative program. It has faculty members of all four participating departments, which will naturally form the core faculty members of the collaborative degree program. Most graduate students of these supervisors have optics as their main thesis focus, satisfying again the requirements if they were to enroll in the collaborative program. A number of optics courses are already being offered by the four departments. Furthermore, the IOS already offers several common activities for students aiming to build a community of optics students at the University of Toronto. As a result, the Institute for Optical Sciences is in the process of setting up a collaborative graduate program in optics at the University of Toronto.

As a first step, the IOS will set up a Collaborative Master's Program in Optics, with a PhD program to be added in future years. Eligible students will be those admitted to one of the four departments of Chemistry, Electrical and Computer Engineering, Material Science and Engineering and Physics. While students of IOS faculty members will be encouraged to register in the program, it will be open to all students in these departments. They will have access to courses from all four departments, with the requirement that at least one course be taken from outside their home department.

3.1. Building an Optics Student Community within the University of Toronto

A very important OCGS requirement for collaborative programs is the common activity for all students. This is particularly important, since students are registered in different departments, and have little opportunity to interact. As they share a common interest in optics, however, they need to interact and draw value by exchanging different viewpoints – which necessarily come from the different departments – on the same subject.

To reinforce its international profile, the IOS runs a yearly *Distinguished Visiting Scientists* seminar series. In this series, four world-renowned scientists each spend two weeks at the IOS and give a series of four lectures aimed at optics graduate students. The extended stay is meant to foster individual contact between IOS students and the visiting scientists. In order to introduce students to each other more directly, the institute also runs a series of bi-weekly seminars, where students present their research topics to their peers. The presentations are complemented by formal introductions of students, and informal networking. The IOS also delivers a series of best practice sessions, teaching students essential skills for the optics laboratory and for research work in the field of optics. Finally, the institute organizes a series of professional skills activities, to supplement the very strong technical training of the students with essential business skills. When the collaborative program launches, the IOS will also set up an optics conference, where students will present their latest research results. All these activities are open to IOS students from all four departments, encouraging the formation of an optics student community at the University. Students registered in the collaborative program will be required to participate in these activities. In order to give credit for student participation, these activities will be collected into a new IOS course. No numerical mark will be received in the course, only a pass/fail status; the course will not involve an additional teaching load.

3.2. Organization of the Collaborative Program

The collaborative program will be overseen by a graduate program committee, with one member from each participating department and a chair. When selecting members for the committee, the aim is to find members of the IOS, who are also on their departmental admissions committee, and will therefore be able to make an informed decision about admissions to the collaborative program as well. In order to satisfy the requirement that the collaborative program be able to approve the granting of the degree, an IOS faculty member will be required to participate in the thesis examination committees for the students.

The chair of the committee will be the director of the IOS. While the individual courses of the program will be offered by the participating departments, the Institute for Optical Sciences will organize all other common activities of the program, including the sessions on the best practices in optics research. The institute will also be responsible for the detailed administration of the program through its academic program coordinator.

3.3. Related Activities of the Institute for Optical Sciences

Being committed to student education, the Institute for Optical Sciences is also in the planning stages of a course on experimental methods in research, which will become a central part of the collaborative program in optics. The course will teach incoming graduate students useful techniques to be used in a research lab, with an emphasis on optics. Topics to be covered include alignment of optics, signal to noise analysis, etc. Students participating in the collaborative program will be encouraged to take this course. For undergraduate students, the IOS will offer a course on holography, demonstrating many principles of optics, such as interference and diffraction, in a visual way.

4. Benefits of the Collaborative Program

The collaborative program brings benefits to both the students and the participating departments and faculties. Students will have access to a wider range of courses, which provide a more complete coverage of the field of optics. They will also benefit from the participation in the best practices sessions, the optics conference and an optics retreat to be organized by the institute. All these activities will result in the formation of a community among the optics students, which currently does not exist: at the present time the optics student body is segregated between the various departments, with few opportunities for communication between them. Finally, by receiving the special mention on their degree, students will receive credit for participating in an innovating multi-disciplinary program, and will be able to demonstrate their commitment to optics to future employers.

By working with the four departments, the IOS will also ensure that the curriculum will be more consistent. At the present time, optics courses at the University of Toronto are introduced by each department independently, with little regard to overlaps or gaps with the courses of the other departments. The IOS is working with faculty members in the four departments to identify such areas of overlap. The university and its faculty will benefit from a reduced teaching load, by removing any redundancies between the courses offered by the four departments. Since there are few such specialized programs in Canada, the program in optics will also demonstrate the university's commitment to pursuing an area of study of great importance in today's technology based economy.

5. Summary and Conclusions

The collaborative program in optics of the Institute for Optical Sciences will bring together students from the four departments of Chemistry, Electrical and Computer Engineering, Materials Science and Engineering, and Physics who share an interest in understanding and using light. This is a natural continuation of the way the IOS connects researchers from these four departments with a common interest in optics. Although students can already take advantage of courses from other departments, and of many of the activities already offered by the IOS, the collaborative program will organize these in a coherent fashion, and give credit to students for their participation.

At the present time, the preliminary proposal has been approved by the School of Graduate Studies and work is currently under way to define the exact program requirements. In addition to internal approval at the University of Toronto, the program also needs to be approved by the Ontario Council on Graduate Studies (OCGS). The collaborative Master's program is, however, only the first step in the introduction of optics programs at the University of Toronto. This will be followed by a collaborative PhD program and in the longer term by an undergraduate program in optics. Together, these programs will provide our students with a complete optics education, from an institution that is already world-renowned for its work on optics.

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I.

Science and Fun in a "Magic Show of Light" from *Optical Demonstrations on an Overhead Projector* for elementary school students.

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Abstract: We seek methods of stimulating young school children to develop an interest in science and engineering through a natural curiosity for the reaction of light. Science learning now begins fully at middle school. Reading skills develop with activity at home and progress through the elementary school curriculum, and in a like manner, a curious interest in science also should begin at that stage of life. Within the ranks of educators, knowledge of optical science needs to be presented to elementary school students in an entertaining manner. One such program used by the authors is Doug Goodman's *Optics Demonstrations With the Overhead Projector,* co-published by and available from OSA (Optical Society of America) and SPIE-The International Society of Optical Engineering. These demonstrations have found their way into middle and high schools; however, as a special approach, the authors have presented *selected* Goodman demonstrations as a *"Magic Show of Light"* to elementary schools. Both students and faculty have found the show most entertaining! If optical knowledge is utilized to stimulate science learning in the coming generation at elementary school level, there's a good chance we can sow some fertile seeds of *advancement for all future segments of the workforce*. Students can enjoy what they are doing while building a foundation for contributing gainfully to society in any profession. We need to explore expanding exposure of the *"Magic Show of Light"* to elementary schools.
OCIS codes: (000.2060) Education

1. OPTICS EDUCATION NOW AND FOR THE FUTURE

1.1 Getting "Out of the Box"

Successful education produces individuals who possess a large foundation of conceptual knowledge coupled with a wide range of problem-solving and communication skills. While memorizing is important, largely in organizing concepts, practicing effective reasoning develops habits of logical analysis and focused searching for solutions. In addition, the pursuit of scientific principles requires clear and accurate communication, often a nontrivial goal. The word from higher academia and the workplace is that significant portions of today's high-school graduates are missing technological, problem solving, and communication skills.[1]

Root causes for the current educational dilemma come from many directions. One such cause could be the emphasis on rapid action. Then too, there's "the box." Yep, that ubiquitous computer and its "box" counterpart, TV, have invaded our lives, and the world, with excessive attention to on-screen images… *Haven't we all heard about "out of the box"?*

"For a whole generation of kids, direct experiences in the backyard, in the tool shed, in the fields and woods, have been replaced by indirect learning, through machines," states Frank Wilson, medical director of the performing-arts health program at the University of California School of Medicine (San Francisco. CA). "These young people are smart, they grew up with computers, they were supposed to be superior--but now we know that something's missing."[2]

So what does a member of the optics--or education--community do to solve such problems, or at least work to correct them? *Answering deals with* ***the when*** *and* ***the how***.

First, though, it's important to recognize that math and science education produces extended skills, assuming students have good reading skills (another essential subject we don't have room to discuss here). Those extended skills force the student to engage the mind *"out of the box"*--not exactly what a "cyberspace-educated" middle- and high-school student readily embraces.

1.2. "THE WHEN" - Early in Life

We really need improvement in science and math education, which most often begins in middle school. Good reading skills are developed with activities at home and in the elementary school curriculum, and in a like manner, interest in math and science learning also needs to begin at that stage of life. If a young person has not been stimulated to have an interest in the logical analysis and focused-solution approach before reaching middle school, it is going to be hard--most likely impossible--to get going. There are always exceptions in any grouping; however, let's consider what can be done for the elementary school student body in general to improve awareness and interest in math and science.

Learning skills proceed most effectively when learning is both fun and informative. Since math and science are based on a foundation of logic, it follows that their basic knowledge is most useful in life--even if one does not choose to pursue a career in science. Just consider the implications of a generation of students implanted with the notion that science is fun!

Fig. 1. Douglas S. Goodman "Optics Demonstrations With the Overhead Projector"

1.3. "THE HOW" - An Educational Presentation to show Science is REALLY FUN

Within the ranks of SPIE, there is a wealth of knowledge easily accessible to expose science to elementary school students in an entertaining manner. One such program is Douglas Goodman's *Optics Demonstrations With the Overhead Projector*[3], co-published by and available from OSA and SPIE, Fig. 1. The demonstrations have already found their way into middle and high schools; however, a special approach is required for elementary school demonstrations. Performing a select set of the Goodman demonstrations as a *Magic Show of Light* is extremely well received by elementary school students. Demonstrations need to be chosen for their simplicity and entertainment. In so doing the demos can really hold the limited attention span of elementary school students, who get quite excited at the action. A sampling of the Goodman demonstrations that work well for elementary school students include Lamp Reimaged, which uses a simple lens to show what the projector lamp looks like; Handedness or Parity, which involves rotating an image around the room with a mirror; and Rainbow, which shows how light through a water drop creates a rainbow.

A major impediment to convincing elementary school teaching staff they can present the Goodman demonstrations is an understandable lack of knowledge in the science of optics. Yes, it wouldn't be appropriate to "lecture" on a subject of which one is not knowledgeable, for questions from the audience would become problematic. So what we must do is shift the activity from being perceived as a "lecture" to an opportunity for "entertainment".

We are currently experiencing movement to promote bringing science into the elementary school curriculum. A *lesson plan stimulating optical scientific curiosity* will create just such an event, which hopefully can someday become part of a National Science Education Standard for Teaching at elementary school. To that end what follows is an introductory Magic Show Script. Presenters need only follow the script with freedom to "ad lib" according to reactions of the elementary school "audience". *It is imperative to keep in mind the presentations are to be purely entertainment…. **NOT A SCIENCE LECTURE!***[4]

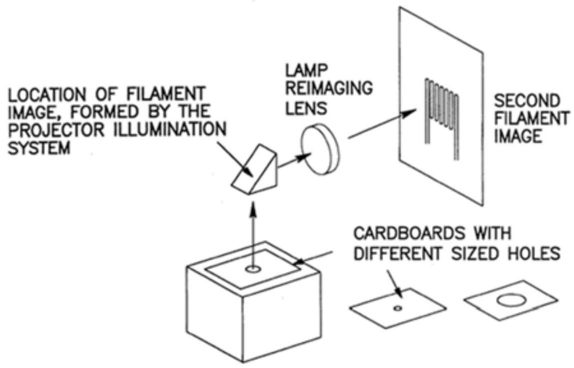
It really works! *(See the Epilogue.)* Try it with the *Introductory Demonstration Script* that follows and watch for more details of a full production script "*coming soon to a classroom like yours*".

2. AN INTRODUCTORY DEMONSTRATION FOR THE MAGIC SHOW OF LIGHT - WHERE MAKING SCIENCE FUN IS IN FOCUS!

…Today I am bring you a Magic Show of Light, but I will break the Magicians' rules and give some hints about how the magic tricks are done.

LAMP REIMAGED

The lamp image at the projection lens can be reimaged at the screen with an additional lens.



The image of the lamp that the Fresnel lens forms is not a sharp one. (The normal functioning of the projector does not require a sharp source image.)

A cardboard with a hole on the platen makes the source image sharper by stopping down the Fresnel lens. The smaller the hole, the sharper the image.

To reimage the source on the screen, a second Fresnel lens works well, since the diameter of a Fresnel lens may be large relative to its focal length.

Lamps without integral reflectors make nicer images.

OVERHEAD PROJECTOR
11

Fig. 2. Lamp Reimaged Demonstration from Doug Goodman "Optics Demonstrations with the Overhead Projector"

…Deep inside the box at the bottom of the projector is a very bright light bulb.

…I have in my hands a "Magic Lens" with which we will look into the box and find the light bulb.

…**There it is**! *(See Note below.)*

…**Look**, you can see the bright wires that are in the middle of the light bulb.

…The wires are glowing very hot which makes the light for all the fun we will have today.

…We can see the wires because this "Magic Lens" reaches inside the box and puts a picture of the wires on the screen for us to see.

Note to Presenter:

1. It is important to use the cardboard with a hole in the center.

2. To focus the lamp image - hold the lens by the edges and place it in the center of the beam on the side of the projector head facing the screen as shown in Fig. 2. Move the lens **slowly** toward the screen along the axis of the beam from touching the projector head to a point where the image appears in focus on the screen. (The results are quite spectacular!)

3. A LIST OF GOODMAN DEMONSTRATIONS ADAPTABLE TO A " *MAGIC SHOW OF LIGHT*"

Technical description pages from *Optics Demonstrations with the Overhead Projector* listed in suggested order of presentation for the *Magic Show of Light* are presented in the following table.

Table The Suggested Order of Presentations

No.	TITLE	SECTION	PAGE
1	Lamp Reimaged	Overhead Projector	11
2	Handedness or Parity	Overhead Projector	7
3	Object and Image Rotation	Imaging - Basic Properties	10
4	Image Revolution Without Rotation	Monochromatic Ray Optics - Prism	15
5	Lens Sharing	Imaging - Additional Optics	15
6	Rotating Transmission Scanner	Monochromatic Ray Optics - Plane Parallel Plate	8
7	Total Internal Reflection	Monochromatic Ray Optics	19
8	Imaging Through Turbulent Media	Imaging - Degradation	44
9	Wave Patterns	Monochromatic Ray Optics - Miscellaneous	18
10	Complimentary of Transmitted and Reflected Light	Interference Colors	5
11	Absorption Spectroscope	Spectroscope	3
12	Rainbow	Polychromatic Ray Optics	8
13	Varying Syrup Distance Through which Light Passes	Polarization - Optical Activity	35
13a	Polarizer Material Sources	Polarization	9
13b	Some Practical Considerations	Polarization	6
14	Patterns with Different Periods	Moiré	7

4. PLANTING SEEDS FOR THE FUTURE OF ELEMENTARY SCHOOL EDUCATION

If optical science is utilized to stimulate the coming generation at elementary school level, there's a good chance we can sow some fertile seeds of advancement for all segments of the workforce. The goal is that the students will not only enjoy what they will be doing but also will be contributing gainfully to society in the future.

Fig.3. Joe Lones, Nadya Maltseva, and Kurt Peterson - Advocating Science for Elementary School

5. EPILOGUE - ON BIRTH OF THE *MAGIC SHOW OF LIGHT*

SPIE Members Reach out to Improve Science Education[5]

If you were to ask a group of 5th graders what they wanted to be when they grew up, what percentage of them would you expect to say, 'I want to be an optical engineer!' ZERO, perhaps? Right you are! And why is that? The answer may seem obvious, but its importance shouldn't be over looked: THEY DON'T KNOW WHAT AN OPTICAL ENGINEER IS. The result of the same experiment on a group of high school seniors would probably not be much different. At a time when few students are electing to pursue careers in science, and demand for trained optical scientists and engineers is on the rise, it is important to let people know what we do and why we love it.

SPIE member Doug Goodman helps entertain a group of 5th graders from Brookline, Massachusetts each year when they visit Polaroid's Optical Engineering Department. The students play with optical toys, tour the facility from the machine shop to the vacuum deposition chamber, delight in optical demonstrations performed by Doug with an overhead projector, and then ask questions. How many of these students would you expect to say they wanted to be optical engineers? After a show like that, I wouldn't be surprised if half of them spent at least the next week dreaming about playing with light all day, just like that cool scientist Dr. Goodman.

Joe Lones, SPIE Fellow member and President/CEO of Adroit Engineering, Inc., has had the opportunity to take some of Doug's demonstrations on the road. He sent me the following description of his first performance in front of an elementary school audience, with which I will leave you.

It becomes both a challenge and fun to stimulate young student minds using science demonstrations with a little imagination. Optics probably is one of the most portable of the sciences that can grab the attention of a younger generation - provided it is presented in a context that is both informative and entertaining. When professionals share their world of satisfaction in scientific endeavor it can launch a new generation of problem solvers over unlimited fields often unrelated to the original exposure. What follows is but one success story not at all uncommon when students find science and engineering can be fun.

The San Diego Section of the Optical Society of America has embarked on an endeavor with the cooperation of SPIE to assemble a demonstration kit to perform the classical Optics Demonstrations on an Overhead Projector ingeniously created by Doug Goodman of Polaroid. These demonstrations have proven to be quite popular in middle school and high school classrooms.

Giving absolutely no thought to the idea that Goodman's Demonstrations were determined above the heads of the elementary school crowd, this father responded to his daughter's request to appear in her teaching classroom on a day that the entire school would be having a Science Discovery Day. After all, in the eyes of daughters, daddies are supposed to know everything, so this project was launched with confidence on all sides. Dad had decided that he'd have no trouble finding words appropriate to a group of third graders. However, approaching the big day, daughter informed Dad that… since this would be a day of science for all the school, the principal had requested a change of venue for the visiting science demonstration. Dad would be performing before an assembly of the whole school!

By due process Dad's confidence was thoroughly rattled when, on the way to the school, it suddenly became a grim reality that the audience would consist of young minds in the stages of development from kindergarten to the sixth grade! As setup was completed and the room filled with students, faculty, and even the entire cafeteria staff, Dad was still wondering what he's going to do with this crowd? Anyhow, one very important item loomed in his favor… No one out there had the foggiest idea what was about to happen.

This being a last minute change in the schedule, no announcement had been made except that a third grade teacher would introduce her Dad.

With elementary school students assemblies lasted usually thirty minutes, only a few of the optical demonstrations were selected. Dad was getting down to the wire for starting this debacle, and then an amazing thing happened. Pulling from early childhood memory of just such an assembly and remembering the delight when a magician regularly came to be featured, dad announced to a gleeful reception that a "Magic Show of Light" would begin. It was then announced that as a special treat for everyone, the magicians' rule would be broken by explaining how all the tricks would be done. Let me tell you, that place went up in pandemonium then quickly hushed at energizing of the projector for a screen of many colors starting the show.

Lenses, prisms, mirrors, filters, and slits went into the projector's optical path to applause at every event on the screen, the walls, and the ceiling … followed again by immediate hush as the phenomena was concisely explained to *the sixth graders in the back of the room. In the end there was a spectacularly messy Karo syrup polarization demonstration followed by a five-minute overtime encore of moiré fringe patterns eliciting laughs around the room.*

All done, dad packed his stuff in the car, departed, and received a startling phone call from daughter that evening: Dad was now in big time trouble! He has been invited to bring the "Magic Show of Light" back every year! That day was the first time the school staff could recall experiencing an assembly without one student misbehaving.

Just maybe, someday, there's gonn'a be a few scientists and engineers emerge from those eager young minds… And that's just plain fun to contemplate!!! – Thanks to Doug Goodman!!!

Acknowledgments

Generous participation of members of the Optical Society of San Diego, a Chapter of the Optical Society of America, for assembling original props used in presenting Douglas Goodman Demonstrations

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I.

An Activities-Based Course in Optics for Non-technical Majors

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Abstract: Teaching Optics to students without a technical background lends itself particularly well to activities-based methods. Restricting the discussion to a lecture format, even if demonstrations are included, misses the opportunity to have students directly investigate something which is, quite literally, right before their eyes. At Southern Illinois University Edwardsville, we have redeveloped a course, entitled "Light & Color," to be activities-based. Using hardware purchased specifically for this purpose, we have developed a set of student activities which are integrated into the syllabus. This course has been taught twice under the new paradigm with encouraging results. The activities developed are described and discussed and their impact on student performance is presented.

1. Introduction

With the creation of a Master's degree in Photonics at Southern Illinois University Edwardsville (SIUE), a significant number of courses in Optics and related fields at advanced levels were created and faculty specializing in research in various branches of Optics were hired. In order to make the activities of these faculty of more direct benefit to SIUE's non-technical students, the program in Photonics is complemented by a lower-division course entitled "Light & Color." The purpose of the course is to teach elementary optics to students with little or no background in math or science.

The topics covered in the course include: Basic wave phenomena, the nature of light as an electromagnetic wave and methods of its creation, the eye and the relation of light to visual perception, color theory (additive and subtractive), the ray approximation, laws of reflection and refraction, basic optical devices, polarization of light, and optical phenomena in nature. The overall goal of the course is to demystify everyday experiences and to increase the students' understanding of uses of light as a tool.

This course fulfills group requirements for students in a variety of non-technical majors. The overwhelming majority of the students in the course are drawn from three majors: Art & Design, Elementary Education, and Liberal Studies (a generic major in which the students develop an interdisciplinary program of study). As such, the level of preparation in mathematics of students in the class is extremely low. It has been found that explanations including even rudimentary mathematics will not be understood by a majority of the students in the class. Further, phenomena which are described, even if the description includes illustrations, are poorly absorbed. Classroom demonstrations have been observed to mitigate these problems only slightly.

These problems are common throughout Physics education, particularly when the students lack technical preparation. In Optics, however, many of the phenomena are directly visible under proper circumstances which are easily realized. To take advantage of this, we have begun redeveloping the curriculum of this course to be activities-based. Students explore the concepts at the core of the course via hands-on activities undertaken in small groups (3-4 students per group).

After the authors received an internal grant from SIUE (Excellence in Undergraduate Education Grant Number 06-12) to acquire hardware necessary for this modification to the curriculum, approximately 1/6 of the class meetings in the Fall, 2005 semester were devoted to activities. In the Fall, 2006 semester this fraction was increased to more than 1/3 of class meetings. It was found that the level of comprehension of the subject was increased over that in prior semesters. Further, we were pleasantly surprised to note that the amount of material covered, overall, was utterly unaffected by replacing this fraction of lectures with activities.

2. Project overview

The development of the new curriculum was undertaken by the authors. One of the authors (Glassman) holds a Ph.D. in Optical Sciences and was the Professor of record for the course. He set the overall goals for the course and defined and prioritized the key concepts it was desired that the students master via the course. The other author (Lindell) collaborated on the development of the activities and oversaw the collection of data for assessment.

The following key concepts were identified as candidates for benefit from the addition of an active learning component:

- Basic electrostatic interaction—charge and Coulomb's law
- Oscillatory behavior—period, frequency, and amplitude of oscillations
- Wave motion—wavelength, period, frequency, amplitude, and propagation speed of traveling disturbances
- Differences between spectral properties of light sources
- Human color perception—"primary colors" as a manifestation of human trichromatism
- Additive color mixing
- Subtractive color mixing
- Light in the ray approximation—laws of reflection and refraction
- Basic optical devices—prisms, lenses, and mirrors
- Practical optical devices—telescopes and microscopes

For each of the above concepts, we sought to enhance the students' learning experience by creating activities which would guide students to a more intuitive grasp of the concepts. The "Interaction Sessions" incorporating these activities replaced approximately one lecture per week for approximately half of the semester in the Fall, 2005 semester (the class met three times per week) and one lecture per week for almost the entire semester in the Fall of 2006 (in which the class met twice per week). Some activities spanned more than one class period. Conventional lectures, augmented by extensive demonstrations performed by the professor, were used in the remainder of the class meetings. It is worth reiterating that, despite the fact that the total number of traditional lectures in the course was reduced by approximately 20% in 2005 and more than 30% in 2006, the total amount of material covered in the semester was identical to that covered in previous, lecture-only semesters taught by the same professor.

3. Course structure

The overarching goal of the course is to increase the understanding that students have of the world they perceive visually. One crucial meta-concept that we wrestle with teaching students is that vision is a mechanical act. A specific study of student preconceptions about the nature of vision remains for future work. However, anecdotal observation and discussion with students leads us to infer that the students (and, one can presume, the bulk of the population as a whole) regard vision as an avenue of direct perception. This is exacerbated by the false concept frequently taught at the primary school level that "all colors are made from a combination of primary colors," relating the role of primaries to the light rather than to the physiology of the human eye. We worked to lead the students to an understanding of color perception as an interaction between light of various intensities which depend on wavelength and a set of light-sensitive cells in the eye that interact with the light with a set of sensitivities which are also wavelength dependent. But this sort of understanding is contingent upon understanding basic properties of light itself.

In order for students to gain insight into the behavior of light, it is essential that they obtain some understanding of its basic nature as an electromagnetic wave. While an explanation of this phenomenon in the context of Maxwell's equations is significantly beyond the level of this course, some understanding can be motivated by beginning with an exploration of classical electrostatics. While far from giving a complete picture of classical radiation, this at least motivates the notion of force at a distance. To make that force oscillatory is only a modest step. (Ampere's law and Faraday's law are presented via demonstrations to add the necessary magnetic force to the picture.)

We noted that students have tremendous difficulty mastering the concepts of frequency, period, and amplitude essential to any reasonable discussion of waves. Before attempting an exploration of wave propagation, these concepts need to be given concrete meaning for the students or subsequent discussion lacks context. So the class's exploration of electrostatics is followed by one of oscillatory motion.

The propagation of waves in the context of single pulses is next explored. This gives students a chance to develop their understanding of time-retarded effects and the concept of propagation speed for a disturbance as distinct from the speed of bulk motion of an object. Only after oscillations and wave propagation are explored separately is the notion of a traveling wave, driven by an oscillatory force, introduced.

Only after electromagnetic forces, oscillatory motion, and wave propagation are fully digested is electromagnetic radiation introduced. Spectra of atomic discharges, fluorescent sources, and blackbodies are studied by the students directly. A tool that was frequently employed, throughout the course, to aid the students in understanding the spectral composition of light was a small diffraction grating. Each student was given one of these at the beginning of the semester with instruction to bring it to every class session. The students were permitted to keep the gratings at the end of the semester. (Students were told that they would have to pay $1.00 for a replacement grating if they lost the one they were given. None were lost in two semesters.) The professor, therefore, could at any time call upon the entire class to take out their gratings to observe something of interest. Students were strongly encouraged to make casual observations using their gratings outside of class as well.

Having established the nature of light as a traveling wave of oscillating electromagnetic force the role of the human eye as a mechanism of perception is introduced. Frequent recourse to the above-mentioned diffraction gratings is made. The limited range of wavelengths available to human perceptions is explored using a blackbody source (a filament lightbulb with a dimmer). Trichromatism is then explored. We have found that leading the students through the "unlearning" of preconceptions and misconceptions about vision makes this phase of the course the most challenging. The opportunity to have the students see for themselves that a "white" source composed of primary colors and an approximately white blackbody appear the same while having profoundly different spectral properties aids them in this process tremendously.

With trichromatism at least accepted, if not fully integrated, both additive and subtractive color mixing can be explored by making regular appeal to stimulation of cone receptors as the true definers of "color." Students examine various light sources through combinations of filters both directly and after dispersal by their diffraction gratings. Since the students were presented with the relationship between subjective response and objective source from the outset of their encounters with the concept of color, mixing can be explored in that context very naturally. This also allows for a brief discussion of photographic storage media.

The ray model of light is introduced very late in the course compared to the approach traditionally used in courses such as this. We noted that many authors begin with light in the ray approximation only to explore its underpinnings as a wave phenomenon later. We have found that approaching from the "bottom up" is less jarring to students. They discover the ray approximation, and its ability to lead to the concept of an image, through an exploration with pinhole viewers. Since they discovered the phenomenon of wave propagation, the speed of that propagation, and the relationship of that propagation to wave frequency and wavelength earlier in the course, the introduction of reflection and refraction flows naturally from the exploration which led to the ray model's introduction. Further, since their view of wave propagation was motivated by a basic exploration of electrostatic forces, the introduction of the effects of ponderable media requires only a modification of what they have previously learned and not the acceptance of a statement, made without context, about the effect of such media on the speed of light and its direction of propagation.

Explorations of basic optical components and their role in practical devices follow directly from the examination of general properties of light in the ray approximation. When exploring imaging devices, particular emphasis is placed on distinguishing between images formed directly in the viewer's eye and those formed on an external surface. We have found that students are particularly pleased to understand common eye diseases (e.g., myopia and hyperopia) and the role of corrective lenses. They seem to enjoy very much the demystification when we decipher an ophthalmologist's prescription!

A brief exploration of polarization is made particularly easy by the plethora of common devices which utilize polarization to achieve their goals. In both semesters, students have independently conceived of the notion of polarization when the original discussion of the creation of electromagnetic waves took place. Since they are presented with the idea of light as being a traveling disturbance resulting from oscillating charges at the outset, they very naturally consider that the direction of the oscillation must matter in some way. So the discussion of polarization effects and an exploration by the students of those effects is almost an afterthought.

The course concludes with an exploration of blue skies, rainbows, and other atmospheric phenomena. Again, the demystification of these is something that many seem to find very satisfying.

4. Specific activities

We will outline the activities introduced into the course so far. Others are under development and will be added to the course when it is next taught (by Glassman) in the Fall, 2007 semester. To present them in full detail is beyond the scope of this paper. We must hasten to note that some of these activities were developed by other researchers and have been taken from the literature while others were developed by us or our colleagues for use in other courses. The work presented here is the development of the curriculum around the stated activities rather than the development of the activities themselves.

As of this writing, the activities used are:

1. "Exploring Force at a Distance"—students perform the classic "sticky tape" activity to observe Coulomb's law and to motivate the concept of "charge."

2. "Exploring Oscillatory Motion"—students build pendula and make observations of their frequencies, periods, and amplitudes.

3. "Pulse Propagation"—students use long springs to observe pulse propagation rates. By creating pairs of pulses, they also observe destructive and constructive interference.

4. "Exploring Intensity Distribution"—using their diffraction gratings, the students observe a variable-intensity filament lamp. They extract perceived intensity distributions for the lamp at different brightnesses. Doing this, they learn about blackbody spectra and begin to recognize that their own eyes react differently to different wavelengths. They also observe atomic discharge sources and a fluorescent source.

5. "Understanding Color Mixing—Part I"—using "Color Makers" (Fisher Scientific part #S65092), boxes with red, green, blue, and white LEDs controllable with potentiometers, students discover that subjective perception of color can be quite different from spectral reality. They observe the Color Makers through their diffraction gratings and see the limited spectra of the output. By changing their distances from the Color Makers, they are able to see the source seem to transition from tri-colored to white. This introduces them to the concept of trichromatism.

6. "Exploring Filters—Part I"—students use colored filters to explore additive color mixing. This is put in the context of trichromatism as part of the exercise.

7. "Exploring Filters—Part II"—students again use colored filters, this time to explore subtractive color mixing. The addition of the diffraction gratings to the process particularly aids their understanding in the context of trichromatism.

8. "Exploring Rays—Part I"—students use "Ray Boxes" (Fisher Scientific part #S42580B) to explore the behavior of rays at surfaces. Laws of reflection and refraction are inferred. Dispersion is observed. Total internal reflection is observed, although discussion of it is deferred until a future class.

9. "Exploring Rays—Part II: Imaging"—pinhole viewers (Pasco part #OS-9498A) are used to motivate the concept of an image as a mapping of rays from an object point to an image point. The ability to create an

approximate image with an approximate mapping is explored. (Students frequently expect things to be all-or-nothing and so benefit from being shown that approximate results can be acceptable.)

10. "Exploring Rays—Part III: Imaging with Lenses"—students create images with lenses on a simple optical bench. They observe real images and begin to understand raytracing. Concepts such as magnification and inversion are explored. Also, virtual images are explored. Combinations of lenses are used as well as single lenses.

11. "Exploring Telescopes"—students build simple refracting telescopes. They explore the use of these without the eyepiece at first, forming a real image on a sheet of paper and then on their own cornea. We have noted that many students (including those at advanced levels) fail to consider that a view-through device is intended to form a real image on a human retina and so must consider the presence of the lens/cornea of the viewer's eye. In this activity, the students learn the utility of zero-power imaging devices.

It should be noted that some of the above activities require less than a full class period while others span more than one. Other activities are under development and are expected to be implemented in the Fall, 2007 iteration of the course.

In addition to the direct advantages of active learning, we have found that the addition of activities to the curriculum tremendously enhances student engagement. In particular when the course is taught in the evening (as it was in 2006), the need to enliven a group of students who arrive already exhausted is profound. It has been noticed that if even a portion of a class period is devoted to an activity the level of student engagement and apparent comprehension is greatly increased for the remainder of the session.

5. Evaluation of Student Learning

To assess the effectiveness of these techniques, we performed a Primary Trait Analysis [1] (PTA) on each of the course exams. This analysis involves totaling students scores for each of the different subjects covered during the course. In addition we tallied scores for performance on the integrated portions on each of the three exams. All attempts were made to make all sections uniform, however this was not always possible. We judged the instruction to be successful if the PTA were above 70%, moderately successful if above 60% and not successful if below 60%. While we are disappointed with the results for Wave Motion, it is worth noting that this level is markedly higher than that for the same topic when taught without activities in the previous years. Before the introduction of activities, the level of understanding of students was essentially zero. Nevertheless, we hope for improvement in this area in the future. (Mastery of "Practical Optical Devices" was not explicitly assessed.)

Topic	Avg. Percent Total (STDEV) Fall 2005; N=33	Avg. Percent Total (STDEV) Fall 2006; N=26
Basic electrostatic interaction—charge and Coulomb's law	57.42% (25.19%)	68.91 (26.19%)
Oscillatory behavior—period, frequency, and amplitude of oscillations	66.46% (22.25%)	93.96% (22.20%)
Wave motion—wavelength, period, frequency, amplitude, and propagation speed of traveling disturbances	59.64% (44.15%)	44.78% (33.01%)
Differences between spectral properties of light sources	Not Evaluated	83.74% (29.48%)
Human color perception—"primary colors" as a manifestation of human trichromatism	Not Evaluated	70.79% (22.39%)
Additive color mixing	70.91% (16.54%)	72.94% (28.11%)
Subtractive color mixing	33.94% (35.06%)	60.22% (34.82%)
Light in the ray approximation—laws of reflection and refraction	69.76% (28.14%)	68.02% (24.44%)
Basic optical devices—prisms, lenses, and mirrors	Not Evaluated	68.70% (30.42%)

6. Conclusions and plans for future development

Our intention is to increase the number of activities when this course is next taught (Fall, 2007). We hope to have at least one active-learning session per week in this next iteration. Also, the activities that have been used previously will certainly be revisited and revised to improve their effectiveness. Teaching in an active-learning environment makes particular demands on the instructor, distinct from those of a traditional lecture course. We expect improvement in student mastery of the subject as the professor's mastery of this distinct skill set increases.

We are very pleased with the successes of the revised curriculum. The measurable aspects of these improvements, described above, tell only part of the story. An increased level of student satisfaction is obvious to the instructor and to colleagues who have observed the class. The fact that the improvement in student performance came at no cost to course breadth is a particular source of pride: We taught them just as much, we just taught them better!

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Reference

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II.

Integration of Optics into the Undergraduate Physics Curriculum at Millersville University

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Abstract: A discovery based lab course in applied optics was developed and will be offered for the first time at Millersville University (MU) in the fall of 2007. The course will deal with fundamental optics and optical techniques in greater depth so that the student is abreast of the activities in the forefront of the field. The goal of the course is to provide hands-on experience and in-depth preparation of our students for graduate programs in optics or as a workforce for new emerging high-tech local industries. The new 300 level course will be required for BS physics majors, but will be open also to the full spectrum of science majors, who have the appropriate background. The optics course consists of four contact hours per week including a one-hour lecture and a three-hour lab. Students will learn applied optics through sequence of discovery based laboratory experiences. The guided but open-ended approach provides excellent practice for the academic model of science research. The lab experiments are chosen from a broad range of topics in optics and lasers, as the emphasis is on geometrical optics, geometrical aberrations in optical systems, wave optics, microscopy, spectroscopy, polarization, birefringence, laser generation, laser properties and applications, and optical standards. The starting budget of about $60,000 provided state-of-the-art lab equipment from Newport Co. and MICOS Co. The attraction of the course is shown by the active registration among physics, chemistry and biology majors.

Keywords: optics, laboratory course, optics education

1. Introduction

The purpose of this paper is to describe the rationale for the development of a new course and educational materials in optics at Millersville University, PA. We have studied carefully the experience of the optics programs at New Jersey Institute of Technology (NJIT) [1]-[2], North Dakota State University (NDSU) [3] and Indiana University of Pennsylvania (IUP) [4]. The optics course will provide the basic resources for both research and training in modern optics. It will promote learning, teaching and training of students, faculty and K-12 teachers. A budget of $60,000 was allocated and already used to cover the initial equipment costs. Our optics course implements commercially available kits from Newport Co. and MICOS Co. The course goals, objectives, content, equipment, and assessment methods are discussed in the paper. Our long term goal is a new option for a BA degree in physics with optics, which the department will be able to offer in the future after the implementation of another advanced optics courses.

1. 1 Who are we?

Millersville University (MU) is one of the 14 universities within the Pennsylvania State System for Higher Education (PSSHE). Founded in service to a rural nineteenth century Lancaster Pennsylvania, twenty-first century Millersville University is a vibrant public liberal arts university in a vital economic region. MU promotes intellectual development through a comprehensive range of meritorious baccalaureate and master programs offered to more than seven thousands undergraduates and about a thousand graduate students. Millersville has earned its place among *US News & World Report's* top public universities in the North and is recognized for its academic excellence in Martin Nemko's book, "How to Get an Ivy League Education at a State University." [5]

All resources, time, funding, and energy of the MU Physics Department are focused on doing one thing extremely well: Undergraduate Physics. We challenge thoughtful students, providing the opportunity and incentive for all to achieve their fullest. The Department offers high-quality four-year undergraduate degrees of BS and BA in Physics (option in computer science, meteorology, nanotechnology, philosophy and polymer science), and BS in Education, as well as two co-operative programs. The first is a 3/2 Program - three semesters at MU and two at Pennsylvania State University (PSU) or University of Southern California, after which students get two degrees, BA in Physics and BS in Engineering. The BA with Nanotechnology option is also a co-operative program with Penn State. A student takes the basic physics courses of a B.A. degree at Millersville, and after spending a semester at the Penn State Nanofabrication Facility learning the specialized techniques of nanotechnology, receives a BA degree from Millersville in Physics with a Nanotechnology Option. The second co-operative program is a 4/2 Program with PSU which offers BS in Physics and MS in Engineering degrees. The department of physics is one of seven departments in the School of Science and Mathematics and consists of seven full time faculty and one permanent part time faculty. At any time we have 60 to 100 physics majors. On the average, nine students graduate every year from our department. We have low student/faculty ratio (15/1) and all labs are taught by Ph.D. faculty using hands-on experiments and not simulations. Many upper level elective courses in Physics have 5-15 students. Because we do not have a graduate degree program, advanced projects are integrated into the curriculum and are focused on the undergraduate student. In 2001 the department moved into new facilities in a new building and older facilities were then renovated. This expansion of space and resources has been extensively developed over the last five years and provided the base for expansion of new programs and research ideas.

Millersville is conveniently located in the heart of Susquehanna Valley, almost equally distant from Philadelphia, Baltimore and Washington DC, and at about three hours drive from New Jersey and New York, an area of abundant advanced research centers and high-tech industries providing more opportunities for employment and graduate studies while keeping vital the connections to the local community. The driving distances to Pittsburg, State College and Rochester facilitate the contacts with the Northpointe Technology Center in Freeport (33 miles from Pittsburg), Penn State Technology Park and The Institute of Optics, University of Rochester.

1.2 Rationale

Optics, the study and manipulation of visible light, has always been an important sub-discipline in physics, and clearly, it will contribute to the most important technologies of the 21st century. Optical devices and laser applications are already an inherent part of our daily life. In recent decades, the use of optics has transcended the traditional devices such as cameras, microscopes, and binoculars and has merged with atomic physics and nanotechnology. The development of the laser and the use of optical cable for communication initiated a new technological revolution. The euphoria for internet connectivity and the huge amount of information upload daily via the internet impose rapidly rising demands for higher bandwidth and faster speed which drives the incessant growth and development of fiber optic communications [6]. Every single student in my class has a cell phone and a CD player, but few know what an optical fiber is and how a laser works.

Understanding the nature of light, its propagation and interaction with matter is essential to physics and hands-on experiences greatly enhance that understanding. Currently there are no courses at MU dedicated to optics at any level, although optics is woven into some courses and laboratories such algebra and calculus based PHYS 132 or 232. The five-year department review report, as well as feedback from alumni, showed a gap in the department curriculum in the area of applied physics, and more specifically in optics.

Recognizing this gap, the Physics Department has taken steps over the past five years to expand its undergraduate physics curriculum and to increase our expertise in this important sub-discipline. Two experimentalists, a specialist in experimental optics and a specialist in solid state physics whose expertise includes optics, have been recently hired. Their presence at the department resulted in an increased number of undergraduate research projects in optics: measuring the speed of light in water, observation of surface plasmon resonance effect in thin silver and gold films, applications of laser pointers in the secondary physics education, measuring the light momentum, holography in thin films of silver halogenide and holographic recording in lithium-neobate crystal [7]. All this led naturally to the development of a new rigorous lab-based optics course, which will be offered for the first time at MU in fall 2007 and will be required for BS physics majors. More recently the Dean of the School of Mathematics and Science released substantial funds to the development of the new course. The current budget of about $60,000 secured the state-of-the-art laboratory equipment for this course. The equipment will also be used by physics students and faculty for their research in the field of optics, as well as to evoke an interest in top high school students in optics and science carriers. With an addition of another advanced optics course in future, the Department will be able to offer a new option in BA physics with optics.

1.3 Outreach

Because of the mathematics involved and presumptions that physics is a difficult science, most high school students receive little exposure to physics, and, consequently, to optics. As a result, few students are aware of the ample career opportunities in this field. In order to attract the student's attention to this rapidly evolving discipline, I offer annual summer workshops for high school students. The first, *Color Formation*, is addressed to 8-9 graders (usually students with no exposure to physics), while the second one *Physical Colors* targets the junior and senior students (10-12 graders) who may have had taken physics courses. These two workshops are part of the educational and research activities of the Summer Science Training Program (SSTP) held for three weeks on the MU campus for a select group of local and regional high school students. The new optics course will give new opportunities to enrich the existing workshops and to expand our offerings with a workshop suitable for high school physics teachers.

Another way to promote participation of bright students in optical programs is mentoring high school student research projects. I sustain a continuous collaboration with Jim Ringlein, a physics teacher at the Lancaster Country Day School supervising his student's projects in optics and helping them to build optical experiments. I introduced the phenomena of surface plasmon resonance (SPR) to him and to one of his students and opened my lab for them to study SPR in porous gold samples [8].

Millersville University has the most successful science programs of any school within the PSSHE system. The Physics Department, in particular, has generated over the last ten years many more Baccalaureate degrees than any other PSSHE University. However, we cannot be complacent. Technologies and their societal relevance change and we must adapt with them. This optics course will be an important component in maintaining the currency of our programs and retaining our ascendant position within the PSSHE system.

2. The new Optics course at MU

2.1 Objectives

The main objective of the new lab-based optics course is to provide physics majors and other science students with hands-on experience and in-depth preparation for graduate programs in Optics, Optoelectronics, Optical Engineering, or as a workforce for new emerging high-tech local industries, via broader and deeper knowledge of basic concepts and principles of optics and optical techniques. The goal is to provide a clear understanding of the fundamentals, and to provide hands-on experiences which greatly enhance understanding of the nature of light, its propagation and interaction with matter. The course will introduce the science majors to basic optical systems and techniques in greater depth so that the student is abreast of the activities in the forefront of the field. Students will be required to participate in a multidisciplinary project, complete a report and give a PowerPoint® presentation in class.

2.2 Course description

The new optics course will be 300-level of two credit hours and will be taken by students typically in their fifth semester. This course is required for BS physics majors, but will be open also to chemistry, biology, earth science, computer science and other majors, who have met the prerequisite requirements MATH 211: Calculus 2 and university physics PHYS 232 or PHYS 132. This optics course will be very useful for chemistry majors since it provides basic knowledge of optics associated with the analytical part of chemistry. It will be beneficial also for computer science majors, since knowledge of modern optics is essential for fiber optics communication and data storage. Microscopes and lasers are widely used also in biological experiments. The MU Biology Department has a well-equipped microscopy center, including an Atomic Force Microscope (AFM), which is actively used by students and faculties for undergraduate research. Therefore, biology majors will be encouraged to gain knowledge in optics before they handle sophisticated instruments in this center.

The course enrollment is restricted only by prerequisites and lab equipment limitations. The initial budget ensured the equipment for four lab stations. The Department has provided a large laboratory room dedicated only to this course. Since there are only four lab stations in this room, there is plenty of space for the students to perform the laboratory experiments. Considering two or three students per station, the maximum enrollment in the course at this moment is limited to 12 students.

The optics course is designed for juniors and seniors whose background is one year of university physics and two years of calculus and differential equations. To facilitate their transition to the challenges of the new course, we will put some review materials on the department website. The highest priority of our optics course is creative and critical thinking, and life-long learning. This determines our teaching strategies. We emphasize concept development and qualitative and quantitative analysis. Demonstrations, thought experiments, guided class and group discussions, especially about misconceptions concerning optics, case studies, and peer-guided problem solving are part of our interactive learning strategies. Students will learn and experience applied optics through sequence of open-ended laboratory experiments and multidisciplinary projects. In order to enhance interactive learning and deeper understanding of the most important concepts and phenomena of optics, the laboratory exercises are designed as hands-on use of state-of-the-art equipment. This guided but open-ended approach provides excellent practice for the academic model of science research. The lab experiments are chosen from a broad range of topics in optics and lasers, as the emphasis is on geometrical optics, wave optics, microscopy, spectroscopy, polarization, birefringence, and properties of lasers. Both, the lab and lecture portions of the course are taught by PhDs in optics and physics faculties.

The optics course consists of one-hour lecture and a three-hour lab. The laboratory portion is the critical and most important part of the course, since it provides the tools and experience that students can take back to their respective disciplines and projects. The laboratory part uses the discovery based approach in which students have to investigate a hypothesis by designing and realizing the experiments, predicting relations and results, and processing the data. Therefore, no laboratory experiment write-ups will be handed out, but students will have access to the devices and optical kit manuals. Additional materials over the Web may be also used.

Since the new course will be open to different science majors, we envisage multidisciplinary projects which will enable them to successfully apply optics in their respective majors. Bearing in mind the experience of the Optics Program of North Dakota State University, the projects will be offered in the beginning of the course to provide an early start and enough time for accomplishment. The projects will be determined on the base of the student's interests and background, current undergraduate research projects they are working on, prospective plans for graduate studies or eventual job placement. Some example of such projects might be optical properties of thin semiconductor films or sculptured thin films, diffraction from thin films of self-assembled micron size particles, image processing, fiber optics, diffraction effect from butterfly wings, digital holography, ocean optics, etc. Presentations can include theoretical background, life demonstrations, simulations, and experimental results.

2.3 Course content

The general physics courses encompass some concepts of electromagnetic waves and propagation of light: reflection, refraction, and total internal reflection, image formation with lenses and mirrors, fibers, dispersion, interference, diffraction, polarization, atmospheric phenomena, human eye, color mixing, shadows, eclipses. But all these basic optical phenomena are described usually in two chapters, sometimes just a paragraph for a topic with broad applications. The new optics course will enrich and broaden this background with knowledge about aberrations of optical systems, microscopes and telescopes, cameras and photography, visual processing, light sources and detectors, quantum nature of light, lasers, laser applications, holography, birefringence, thin films and optical coatings, nonlinear optical phenomena, ocean optics, ultraviolet (UV) and infrared (IR) optics materials. Part of the lecture material will be covered in the laboratory using *just-in-time* teaching method. Students from different science majors will work on optics projects related to their discipline and will have to make a PowerPoint® presentation to the entire class. Besides background learning on their own, this should cover various topics that would not normally be included in the course.

The lecture portion of the course will follow the main topics in the E. Hecht, *Optics*, 4th ed., Addison Wesley, 2002. But other classical texts will be also recommended to the students and will be possibly in use [9]-[13]. Course materials will be available to students also through the university's Blackboard website. There is rich information posted on the websites of NJIT and NDSU which will be also referred to students. This, in addition, will introduce our students to the facilities and curricula of these leading Optics programs.

We plan fourteen separate experiments completed in three-hour blocks. The lab portion of the course will start with an introduction to the safety standards of using optical and laser sources and systems. The basic equipment for most of the experiments is The Projects in Optics Kit of Newport Corp. This is a set of laboratory equipment containing all of the optics and optomechanical components needed to complete a series of experiments that will provide students with basic background in optics and practical hands-on experience in laboratory techniques. The kit comes with a very well written workbook [14], which will serve as the main supplement to lectures and will be available to students as a source of information for the lab projects. For the last experiment, an investigation of the Helium-Neon (He-Ne) laser cavity, students will be challenged to build a He-Ne laser using the state-of-the-art MICOS' He-Ne laser kit. We are aware that the lab experiments and individual projects will be challenging and will require careful guidance to secure the successful student's performance and data interpretations. We rely on the previous experiences of the science majors with our PHYS 232 general physics course which uses the peer-reviewed discovery based approach in the physics lab.

Table 1: *PHYS 331 Optics Laboratory*

	Lab projects	Description
1	The laws of geometrical optics; Image formation	This will be an introductory lab which will make the transition to the new course via summarizing the student's previous experiences in optics from the general courses in physics and will introduce students to more complicated optical systems. Students get familiar with safety standards.
2	Geometrical aberrations	Telescopes and binoculars, correction of aberrations, photodetectors and computer data acquisition with Vernier Software\Logger Pro 3.
3	Microscopy	Optical microscope, magnification and resolution limits, electron microscope, Atomic Force Microscope (AFM)
4	Reflection and Refraction	Prisms: Dove prism, roof prism, retro-reflectors; total internal reflection; attenuated total internal reflection; surface plasmon resonance in silver films, waveguides and optical fibers.
5	Expanding laser beams	The experiment demonstrates the design of two types of laser beam expanders – the Galilean and the Keplerian. Students gain experience in alignment of laser beams.
6	Diffraction of circular apertures	Fresnel and Fraunhofer diffraction. Students measure the diffraction effects of circular apertures and experience how the size of the aperture determines the resolving power of all optical instruments.
7	Single slit diffraction and double slit interference	Using a single "infinitely" tall slit, students witness the diffraction which takes place in direction perpendicular to the small dimension and investigate the interference pattern of two nearby slits, and diffraction grating properties.
8	The Michelson interferometer	Students build a Michelson interferometer and use it as a means to observe small displacements and refractive index changes.
9	Interference of light	Newton's rings, thin-film interference. Students will use the same arrangement as in lab 8 to test optical components in monochromatic light (Twyman-Green interferometer).
10	Lasers and coherence	Students examine the frequency separation between the axial modes of a He-Ne laser with Michelson interferometer.
11	Polarization of light	The students use a He-Ne laser with three modes (two of the modes polarized orthogonally to the third mode) to get experience in the orientation and generation of polarized light, as well as mode sweeping.
12	Birefringence of materials	Students become familiar with uniaxial crystals, the extraordinary index of refraction and quarter-wave plates by using birefringence of a material to change polarization of light; students build an optical isolator and polarization rotator.
13	The Abbe theory of imagining	Students investigate the spatial frequency content of objects and how they could be used to control shape and quality of image.
14	He-Ne Laser Cavity	Students use MICOS' state-of-the-art laser education kit to get familiar with optical cavity (confocal cavity, near concentric cavity), to build a He-Ne laser and to optimize its properties (intensity distribution, divergence).

2. 4 Course budget

The funds for the new course in Optics were provided solely by the Dean of the School of Science and Mathematics at MU. The total cost of equipment was constrained to be within $58,212. The limited budget required a cost-saving and cost-comparison approach when planning and buying the state-of-the-art equipment needed for the optics laboratory. The NJIT approach of computer interfaced experiments was not possible within the budget constraints. For us, the optimal solution of the “equipment list and cost” problem was found in buying five sets *The Projects in Optics Kit* of Newport Corp. ($5,230 each), one set of the state-of-the-art CA-1200 He-Ne laser from the German manufacturer MICOS Gmbh ($19,957), and one Modern Interferometry Kit from TEACHSPIN Inc. ($12,000). The Newport kits include 3’x3’ optical breadboards and all standard components required for the lab projects described in the Newport’s Projects in Optics Workbook - lasers, power supplies, optical elements, holders, etc. As a matter of fact, these kits prove to be less expensive than buying individual components. We also purchased individual elements, such as PM 100 power meters and motion controlled stages (continuous rotation stages and XYZ-translation stages) from Thorlabs Inc.($14,519), safety goggles, prisms, retroreflectors, half-wave plates, consumables (in multiple of four). We are currently evaluating the specifications of each component or system to determine how it would work for the proposed experiments. This equipment will satisfy our immediate needs, but to be able to offer various projects for undergraduate research we would also like to buy light emitting diodes (LEDs) with different wavelengths, an optical chopper, optical filters, an Abbe refractometer, a Schlieren system, photorefractive crystals and holographic plates, beam splitters, optical fibers and fiber couplings. After evaluating the success of our first semester, we intend to write a National Science Foundation (NSF) project requesting additional funds for enriching the current optics lab and possibly offering an advance course in optics.

3. Evaluation

3.1 Assessment of student’s learning

Student’s learning and progress will be assessed on a continuous base through the entire course. The continuous screening will involve class and group discussions on thought-provoking questions, as the emphases will be on student’s misconceptions and experimental missteps. The student’s preparedness and performance will be reviewed, and the lab report for each lab experiment will be graded on the basis of meaningful quantitative data, as well as qualitative interpretations. Three (two midterms and a final) exams are scheduled for the lecture material. The exams will include also questions on the laboratory experiments in order to assess the student’s understanding of the lab procedures and data analysis. The student’s individual work and self learning will be assessed via the student’s individual projects and PowerPoint® presentations. The presentations will be evaluated based on content, oral delivery, visual aids, and relevance.

3.2 Course evaluation

At the end of the course, students will complete a questionnaire on various aspects of the course. Students will evaluate their background preparedness for the course, qualitative lap of knowledge, preliminary competency in lab techniques, the effectiveness of the lab experiments and projects, what lab experiments meet the course objectives, the effectiveness of the instructor’s guidance, what should be improved in the lecture and lab portions of the course. The constructive students’ suggestions will be the base for changes and improvement of the course. The interest shown by students will be the prime motivation for the frequency of course offering, as well as for developing a more specialized advanced course in optics.

4. The impact of the Optics course

4.1. Undergraduate Research and Training in Optics

We expect that the new optics course will impact strongly the department’s advanced lab, undergraduate research and training program. A few research projects in optics were already offered to students for their two-semester senior seminar courses, PHYS 492 and PHYS 498, which are required for graduation for all physics majors. We plan to incorporate the optics teaching laboratory into the PHYS 451 and 452 advanced laboratories and the department’s undergraduate research. Possible research projects may include optical sensors based on the surface plasmon resonance technique, studying the nonlinear optical properties of materials using the *z*-scan method, measuring small angles using Michelson interferometer, etc. Double majors, computer science &

physics or chemistry & physics, may be offered optics undergraduate research projects that connect both disciplines. For example, computer science & physics majors might be interested in the field of fiber optics, communications, holographic data storage, and pattern recognition. The chemistry & physics majors will find their interests in spectroscopy, optical sensors, photoluminescence or optical properties of new materials synthesized in the Chemistry Department.

4.2. The impact on the other departments through the School of Mathematics and Science

We believe that the new course will inspire new projects and, possibly, new opportunities for collaborations. It is expected that the course will have a positive impact on other programs, like Chemistry, Biology, Earth Sciences, where sufficiently prepared students can benefit from learning about optical equipment and optical methods for measurements and control that they can use in their graduate studies for characterization of new materials and bio-objects. This might also increase the interdisciplinary work and joint activities among the departments of the School of Mathematics and Science.

4.3 The impact on the department's curriculum

The newly developed optics laboratory is expected to stimulate the development of additional optics experiments, and possibly, an advanced optics laboratory course. An advanced optics course might include elements of nonlinear optics, ultrafast spectroscopy, and optical properties of nanostructures and characterization of nanodevices, as well as scanning probe microscopy, atomic force microscopy, photonic crystals, semiconductor lasers. A part of the advanced course will deal with detailed introduction to basic optical standards and international standardization aspects of optical engineering, and laser safety standards, which will provide insight to terminology, requirements, interfaces, test methods, and product safety, that apply to complete optical systems, devices or components. With an additional advanced optics course, the Department will be able to offer a new option in BA physics with optics. Therefore, the described efforts will provide new opportunities and enrichment of the already existing two cooperative programs between our Department and The Pennsylvania State University and University of Southern California.

4.4 The impact on the community

The optics course will provide the basic resources for both research and training in modern optics. It will promote learning, teaching and training of students, faculty and K-12 teachers. Based on our experience with the course in fall of 2007, I anticipate offering a summer training workshop for K-12 teachers in summer 2008.

Our current percentage of female physics majors is typically between 10 and 20 percent. Most of our female students are enrolled in the BS in Education (Physics) program. Since optics is one of the most demonstrable parts of physics, we believe that the new optics course in combination with the BSE option will attract more female students to the field of physics and physics education.

We plan to regularly host open house receptions for the campus community and students and teachers from the local high-schools. The guests will visit our optics laboratory and will have the opportunity to speak with instructors and students involved in the optics course and to hear by word of mouth their experiences and future plans.

5. Conclusion

A rigorous lab based course in applied optics has been developed at MU. The new course, PHYS 331, Introduction to Optics, will be introduced for the first time at MU in fall semester, 2007. This course is required for BS physics majors, but will be open also to all majors from the School of Mathematics and Science, who have met the prerequisite requirements. Enrollment is restricted only by prerequisites and lab equipment limitations. The primary goal of the course is to provide students with the theoretical background and hands-on experiences necessary to enable them to successfully apply optics in their respective majors. Students learn the fundamentals of applied optics through a sequence of hands-on laboratory experiments using state-of-the-art equipment and multidisciplinary individual projects. Because of the hands-on experience requirement the enrollment is limited to maximum 12 students per semester. Initially, the optics course will be offered annually, and the interest shown by students will determine the frequency of its future offering. Adapting our educational efforts to the future challenges of our students, college education and training in optics becomes a high priority topic for the Physics Department at MU.

Acknowledgments

I acknowledge the input of Dr. Tariq Gilani during the development of this course, as well as the support of the Chair and the members of the Physics Department. I thank also Dr. E. Shane, the Dean of the MU School of Mathematics and Science, for his encouragement and the financing of this project.

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III.

Detectors, devices and electronics for optics

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ABSTRACT
Objectives: The present course is devoted to engineers, physicists, and techniques which require basic tools for applying in experiments, measurements and research with optical instruments.

Content: It is composed of the following topics: photodetectors, semiconductor devices, photomultiplier tubes, Faraday modulators, lock in amplifiers and automatic polarimeters. It begins with the definitions, classification and general characteristics of the photodetectors and its selection criteria for specific applications. There is included a section relative to different types of photodiodes and its differential characteristics, the photomultipliers are described showing its validity and application range. The different characteristics of Faraday cells which are widely employed as optical modulators are analyzed. Lock in amplifiers are shown and its applications in experimental arrangements.

Results: a complex optical instrument (an automatic laser polarimeter) is described where can be applied the knowledge obtained from the previous topics. Laboratory optical practices are included optionally.

Conclusion: this course could be given as a postgraduate course for Master in Science or Ph. D depending on the number and content of selected topics. It has been applied as an obligatory subject of the Optical Master in Science curriculum in the Superior Technical Institute (José Antonio Echeverría) of Havana, Cuba.

Keywords: detectors, course, optoelectronics

1. INTRODUCTION AND CONTENT

The specificity of photodetectors and the requirements of the optical experiments recommend a special treatment of the electronics devoted to this application which constitutes the principal aim of the present postgraduate course. In the first part are treated the study of the photosensors and the coupling typical electronic circuits. From the whole universe of photosensors the most deeply study is devoted to two types widely employed: photodiodes and photomultipliers. In both cases there are described principally its exploitation characteristics, equivalent circuits, the noise and signals and the coupling with preamplifiers.

From the rest of the photosensors it has been made a selection among the more used at present and a brief description is included. In the majority of the cases the explanation of the physical processes is excluded. Anyway sometimes, it has been necessary to analyze some functional physical aspects necessary for understanding the characteristics of the devices.

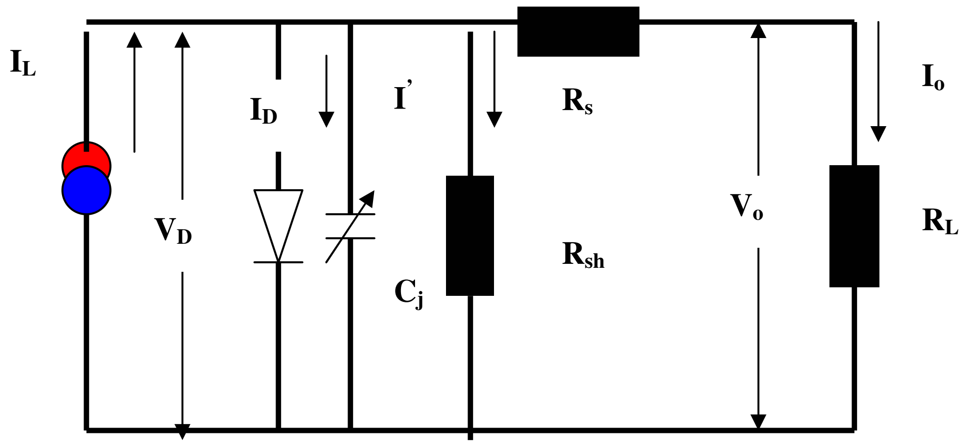

Fig. 1 Equivalent circuit of juncture photodiode (p-n or p-i-n type)

Two conferences are devoted to the study of junction photosensors (Fig. 1) (photodiodes, photocells, phototransistors, etc.) [1], [2] where the photodiodes are studied in more detail. Other 2 conferences are dedicated to the study of photomultipliers [3].

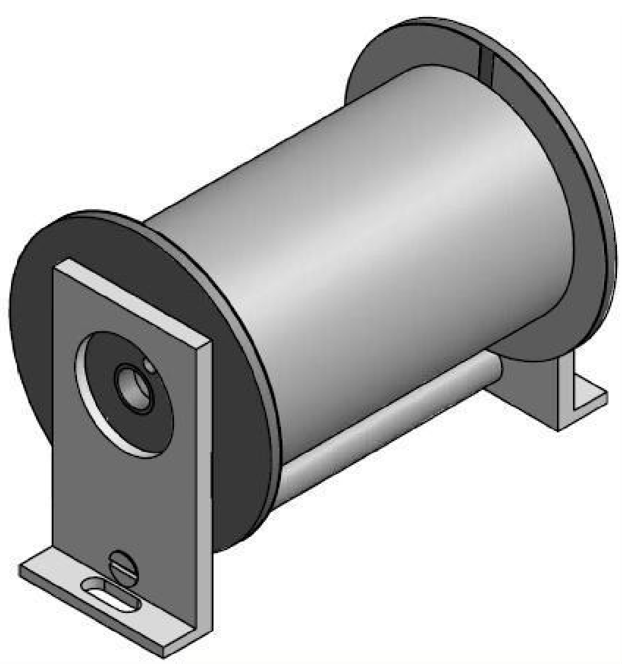

Fig. 2 Faraday cell often employed in optical instruments and experiments.

The modulators are devices commonly employed in experimental setups and optical instruments (Fig. 2) due to the necessity of the analysis of light signals through alternating current signals for its handling by analog and digital electronic circuits, it permits the proper selection of the optimal signal frequency for the specific application.

Among the modulators employed in optics are found the mechanical switches, the electro optical modulators which employ the Kerr effect and the magneto optical modulators like the Faraday cells [4]. Due to its constructive simplicity and its wide application spectra, the course concentrates in this type of modulator that constitutes and important study objective.

The study of lock in amplifiers constitutes and important topic of the course because of its diffused applications in optics, the mentioned study is exposed in two conferences. The lock in amplifier is a specialized voltmeter of alternating current which uses the synchronic demodulation for measuring the intensity or phase, even in severe noise conditions, it is referred to conditions in which the noise approximate 130 db, sensitivity at full scales of 10 nV or 0,1pA are typical. The instrument can be employed in any case which the signal that could be synchronized with or derived from a suitable reference signal. The output of the lock in amplifier, a direct voltage sensitive to phase and proportional to the useful signal, is available for recorders or for future processing. It can also be employed as a control signal for a closed loop system.

For observing the application of the photodetectors and circuits studied in a complex optical instrument (Fig. 3) it was selected an automatic laser polarimeter for this purpose [5],[6]. The polarimeters are instruments which measure the rotation of the light polarization plane after traversing an optical active substance. This fact permits that these instruments determine the concentration of substances like glucose, essential oils and hundreds of raw materials and pharmaceutical products being of great utility in the sugar and pharmaceutical industries, in clinical laboratories and other branches of the chemical and biochemical analysis.

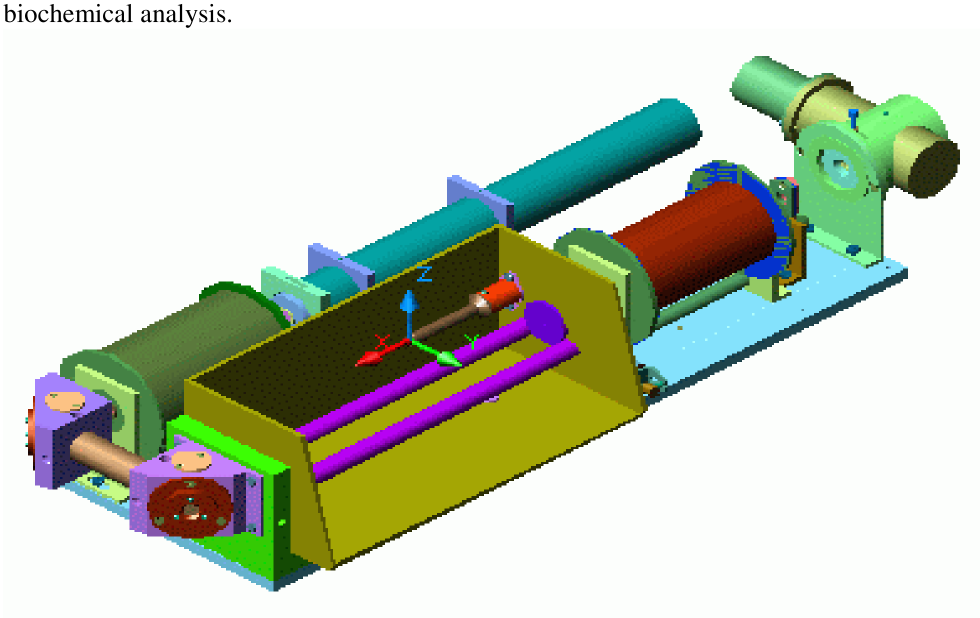

Fig. 3 Optical bench of the automatic polarimeter LASERPOL that includes a photmultiplier as optical detector and Faraday cells as modulator and compensator.

In two conferences are presented some of the electronic circuits of the automatic polarimeter LASERPOL 101 developed by the Centre of Technological Applications and Nuclear Development (CEADEN). This instrument has the magneto optic system as working principle.

2. CONCLUSIONS

The referred course accomplishes the necessity of given in a short time a valuable and integrated information for physicists and engineers working in the field of optics and its applications.

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IV.

Electro-Optics Short Course

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Abstract
A two-week short course in optics and photonics was organized and presented at the Royal Military College of Canada, Kingston, ON, from 1988 to 1995. It was designed for personnel in the Canadian Forces who were entering management positions that required some understanding of optics and photonics. The course attracted between 15 to 22 participants every year; individuals came from the ranks of Warrant Officer, through to L/Col, as well as civilian. Variations and improvements were made over the years. A history of events: the course, the personnel, the circumstances, the financing, some of the difficulties and successes, are presented. Much good will, trust, and integrity, were needed by all to bring it to fruition. Suggestions are given.

Introduction & History

I came to RMC in the Fall of 1976 to do research and to teach in the Mechanical Engineering, ME, Department. Having come from an optics and photonics background(1) and where I had organized many short courses, I was uniquely qualified to propose new programs. However, there were problems and hurdles to overcome lasting a number of years before to bring an optics and photonics course to fruition.

Initial discussions about a short course were broached to the Director Individual Training, DIT, at National Defense Headquarters, NDHQ, in 1980. It did not involve training on specific equipment so the proposal for a course of a few days duration was destined for rejection. The Directorate Avionics, Simulator and Photography, DASP, was approached later. DASP had its focus on optics and photonics, but again the proposal was not accepted. Under Treasury Board and Department of National Defense, DND, rules, it was not allowed to ask outside DND for financial support.

In 1982, I was privileged to visit CFB Greenwood and toured the flight line where the CF140, Aurora, was based. Personnel there were not allowed to open many of the electro-optic sub-systems for observation and to attempt simple repairs! An entire unit that was deemed unserviceable would routinely be sent back to the manufacturer. Nice for the manufacturer to build into his repair and overhaul contract such a condition; costly to the taxpayer; frustrating for the operators, repair, and maintenance personnel, especially when they want to understand. It was a revelation that I, a visitor from RMC, could explain: how components worked in the different sub-systems, the detail within the thermal imager, and warning systems, and explain why certain characteristics were the norm.

This visit rekindled the short course proposal. It was aimed at: personnel with a non-optics background who were in or about to be posted to project management positions that required some optics and photonics; and other personnel who desired to fill this gap in their knowledge were likely to be interested too.

There were hurdles: The main one was that DND was(still is) focused on training, and less on developing an educational program. The DND tendency, when a lack of knowledge is uncovered, is to send the individual(s) on a short course somewhere (anywhere!) that hopefully comes close to fill the lack. A course that anticipates a potential lack is deemed education and is unlikely to get support.

Another problem for any course is the time required that participants need to be away from their desks.

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The proposed Electro-Optics Short Course was for two weeks. Typically, a short training course is one to three days. A longer time has great difficulty to overcome the hiatus from the post. Adding to this are: funds for travel, accommodation, and living costs.

A third hurdle was money and time for lecturers. RMC is geared towards undergraduate teaching with a typical teaching assignment of two undergraduate courses per term. There is little time for faculty to prepare other programs let alone an extra-ordinary program; no funds were available for visitors.

A fourth problem was credibility; while I might be known in the research community, I was not known within DND. My appointment and visibility, such as it was, was in ME, not in "Optics and Photonics". The conservative DND attitude does not associate optics and photonics with ME even though perhaps 50% of any optics system's cost is for its mechanical design.

The fifth problem was that the window of opportunity for lectures is short. The timing has to fit into the RMC teaching year as well as into DND work schedules. The military community sets aside time for postings to new jobs in the summer months; families are then not tied to their children's school schedule. Late May or early June also offered the best possibility for a hotel to avoid tourist competition for rooms.

A sixth hurdle arose out of the reason for proposing the short course. The personnel in most need had graduated with commerce, or arts degrees, or perhaps were non-commissioned officers with no degree at all. Cross training or "re-posting" is constantly practiced by DND for there are not enough personnel in any one discipline. The course could not depend on mathematics.

A seventh problem was that the participants had been out of the education stream for several years, some for 15 years or more! It was going to be a challenge to re-introduce participants to a new subject, keep their interest, and indicate its utility.

An eighth problem was a personal one: I had worked all my career, roughly 14 years in Quebec, in English; but came to RMC in 1976 to work in (shaky) French and needed considerable time to organize and prepare all my undergraduate lectures. Time was at a great premium to prepare any course.

Encouragement was provided by the department head, the dean, and the principal; encouragement, but no money, nor relief from undergraduate lecturing. This was a volunteer activity.

It was obvious that the short course proposal needed a champion in Ottawa. That champion was the first master's graduate from the optics and photonics PG program(2). Two proposals were submitted. The first, in 1982, was not aggressively pursued and failed, but the second was accepted. The first Electro-Optics Short Course(3) was advertised, travel funds were found, participants were found, and the time was set aside via DASP, NDHQ. Brig/Gen W Niemy, RMC Commandant, welcomed 15 participants in late June, 1988.

A word about the term Electro-Optics: Electro-optics in the argo of optikers is often identified with crystals, polarization, and the myriad of devices that are manipulated by stresses furnished by an electric or magnetic field. Electro-Optics in military lingo is about detection, identification, and recognition of targets in a field of regard for observations. Since "targets" for the program were exclusively military personnel, the term Electro-Optics was maintained even though the program had a much wider range than an optiker might think.

Organization

The key to the course lies in discussions from Figure1, The Radiometric Problem. Detection, recognition, and identification, are separated into: sources, the atmosphere, optics, filtering and information control, the detector and/or illuminator (for an active system), and the signal processor. This Figure is the touchstone for the Electro-Optics Short Course. As a reminder to the participants to keep "their feet on the ground", there are discussions of Maxwell's equations, but the equation of importance that was repeated regularly and discussed often, was that for signal capture, $\mathrm{P}_{\mathrm{r}\,cd,\,\lambda}$, [W], and the conversion to an electrical signal: $e_{sig} = R_\lambda \bullet \mathrm{P}_{\mathrm{r}\,cd,\,\lambda}$, [V].

$$P_{r\,cd,\lambda} = \varepsilon_{\lambda} N_{\lambda} \bullet A_s \bullet \frac{A_c}{R^2} \bullet \tau_{atmos,\lambda} \bullet \tau_{o,\lambda}$$

The symbols taken in order are: emissivity, radiance, source area, collector area divided by range, atmospheric transmittance, optics transmittance, and R_{λ} is detector responsivity, [V/W]. Any symbol with wavelength dependence shows the subscript, λ, [nm or μm].

The Electro-Optics Short Course had a combination of lectures and demonstrations spread over two weeks and two evening sessions—about 85 hours in all. The signal capture problem was expanded as needed with discussions of: reflection, refraction, polarization, absorption, transmittance, pixels, SNR, and amplification. Electro-magnetic waves and photons were discussed in detail.

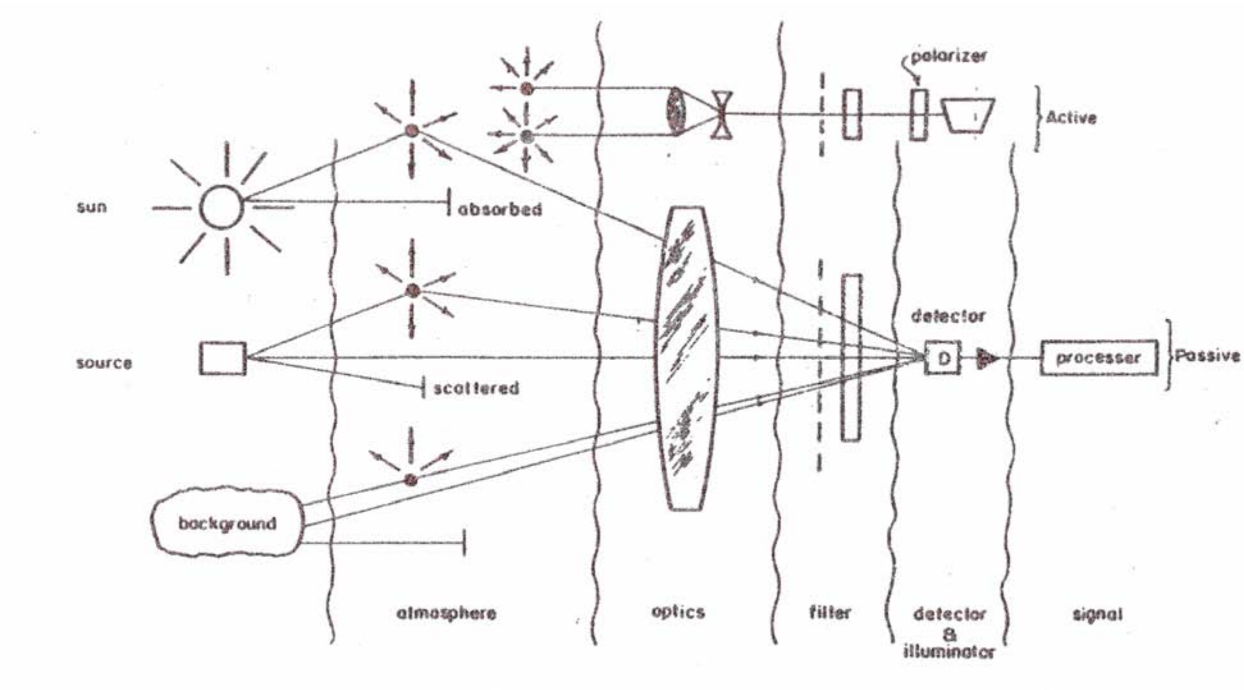

Figure 1. The Radiometric Problem

A discussion of sources—natural, artificial, blackbodies, and lasers—included coherence. There was detail of diffraction, interference, and optical design, with a gentle introduction to Fourier optics and phase. Detector types were explained together with the figures of merit: BLIP and D*. Information control via mechanical scanning, optical and electronic filters, and electronic phase was important. Detector arrays, pixels, and electronic scans were emphasized. Total internal reflection, TIR, prisms, and optical valves, were demonstrated, together with contrast and the modulation transfer function. System figures of merit: the NETD, MRTD, and OTF, and the Johnson criteria completed the course.

The principal lecturer and demonstrator for the activities was me. Colleagues at RMC were approached to present lectures, both as relief for participants who might have to listen to me for too long, as well as for personal relief. Most refused, but Dr T Racey and Dr J Gosselin, Physics Department, agreed. PG students gave a few lectures. Others were drawn by personal invitation from industry and government laboratories[4]. Dedication and trust in the purpose to have such a program were the common unifying thought from all. I was proud of all who took the time to deliver lectures. All took the PR opportunity to show their capabilities, to advertise and demonstrate expertise, and to show some products. A few lecturers required travel and living expenses, these were met by ME at RMC; some civilians accepted a small honorarium. Most paid their own way.

Lectures were from 0800 to 1630. There were two evening sessions to demonstrate: a 17 [cm] diameter collector astronomical telescope, a 200 line b&w thermal imager operating with a cooled MCT detector, several different image intensifiers, various binoculars, target designators, and aiming devices. There were a few laboratory demonstrations spaced throughout the two weeks: Ar, CO2, HeNe, and Nd:YAG lasers were operated, optical fibres, and optical fibre sensors that had been built were shown; a 1-m spectrometer and a ¼ -m double spectrometer were operated, the use of various polarizers, and filters, completed the demonstrations.

The first course timetabled a late lecture start at 1000 hours the morning following the first evening session (darkness at the end of May comes at 2130 hours!), but the course senior participant, a L/Col, pointed out that "this was somewhat slack". The years following did not attempt such consideration!

Course Notes[3, 5] were provided to all participants; lecturers offered hand-outs of materials and brochures, all had static components to show; some presented samples. There was some repetition of material, since the instruction given to the outside lecturers was that their presentation had to be self-contained. The repetition was useful. My 'vetting' of material defined the standard. A revised, re-edited edition of the Course Notes of 227pp was issued in later offerings[5].

There were marked assignments and a final oral examination. Success in the Electro-Optics Short Course was entered into the personnel file of all participants[6].

The first three Courses had participants staying at a hotel in Kingston. Transport from CFB Kingston was used to bring participants to all locations. Using the dormitories at RMC was the way to reduce costs, but RMC cadets in residence from early September to early May, and the requirements for senior cadets removes a further two weeks at each end which placed a stringent constraint on timing. Cost determined that the last five Courses saw the participants in residence in the dormitories.

Results

The Electro-Optics Short Course was useful[6] and became popular. The average participant number was 17 per year; space in the laboratories limited the maximum to 22. As word spread, inquiries would come in March asking about the Course; there was disappointment when some could not get support from a sponsor[1]

At RMC, the Elecro-Optics Short Course was my recommendation for all PG students wanting to start their degree program. It gave an overview for optics and photonics that served as a guide. Because of the timing, not all could take advantage, but most assisted with the lecturing in the following year.

Of the total of 137 participants over the eight years that it was presented: most, about 75, were from the air element; another 45 were from the land element; 7 were from the maritime element; and there were 10 civilians. There were 8 female and 129 male participants. The preponderant military rank was that of senior Captain.

As the 1996 preparations for the Electro-Optics Short Course were started, word was received from NDHQ that the usual time window was not available, but that an August date was desired. Unfortunately, space in the dormitories at RMC had been taken by the Sea Cadet summer school. Because many in NDHQ were involved as sponsors, it was assumed there that control was with NDHQ, that RMC would be ready to accommodate all. Funds were not available for a hotel alternative so the Course was dropped that year.

When the same period in 1997 arrived, the financial structure had changed at NDHQ, many directorates had been reorganized, and funds were scarce. There was no interest in a two-week course; there was interest in a two-day course, but it was impossible to fit ten days of education into a two day instruction offering; all would be dissatisfied with the "mess".

Inquiries continued to be received from individuals in the CF about the possibility for another Electro-Optics Short Course through 2003. The Course was dead. It was a lack of understanding of what the Electro-Optics Short Course had achieved and been trying to achieve[6] that killed it.

There is little doubt that such a course is needed. It must be revived. Instead of its RMC location, it could be held in Ottawa, or where travel and living costs are small, or presented on the Internet as a continuing education program. The last suggestion would completely eliminate the need for accommodation, travel, and living expenses, and would allow the course to be stretched over a longer period under control of participants availability.

Acknowledgements

Maj P Allen[2] , DASP, played the key role to pave the way for the Electro-Optics Short Course. Maj E Harrison, NDHQ, (now civilian) kept the momentum going forward. Ms Gerda de Bokx, RMC, administrative assistant (now retired), was vital to keep the details organized.

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A full-year university course sequence in Detector Array Theory, Camera Building, and System Testing.

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Abstract

In many imaging systems the ultimate performance is determined by the focal plane array that converts photons into an electrical signal that can then be recorded. Such focal plane arrays are available that operate at wavelengths ranging from the X-ray to the radio region of the electromagnetic spectrum. An explanation of the underlying physics of focal plane arrays, the practicalities of operating such devices, and the calibration of these arrays is, in general, not presented as part of a conventional undergraduate curriculum by any discipline. The Center for Imaging Science in the College of Science at the Rochester Institute of Technology has developed a sequence of classes to cover this subject matter for upper division undergraduates and graduate students. The material is covered over a full academic year that consists of three quarters at RIT. These classes has had very positive feedback from graduates who find that they acquire a very useful skill set that they use in their post-graduation positions at various companies and government laboratories.

Introduction

In many systems designed to detect ultraviolet, optical and infrared photons the signal-to-noise is limited by the performance of the sensor used. The sensors used are normally imaging arrays, typical monolithic silicon devices for the UV and visible, hybridized devices consisting of a silicon readout and sensor material such as InSb or HgCdTe for the infrared red and bolometer arrays for the sub-millimeter. In order to be able to understand if a detection system is suitable for a particular application, an understanding of the fundamentals of detector array operation, system construction, and system performance is needed beyond a few performance metrics highlighted by vendors of such equipment.

While such knowledge is needed in disciplines as distinct as astronomy, biology and remote sensing, this subject matter rarely gets very much attention in undergraduate or graduate programs. Often the treatment of these detection systems is as “black boxes” with a few key performance metrics briefly discussed. .An example of the failing of such an approach is with the purchase of cooled CCD camera systems where buyers often focus on acquiring the system with the "best" readout noise and "lowest" dark current for the CCD chip when in fact the practical performance that will be achieved in-situ relates more to the background signal (e.g. astronomical CCD camera systems at most observatories are limited by the night sky background emission level not the sensor itself).

The Camera Class Sequence

To provide a basic knowledge in many aspects of a camera system utilizing a focal plane array, a sequence of three quarter-length classes, each of ten weeks duration, has been created as an offering for upper division undergraduates and graduate students in the Center for Imaging Science at the Rochester Institute of Technology. The goal of the sequence is that students have sufficient theoretical and practical understanding of the operation of a camera system to provide high-level insight to their future employer.

The first class in the sequence is titled "Principles of Solid State Imaging Arrays" (*i.e.* course number SIMG 739). The class meets for 4 lecture hours per week for the duration of the Fall quarter (*i.e.* September through November for 10 weeks). The presentation format is two lectures a week with each lecture of two hours duration. Topics that are covered include ;

- energy levels, band gap, diffusion theory, and carrier lifetimes.
- Field Effect Transistors (FET), JFET & MOSFET construction, sources of MOSFET noise, and use of FETs in a source follower circuit.
- an overview of filtering theory, and an understanding of the correlated double sampling circuit.
- FETs as switches and how to use them to build a multiplexer.
- combining all of the above knowledge to design, conceptually, a CMOS imaging array.
- hybridized imaging arrays and some examples of such devices.
- CMOS image sensors.

The second class in the series is titled "Fabrication of a CCD camera" (*i.e.* SIMG 528/728). The class has two portions, a 1.5 hour-a-week formal class and a 10 hour-a-week laboratory over the ten weeks of winter quarter (*i.e.* December through February). The class material covers topics relating to one particular type of focal plane array, the Charge Coupled Device (CCD). Selected topics include ;

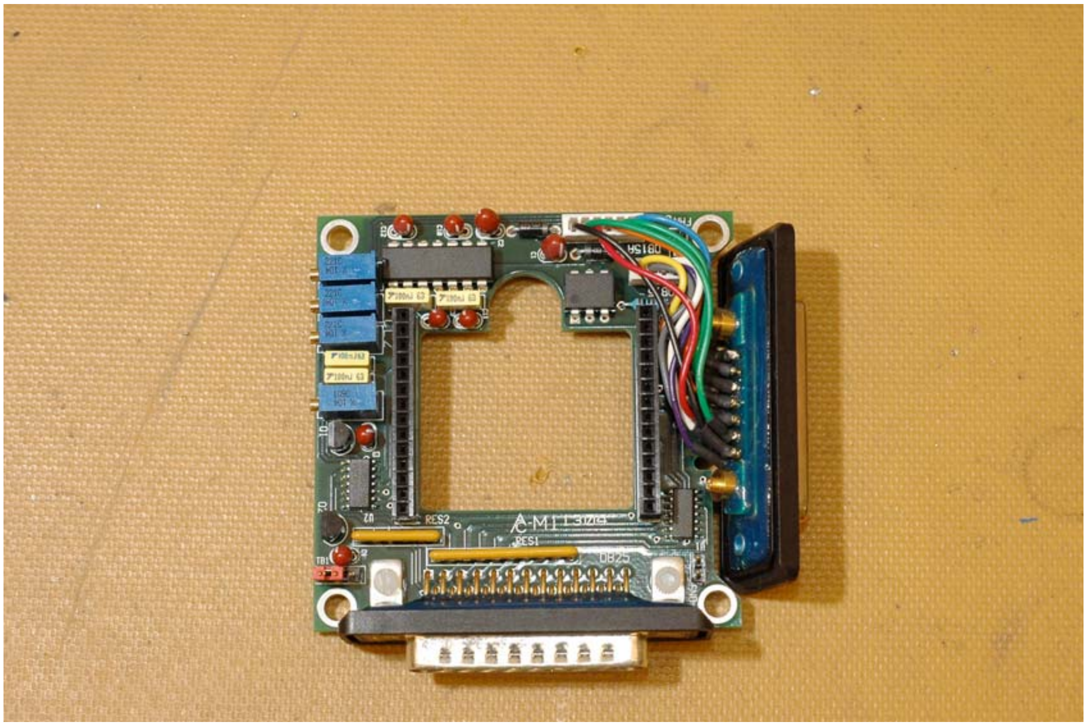
- a review of the principle of a MOS capacitor
- means and implementation of charge transfer
- channel stops
- buried channel CCD
- MPP operation
- Enhancing CCD sensitivity (e.g. back and front illumination, phosphor coating for the UV and X-ray)
- interline and frame transfer CCDs,
- 1-phase 2 phase 2 phase 4 phase operation,

- deep depletion CCDs.

The laboratory portion of the class involves students, organized in groups of three, assembling a cooled CCD camera system. The camera is based on the Audine CCD camera design from France (AUDE [2007]) that was designed with amateur astronomers in mind. It is a successor to the "Cookbook CCD Camera" made famous by Ken Berry (Berry *et. al.* [1994]). Most of the components and circuit boards are purchased from Rick Smith who provides this service under the Genesis CCD name (Smith [2007]). The final camera is a rectangular box that measurers 80 X 80 mm square (3.15 inches) with a height of 95.25 mm (3.75 inches). Its overall weight is 654 grams or 1.44 pounds, complete with shutter and optical tube. Various Kodak CCD sensors are currently adaptable to this circuitry. The device used here is a Kodak KAF 0402ME that has a pixel size of 9 microns square, and a format of 768 (H) x 512 (V) pixels giving a total surface area 6.91mm x 4.6 mm. Various readout modes are supported including full frame imaging, binning, windowing, half-frame and drift scanning. The CCD camera also supports a shutter device that can be purchased from Draco. The shutter is built into the camera body internally and is supported by the operating software. This makes it possible to capture images of brighter objects and timed flat and dark frames.

The camera is controlled through the PC parallel port. It is connected using a twisted pair flat ribbon cable with a maximum length of 22 feet. Acquisition software controls the camera from the PC. As of this time the PISCO software operating under Windows 95/98. This software is a simple and powerful program for acquisition but only as rudimentary image manipulation and processing capability . It can currently be downloaded from the Internet for free. Post-acquisition processing is normally performed by the students using IDL or some comparable software package they are familiar and comfortable with.

Physically the Genesis CCD camera consists of two printed circuit boards. The lower board interfaces the camera to PC using a DB 25 pin waterproof connector. A second DB type waterproof power connector is used to supply all power requirements, as well as external commands for operation of color filter wheels, and peltier temperature control. This lower board has circuitry for the distribution of power for operation of the camera. The upper board has the CCD sensor mounted on it and includes circuitry for generating the clock cycles, level shifting, amplification circuits, and the analog-to-digital conversion circuits.



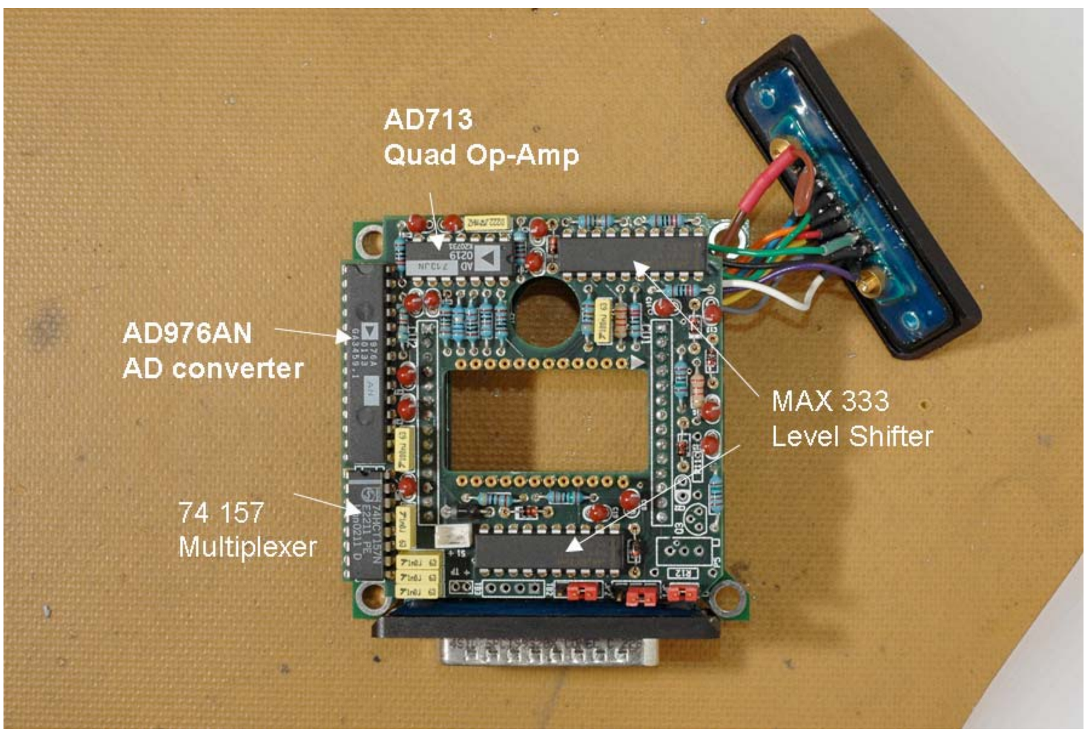


Figure 1 : Upper photograph shows the lower board including the two DB connectors used to interface to the PC computer and to the power supply. Lower photograph shows the upper board . The CCD chip is not inserted but would be seated in the central 2x12 pin connectors. Various integrated circuits and function are identified.

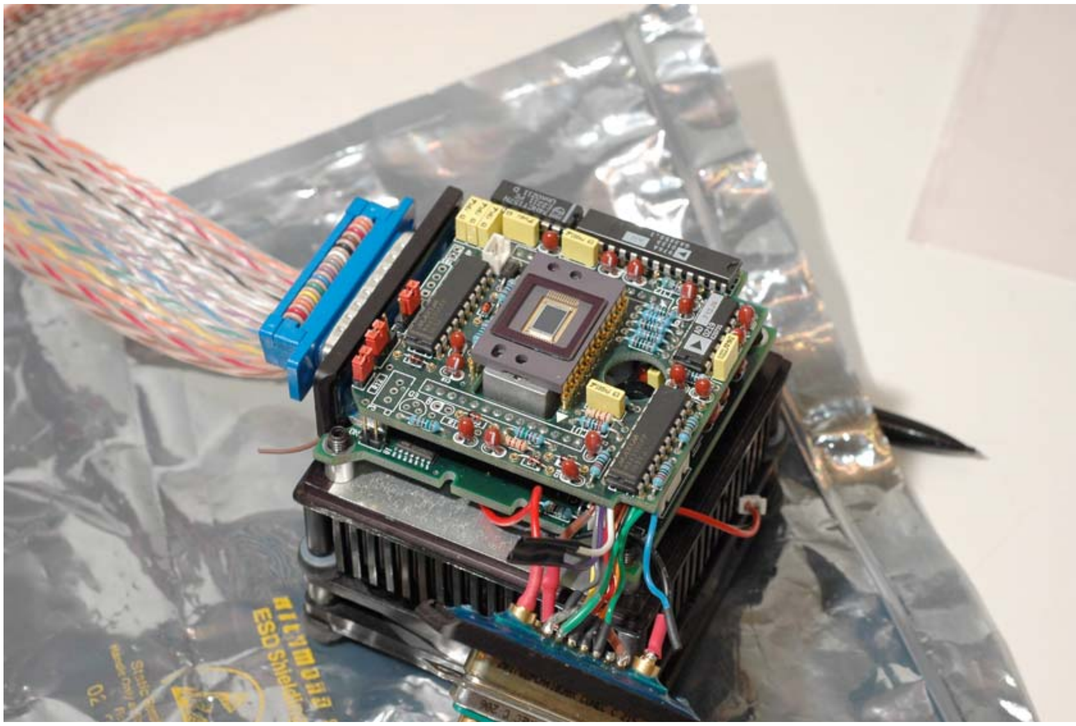


Figure 2 : An assembled camera without the housing case. Clearly seen is the upper board with the CCD sensor (KAF 0402ME) inserted. Below it is the lower board and below that the cooling assembly including the peltier cooler (not seen) and the fan assembly.

The students are provided with all the components and instructions to fabricate this peltier cooled, computer controlled CCD camera. Most of the components are fairly easy to obtain through electronic resellers at a moderate cost or they can be obtained as a package of components from Genesis. An additional benefit of building the Audine designed camera is that there are many news groups dedicated to issues surrounding construction of this system. Students in this class have interacted with other builders of these cameras from around the world.

The third class in the sequence is called "Testing of a CCD Camera" (SIMG 742). This class has two portions a one hour-a-week class and a 10 hour-a-week laboratory. Both portions are presented over the ten weeks of the Spring Quarter (March through May). Students are asked to conduct a series of calibration experiments similar to what they might be asked to do in a commercial, government or academic laboratory. The class time is used to present an overview of each calibration experiment and in the subsequent week to review the results obtained.

Students generally use the camera fabricated in the prior quarter to conduct these fundamental testing experiments. The calibration experiments attempted include ;

- Measuring the gain (electrons per digital count out) using the photon transfer method.
- Measuring the noise, dark current and linearity.
- Determining the quantum efficiency of the CCD using a traceable NIST photodiode and spectrometer.

- Determining the modulation transfer efficiency (MTF) using a sine target.
- Determining the Charge Transfer Efficiency using a Fe-55 X-ray source.

Figure 3 : Two students from the class of 2006-07 (Michael Harris and Katelyn Kern) are shown experimenting with their completed camera. The camera is the gold colored box behind the Nikon lens that is directed at a resolution target mounted on the optical rail. The students are rarely seen as serious- looking as they appear in this photograph.

Outcomes

One surprise has been the diversity of students that have enrolled and successfully completed the classes. The 2007 incarnation of this class sequence has students enrolled from four different RIT Colleges, namely the College of Science, the College of Engineering, the College of Information Technology and the College of Imaging Arts & Sciences. These are students that rarely take a class together at any time during their undergraduate programs as even introductory courses in mathematics and science are now tailored to specific majors. The students in the laboratories are organized into diverse teams of three to build the camera. They generally come to appreciate, as they progress further into the building of the camera, that each student's background is of value to the completion of the task. For example, a Electrical Engineering student knows more about circuit layout, an Information Technology students knows more about compute interface, an Imaging Science students knows more about data handling and analysis, and a Photography student knows more about optics. The elitist mentality (*i.e.* that one's own major is superior to others) that often results from being confined into increasingly siloed academic programs is seen not to be true when building a complex instrument like a CCD camera (*i.e.* students discover that other majors know things that they haven't learnt).

Assessment for the first course in the sequence (*i.e.* Principles of Solid State Imaging Arrays) is achieved by a series of homework problem sets, a final examination, and a class presentation of fifteen minutes duration on a type of focal plane detector array that was not covered in class. A list of possible detector array topics to choose from is provided to the students. In addition for each topic a reference to a seminal paper is provided. Students are expected to utilize the electronic databases (e.g. INSPEC, SPIE Digital Library) available in the RIT library to find additional material. The key element of their presentation must be an explanation of the underlying physics governing the operation of the device and a clear illustration (*i.e.* a figure) of how the detector works. The homework assignments presume that the student has a working knowledge of one of the many higher level computational software packages available (e.g. MathCad, MathLab, Mathematica, etc.) . The reason for this is that the problems are elaborate and much time can be saved by not solving the problems by hand or using a lower level programming language.

The assessment for the second course (*i.e.* Fabrication of a CCD camera) involves a midterm exam, a final exam, maintaining an up-to-date group laboratory notebook, and a final oral exam. The final oral exam is key in a hands-on group project like this to ensure that all students have acquired a minimum knowledge of all areas of construction. The oral exam for this course is often the first time the students have had to respond directly to questions about their work. They are put on the spot and for some the experience is stressful. However it also gives them a taste of what to expect after graduation.

The third class (*i.e.* Testing of a CCD Camera) is assessed by means of a final exam and through the submission of detailed reports and conclusions on each of the laboratory tests the students complete. Since a commercial CCD sensor is used in the camera system the performance metrics determined by students as part of their laboratory can be compared to the specifications listed by the manufacturer. In some cases differences have been found and we have contacted the manufacturer for clarification. In more than one case the difference was found to be the result of an error by the manufacturer in their claimed performance.

There is a sense of personal accomplishment when a student is able to build their own camera, knows how to operate it, and understands the underlying physics. The advantage to building a camera is that the students have personal knowledge of the assembly, and techniques of testing the device. If the unit doesn't operate as expected, the student will not treat the camera as a black box but rather open the unit and probe for the problem. The building of the camera requires study of all aspects of the acquisition of an electronic digital image. This include: electronics, optoelectronics, data processing, mechanics, refrigeration engineering technology, optics and image processing.. Students who construct their own imaging systems have an excellent understanding of any similar instrument's operation.

This type of course is often cited by employers as the type of hands-on, practical course that is highly desirable for their future employees. University curriculum committees also like these sort of "capstone" courses where the years of conventional coursework are integrated with a hands-on experience into something meaningful and practical for students. However this sequence of classes requires a substantial investment of time by the faculty member responsible. Additionally the sequence of classes flows best when one faculty member is responsible for all three classes. The classes also involve a substantial financial commitment each year by the university to permit purchase of the components and to dedicate the laboratory space needed for the class. It is impractical to share the laboratory space with other classes as the cameras and test equipment are left in various states of assembly over the quarters and the laboratory times are individually scheduled by the groups so as to not interfere with one another. The commitment of an institution to providing their students with excellent technical higher education is revealed by their support of programs such as this.

Acknowledgements

Many colleagues have assisted in the development of this course sequence. In particular I would like to thank Professor Roger Easton who has always been happy to listen to problems and help with solutions. All the administrative directors of the Center for Imaging Science have been encouraging of this program including, most recently, Ian Gatley and Stefi Baum. I also thank the many students who have taken the class who have been so enthusiastic and who have tolerated the inevitable snafus with understanding. Rick Smith at Genesis CCD has been helpful with his advise and assistance.

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I.

Photonic Simulation Software Tools for Education

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Abstract

A solid education in optical devices and optical communication systems must include an understanding of the basic building blocks of optical devices and networks as well as the interplay between them. Software vendors, such as Optiwave Systems Inc., provide free as well as for-purchase software tools that can be used in classroom and computer labs as an educational aid. This paper examines the role software simulation tools play in the education of students studying optical communication and related disciplines. The different techniques to employ photonic simulation software in classroom lectures, computer labs and graduate research are discussed.

I Introduction

Despite volatile market conditions, optical communication systems continue to evolve at a rapid pace. In recent years, the focus of industry research has shifted from long haul to metro to fiber to the home networks [1]. These different networks require very different solutions. Many new optical components have been developed and continue to be developed to address these requirements. It is difficult if not impossible for educational institutes to keep student laboratories equipped with a complete inventory of optical components required to demonstrate realistic optical networks. They could, however, develop design and simulation capabilities that may provide a similar and even higher value for educators and students of photonic device and network courses as well as of fundamental optics and electromagnetic courses in general.

Education in optical systems requires knowledge of several disciplines including signal analysis, optics, and electronics. Physical scales range from nanometer device features to thousands of kilometers of optical fiber links. For a student studying optical system design, designing an optical link is about generating the signal transmitting and propagating it over a given distance while maintaining a minimum signal quality. The signal quality depends on many parameters and device characteristics of the electric pulse generators, light sources, modulators, optical channel (typically fiber), photodetectors and receiver electronics (see for example Agrawal [2]). The function of each one of these devices is based on optical and electrical phenomena which can be quite subtle to understand.

This paper will focus on how photonic simulation software (PSS) such as OptiSystem and OptiFDTD can be used to enhance education of phonic devices and optical communication. This paper is organized in the following way: section II provides some background of PSS is. In section III, the general methods for using PSS as an educational tool are discussed. Section IV contains some representative examples of how PSS is used in education. Finally, section V contains a conclusion.

II Photonic simulation software (PSS)

In the domain of PSS, there are many tools from nano/micro-scale component simulation software such as OptiFDTD (finite-difference time-domain simulator), to large scale system software such as OptiSystem (optical communication system simulation software). In between, there are many other specialized tools for designing waveguides, optical fiber, optical gratings, bulk optics components etc.

Low level software such as OptiFDTD, simulate the propagation of optical fields through nano- to micro-scaled devices by directly solving Maxwell's equations numerically [3]. Waveguide software such as OptiBPM, is a specialized software tool used to simulate waveguides and other similar optical devices which have light propagation predominantly in one direction over large distances. OptiBPM is based on the beam propagation method (BPM). In essence, the BPM is a semi-analytical technique that solves an approximation of the wave equation [4]. OptiSystem is a simulation package that can design, test and optimize virtually any type of optical link in the physical layer of a wide range of optical networks [5]. It is based on large collection of realistic models for components and sub-systems.

III Methodology

There are 3 basic levels that PSS can introduced as an educational aid:

1. Lecture examples and visualization,
2. Student assignments and labs and
3. Graduate and post-graduate research.

The most basic use of PSS in education is to supplement classroom lectures. Most commercially available tools provide excellent visualization capabilities for input (system and structure layout) as well as output (graphs, tables etc.). This technique can be used even for students who may not have proficient computer skills since there is no requirement for the student to run the software. It can be used to introduce fundamental concepts of Maxwell's equations to and high level designs of optical systems.

Currently, the greatest increase in the use of PSS in education is in computer labs. In this scenario, professors create assignments and labs for students to solve using PSS. Traditionally, student assignments were often limited to problems that could be solved analytically in a few pages of handwritten calculations. While this is a very important component of learning optics, the limitation severely restricts the amount of problems that can be assigned. Even when the problems can be solved analytically, complex mathematics required for the solution can often obfuscate the underlying physics or engineering concepts that are the purpose of the assignment. Professional PSS have user interfaces that are very closely related to real world problems. In OptiFDTD the user, uses a graphical interface to draw the structure to be simulated. In OptiSystem, the user arranges and connects icons that represent real devices in a clearly visual way.

There are many benefits of using PSS in computer labs. Students have the options to perform virtual experiments instantly. Simulations provide an excellent way to build an intuitive understanding of the physical effects that occur. They provide instant feedback on "what if?" scenarios. This allows students to follow their own curiosity. Computer simulations in a lab environment provide a complimentary educational tool that lies between theory and physical experiments. On one hand, simulations can easily handle a large number of practical problems that are not possible to solve analytically. On the other hand, many more structures and system can be simulated than is practical to construct for real world experiments. In addition to this, computer simulations also provide instant visualization of many more physical qualities than can be obtained easily in experiments. As an example, users can view plots of the electric field inside a waveguide at any point in time; something that can not be done with a real device.

For now, the most common use of PSS in education is at the graduate and post-graduate levels for research. For many years, simulation software has been recognized as an important tool for the design and development of new devices and systems. Device and system researchers can concentrate on concepts and design without spending effort to create the numerical software themselves.

Experience with professional quality simulation tools is an asset in itself. Professional software tools are used by researchers in telecommunication and other high tech companies all around the world. Students that have experience with such software during their formal education have clear advantage over students that do not.

IV Examples

In this section, 2 representative examples are given to illustrate how PSS can be used as a demonstration tool in a classroom environment. The two examples represent opposite ends of the photonic simulation spectrum. In the first example, OptiFDTD is used to demonstrate an important concept of the microscopic vector nature reflected optical waves. The second example demonstrates how a free software, OptiPerformer, can be used in a computer lab tool for an optical communication course.

1 Vector nature of electromagnetic waves

Photonic simulation software can be used for the demonstration of fundamental optics phenomena such as simple reflection, refraction, absorption etc. The particular example considered here is based on the OptiFDTD software – a time-domain simulation tool numerically solving Maxwell's equations. OptiFDTD is applied, in parallel with an analytical analysis, [6] to demonstrate the vector nature of the electromagnetic (EM) waves during the reflection of a linearly polarized EM wave from a mirror (Fig. 1, left) positioned in free space. This is a 2D propagation problem in a plane defined by the Z (longitudinal) and X (transverse) axes of a coordinate system (the Y direction is perpendicular to the X-Z plane and points towards the reader). For the sake of simplicity we consider the case where the input optical beam (positioned at X=3 μm with a Gaussian profile with a half-width of 2 μm) is linearly polarized and there is only one component of the electric field (Ey). Our goal is to provide a visual explanation of the relationship between the direction of EM power flow and the different non-zero components of the electric and magnetic fields. The power flow of an EM wave is described by the time averaged value of the Poynting vector **S** which is proportional to the vector product of the magnitude of the electric and magnetic fields: $\mathbf{E} \times \mathbf{H}$. S_x is proportional to $(E_yH_z - E_zH_y)$ and S_z is proportional to $(E_xH_y - E_yH_x)$. S_y is equal to zero since the propagation is only in the X-Z plane. Since we consider a linearly polarized EM wave (E_y field component only), the two non-zero components of the Poynting vector take a simpler form: $S_x \sim E_yH_z$ and $S_z \sim E_yH_x$..

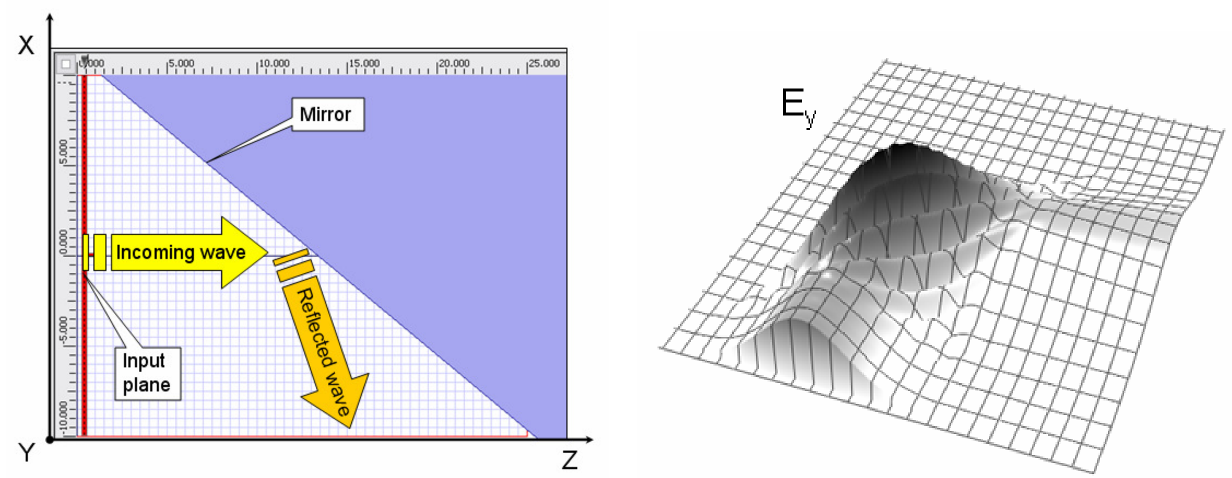

Fig. 1 Schematic representation of the propagation geometry (left) and distribution of the E_y electric field magnitude (right).

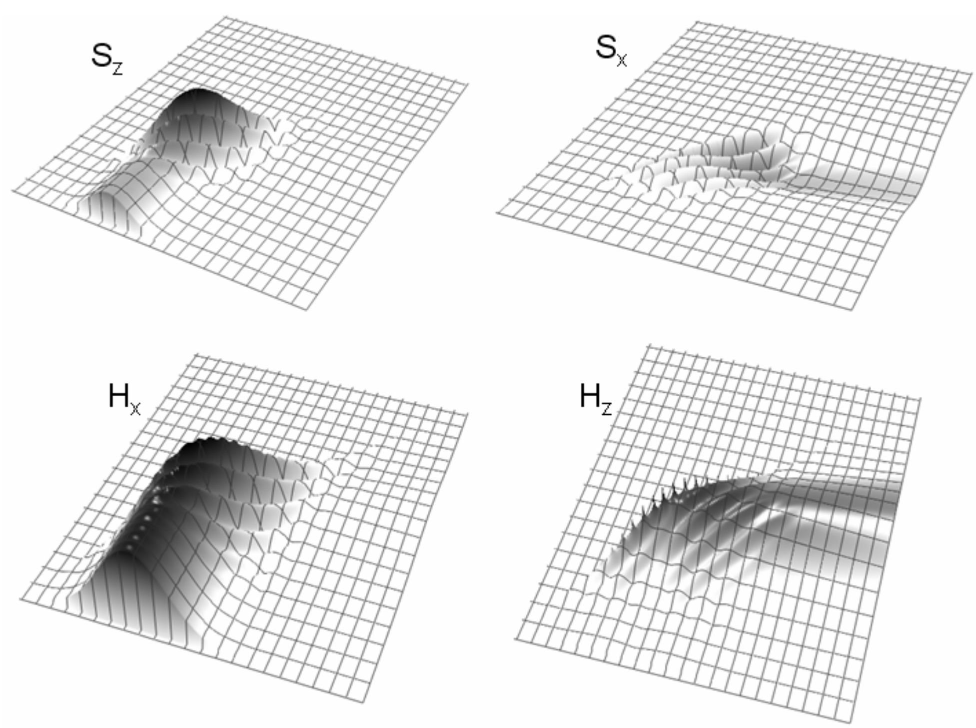

Fig. 2 Visual representation of the distribution of i) the longitudinal (S_z) and transverse (S_x) components of the Poynting vector and ii) the magnitude H_x and the H_z-fields. The redirection of energy in the X-direction is associated with a transfer of energy from the H_x to the H_z component of the magnetic field.

An examination of Fig. 1 (right) can show that if the incoming wave is propagating initially in the Z-direction (i.e., S_x is negligibly small), the mirror will redirect the wave energy predominantly in the perpendicular (X-) direction. Due to the energy conservation law the above mentioned redirection of the energy flow will be associated with a decrease of the magnitude of S_z (or H_x) and increase of the magnitude of S_x (or H_z). This transfer of energy can be clearly seen in Fig. 2. It should be pointed out that the distribution of the S_x-component of the Poynting vector has negative values. This indicates that the energy flow is in the opposite direction of the X coordinates axis.

Example 2 Attenuation-Limited Fiber Length

The next example is based on a lab exercise created by Dr. Warren Koontz [7]. This lab can be downloaded from Optiwave web, including the software, OptiPerformer [8], required to run it. The object of the lab is to calculate the attenuation-limited fiber length based on a power budget equation then to simulate and verify that it meets the performance objectives.

The power budget equation states that the transmitted power minus the receiver sensitivity must be greater than or equal to the sum of the power losses plus the power margin.

$$P_T - S_R = AL_F + L_C + L_A + M \ ,$$

where P_T is the transmitter power, S_R is the receiver sensitivity, A is the fiber attenuation, L_F is the fiber length, L_C is the coupling loss, L_A is the additional know losses and M is the power margin.

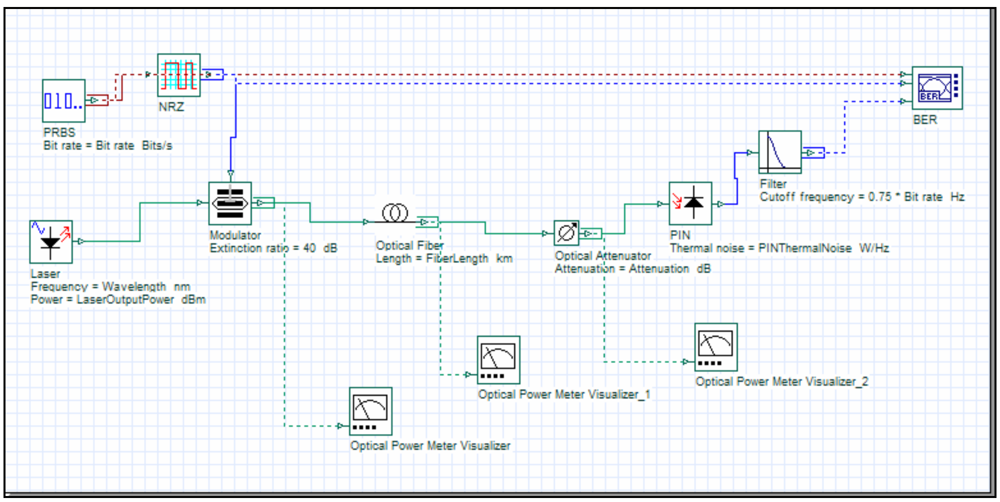

Fig. 3 Screen capture of OptiPerformer. The layout is of a single one channel optical link.

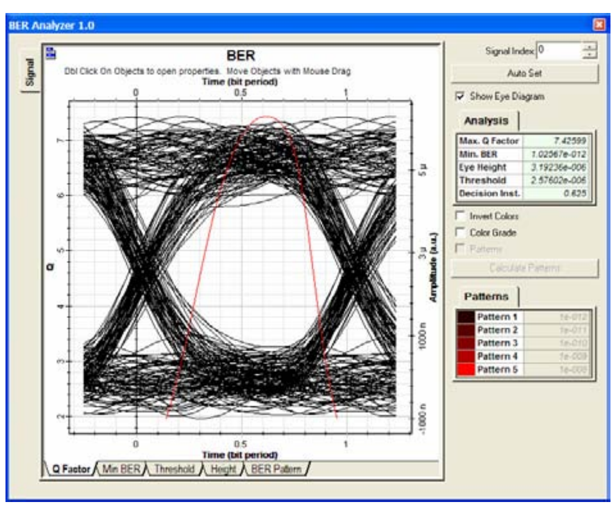

Fig. 4 Screen capture of the BER analyzer. A graph of the Q factor as a function of decision instant is shown with the eye diagram superimposed on it.

The OptiPerformer layout of the single channel link is shown in Fig. The layout is fixed but the user can modify the laser output, the fiber length, the attenuation coefficient of the fiber, the thermal noise of the PIN detector and the wavelength of the laser. OptiPerformer files are created using, OptiSystem. Much more complex system layouts than this one can be created.

The output of the BER analyzer is shown in Fig. 4. This gives the user visual feedback on the quality of the signal as well as numerical analysis of the quality of the signal. This diagram is calculated for any input parameters the user specifies. In this case, the fiber length was set to 120 km. The resulting maximum Q factor is 7.42 which corresponds to a bit error rate of 1.03×10^{-12}.

V Conclusion

Photonic simulation software can be a valuable aid in the education of optical device and optical communication systems. It provides a method to move past the sometimes too abstract level of theory to gain insight into physical phenomenon associated with optical devices and systems. It provides more freedom to explore design parameters than analytic calculations and physical experiments. This allows students to develop an intuitive understanding of optics in a rapid way.

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Applying the Principles of Augmented Learning to Photonics Laboratory Work

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Abstract: Most modern communication systems are based on opto-electrical methods, wavelength division multiplex (WDM) being the most widespread. Likewise, the use of polymeric fibres (POF) as an optical transmission medium is expanding rapidly. Therefore, enabling students to understand how WDM and/or POF systems are designed and maintained is an important task of universities and vocational schools that offer education in photonics.

In the current academic setting, theory is mostly being taught in the classroom, while students gain practical knowledge by performing lab experiments utilizing specialized teaching systems. In an ideal setting, students should perform such experiments with a high degree of autonomy. By applying the principles of augmented learning to photonics training, contemporary lab work can be brought closer to these ideal conditions.

This paper introduces „OPTOTEACH“, a new teaching system for photonics lab work, designed by Harz University and successfully released on the German market by HarzOptics. OPTOTEACH is the first POF-WDM teaching system, specifically designed to cover a multitude of lab experiments in the field of optical communication technology.

It is illustrated, how this lab system is supplemented by a newly developed optical teaching software - „OPTOSOFT“ - and how the combination of system and software creates a unique augmented learning environment. The paper details, how the didactic concept for the software was conceptualised and introduces the latest beta version. OPTOSOFT is specifically designed not only as an attachment to OPTOTEACH, it also allows students to rehearse various aspects of theoretical optics and experience a fully interactive and feature-rich self-learning environment.

The paper further details the first experiences educators at Harz University have made working with the lab system as well as the teaching software. So far, the augmented learning concept was received mostly positive, although there is some potential for further optimisation concerning integration and pacing of various interactive modules.

1 Introduction

The demands on digital high-speed data communication equipment are increasing permanently and so are the demands on the maximum bandwidth of transmission media [Na00]. Modern communication systems need high-speed optical transmitters and receivers for Terabit data transmission rates. Most of these communication systems are based on advanced opto-electrical methods like wavelength division multiplex (WDM), which is one of the most widely used methods. Likewise, the use of polymer optical fibres (POF) as an optical transmission medium is expanding rapidly.

The POF is an optical waveguide consisting of a highly transparent polymeric material. A thin PMMA cladding with a lower refractive index encircles the PMMA core, causing a total internal reflection, an optical phenomenon, which always occurs when light strikes a medium with a lower refractive index and is reflected to almost full extent. Thus, light cannot leave the waveguide making POF usable for communication technology.

The current surge in POF uses in especially visible in market growth – compared to the market for glass optical fibres, the POF market is booming. While POF technology has been around since the late 70s, using polymer fibres for data communication has been a costly business until the turn of the century when prices for transmitter and receiver modules in the visible wavelength area (400nm to 800nm) declined, making a cost-effective use of POF possible [Da01].

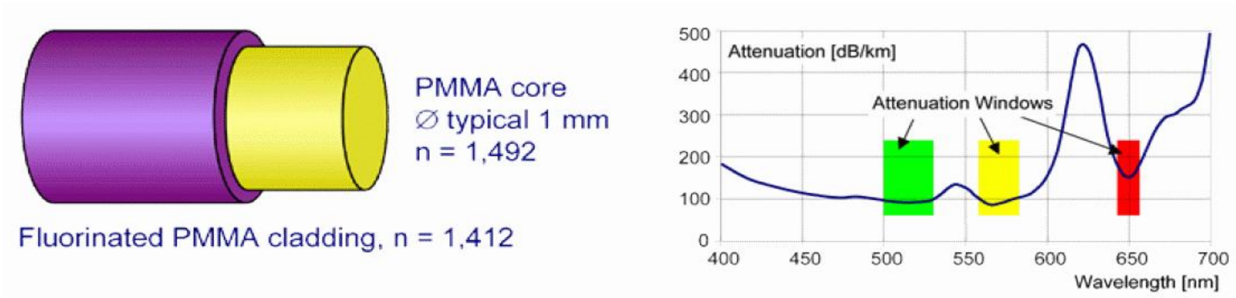

Fig. 1: General structure and of POF (left) and attenuation within the visible spectrum (right) [PO07]

According to a recent study by IGI Consulting [IGI06], the increased interest in POF is mostly due to several current developments in the technical area:

- The demand for cost-efficient high-speed communication technology is increasing
- European automakers have introduced the POF-based MOST-bus[1]
- The 1394b standard has been introduced, increasing the distance between communication nodes to 100m for 3,29 Gbps communication systems
- During the last years, several new POF application fields have been found, including home infotainment, industrial Ethernet, medical technology and sensor technology

Another recent market study, conducted by Harz University itself in 2005 among the members of OPTECNET – the German optical competence networks[2] – shows a clearly risen interest in POF technology. More than 50% of all companies polled are currently in the process of or preparing to expand the use of POF in their own production activities.

Aside from the automotive industry, the industry expected to most heavily shift to POF usage over the next years is the home entertainment sector. A recent market analysis [Ah07] confirms, that although wireless communication systems like WLAN or Powerline Communication have the advantage of relieving the home owner from actually passing any wires, their data rate as well as their technical stability compare to badly against the established Fast Ethernet to make both alternatives viable ones. Lightweight and transparent POF provide home owners an opportunity, to belatedly establish a 100MBit/s data connection without too much effort (because of the extremely simple handling) that is a lot less visible than regular copper cables. Thus, POF has become increasingly interesting for the so-called “last mile” – the last few meters from any city-wide broadband and glass fibre based network to the end user.

The increasing importance of POF and WDM systems makes enabling students and vocational trainees to understand how WDM and/or POF systems are designed, built and maintianed a paramount task for universities and other institutions of higher learning or expert vocational training that offer education in optical technology. This includes honing the practical skills of students and vocational trainees and introducing them to concepts such as WDM not only on a theoretical, but also on a practical, “hands-on” level.

1 http://www.mostnet.com
2 http://www.optecnet.de

Fig. 2: As of 2004, the MOST bus has already been in use in some of the most recognized modern car types.

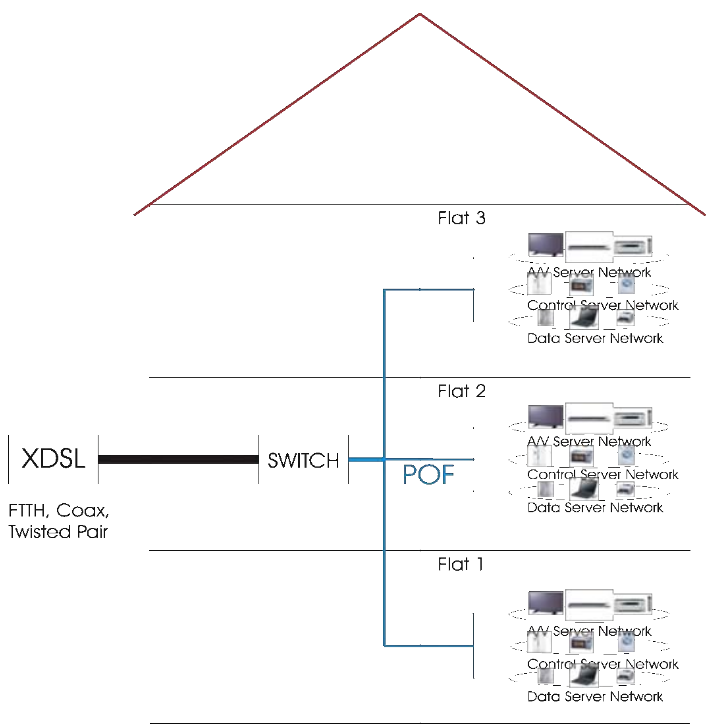

Fig. 3: In-house multimedia infrastructure using POF

In the current academic setting, theory is mostly being taught in the classroom while students gain practical knowledge by performing lab experiments, often using specially designed lab systems. During such experiments, supervising educators have to adapt to the individual learning progresses of single individuals or work groups. In the course of one lab experiment, it is often necessary to quickly and individually rehearse theoretical knowledge or to give problem-specific practical advice. This does not correspond with the idea that students should handle most lab work autonomously as part of the learning experience. By applying the principles of augmented learning to photonics training, contemporary lab work can be brought closer to these ideal conditions.

This paper introduces OPTOTEACH, a newly developed optical teaching system for photonics training in POF data communication and WDM methodology. The paper details the technical layout of the system as well as some of the design concepts behind it. It is then explained, how the system can be augmented with supplemental, interactive software and how this combination of lab system and software creates an effective augmented learning environment.

2 Optical Teaching System

OPTOTEACH is the first POF-WDM teaching system, specifically designed to cover a multitude of lab experiments in the field of optical communication technology, e.g. PI curve and bandwidth measurements or analysis of EMF influences. OPTOTEACH systems are exclusively built and distributed by HarzOptics, an optics think tank and research institute associated with the department of Automatation and Computer Science at Harz University in Wernigerode. OPTOTEACH systems are currently being used for educational lab work at Harz University, Braunschweig University, Dresden University, the University of Mannheim and the Federal Centre for Electronics Technology in Oldenburg.

OPTOTEACH systems consist of two video transmitters, one LED and one laser in cw mode and two receivers. The system enables students to transmit two analogous FBAS video signals or corresponding test signals with a maximum bandwidth of 10 MHz. Both transmitters operate within the visible wavelength, which does not only allow OPTOTEACH systems to be built and maintained at reasonable costs, but also provides students with an opportunity to visually experience the WDM effect first hand. The two signals are joined via a conventional Y-coupler developed by Ratioplast Optoelectronics GmbH[3], the separation is effected by a Ratioplast splitter in combination with red and blue colour filters. Signals can be transmitted over various fibre length, covering 5m up to 100m, whereas the fibre itself is interrupted by a micrometer stage, enabling the students to analyse coupling losses with cut or polished fibres as well as lateral and longitudinal misalignments. The general design of the system can be seen in figure 4.

The system gives students an opportunity to perform a multitude of experiments, e.g.:

- PI curve measurements
- Bit Error Rate measurement
- Signal quality tests (eye diagram)
- Measurement of bandwidth and S-parameter
- Analysis of EMF influence on the transmission
- Identification of modulation characteristics (AM, ASK, PCM)
- Attenuation measurements for different fibre lengths (1-100m)
- Attenuation measurements for different wavelengths (490/520/660nm)
- Analysis of the influence of lateral and longitudinal misalignments on the transmission

A more detailed description of the teaching system itself can be found in [Fi06] and [Re06].

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[3] http://www.ratioplast.com

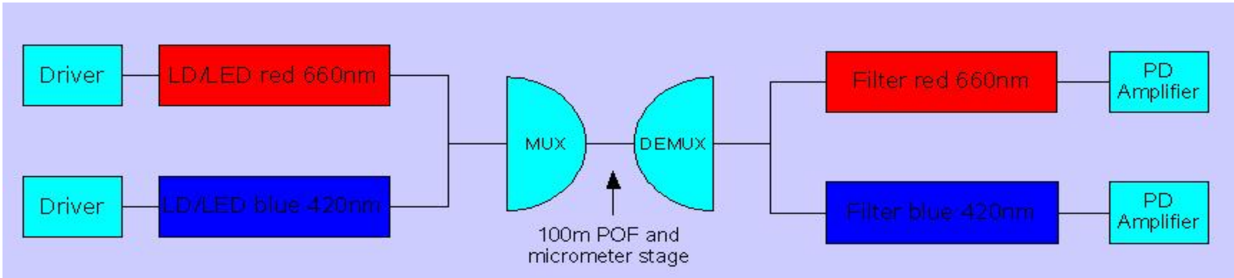

Fig. 4: General technical layout of the OPTOTEACH lab system [Re06]

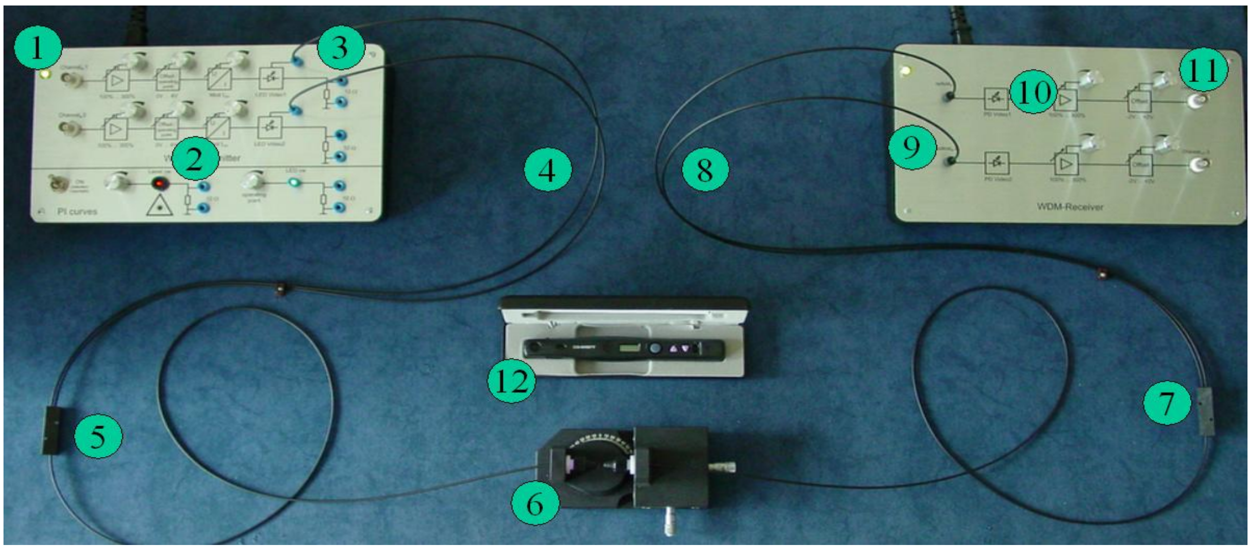

Fig. 5: OPTOTEACH Lab System with (1) BNC-Inputs (2) Potentiometer (3) Optical Outlets (4) Polymer Fiber (POF) (5) Multiplexer (MUX) (6) Shifting Table (7) Demultiplexer (DEMUX) (8) Polymer Fiber (POF) (9) Optical Outputs (10) Potentiometer (11) BNC-Outputs (12) Optical Powermeter

3 General Software Design

3.1 Basic Requirements

Two basic requirements can be determined for teaching software in general: platform independence and the integration of multimedia content.

The software designer has to make sure, that the software can be used independent from the technical equipment available in the universities or vocational schools. This implies, that platform independent technology such as Java or HTML has to be used at all stages of the software development process.

If HTML is used, if has to be considered, that the terminals used in the educational institutions will differ from each other in browser type and version as well as in screen resolution. Thus, the software has to be thoroughly tested and adapted to the various possible configurations before being released. The development of teaching software for any special combination of operating system, browser type and version as well as screen resolution is economically unsound, because the customers are forced to adapt their technology to the software requirements or be content with a lower quality or hardware-triggered software errors.

Integrating multimedia content into the software application is less of a technical and more of a didactic necessity. The contemporary software user generally expects content to be enhanced with multimedia features and the integration of video films or animations has long been known to be a good practice for activating the user's interest and for making teaching software more appealing [Te00]. Short video sequences and animations that depict can be used to visualize scientific theory as well as depicting actual lab work sequences or experiments. Thus, they can be seen as chapters in a "taped instruction handbook" and an amendment of textual descriptions of experimentation sequences or lab work instructions.

The OPTOTEACH software concept acknowledges these possible problems and depends solely on multimedia technologies, that do not require any plugins (such as animated GIFs) or standard plugins that can reasonably be expected on most of all currently used lab terminals (such as Macromedia Flash).

3.2 Navigation

The direct comparison of online questionnaires in market research and interactive teaching software reveals a common design problem: Should contextual information be placed on one scrollable page or should all content be split into smaller information units that can be displayed on one single screen each [Te00].

If at lot of information is displayed on one single page, the overall theoretical context can be compassed almost instantaneously by the student. This prevents any feelings of being confronted with a seemingly endless number of smaller information screens and allows students to get a quick overview of the entire content and to guess the approximate reading time. Such systems are much less complex – from the programmer's point of view – and are therefore easier and quicker to realize than the programming of a more elaborate system of smaller information screens [Te00]. On the other hand, presenting the entire content of one chapter or the entire proceedings of one experiment can entice students into quickly scrolling through the entire text or completely skip the theory to start with the experiment right away.

The most fundamental benefit of smaller information screens is, that it spares students the discomfort of having to scroll through the information – the navigation is much more concise and brings about a more comfortable software handling. It is also possible to easily integrate interposed control questions between the information screens and to instantaneously validate any given answers, which not only enables the students to get an immediate feedback on their learning efforts but also makes it possible for the software to suggest the targeted repetition of certain theoretical aspects based on the direct evaluation of the answers given.

The information screen option therefore offers a higher level of interactivity as well as enhanced possibilities to evaluate student performance. These advantages and the consequential higher software quality and enriched learning experience outweigh the higher complexity in design and programming. To circumvent the aforementioned feeling of "endlessness", a progress bar can be included, which indicates the remaining number of information screens. Additionally, the average time of completion can be shown at the beginning of each self-contained learning module.

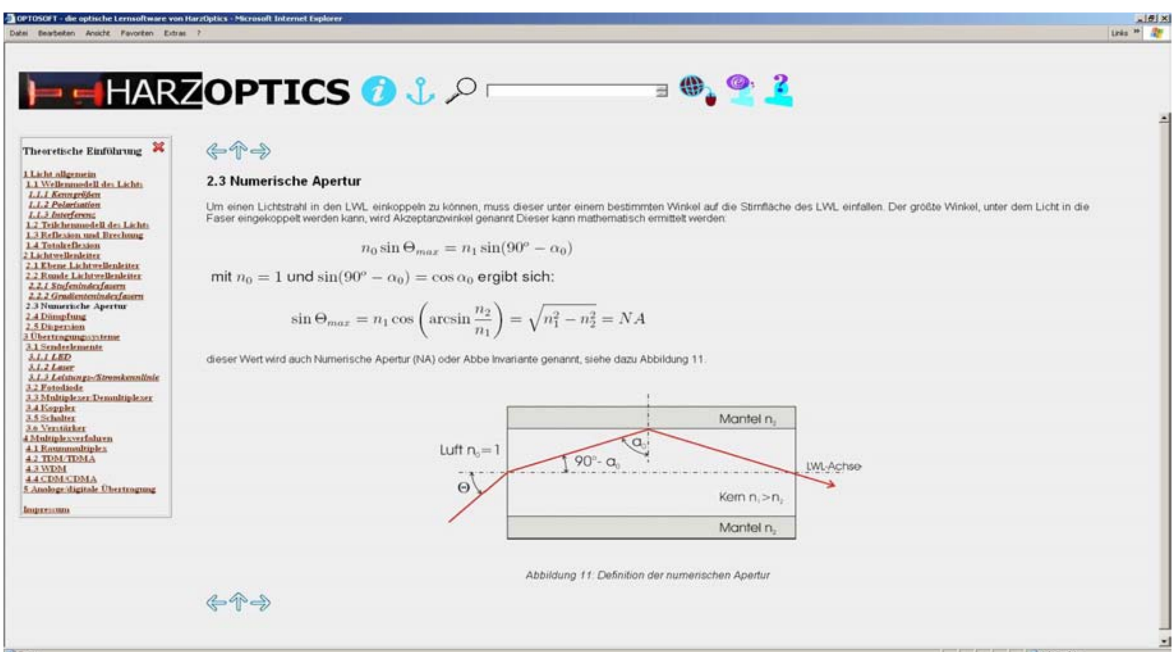

Fig. 6: Screenshot of the current OPTOSOFT beta version (in German language)

The navigation design should allow a comprehensive overview of the theoretical content and enable the student to jump back and forth between the theoretical chapters as well as follow an "ideal learning path". A good example for a practical and concise navigation design is the popular SelfHTML HTML learning software[4]. Another exemplary navigation design can be found on the two online learning sites "Mikro Online"[5] and "Makro Online"[6], developed by Wilhelm Lorenz, professor of macroeconomics at Harz University.

After the navigation design is completed, a pre-test should be arranged along the lines of the conceptual design of any online market research questionnaire. The pre-test allows a testing of the navigation design as well as the general visual impression of the software during a phase of the software development process, in which changes in either the navigational design or the visual presentation are still possible. The basic procedure of such a pre-test can be adopted from market research online pre-testing processes and is described e.g. in [Po98].

4 Didactic Concept

4.1 Learning Phases

Because the software aims to support the entire learning process form theory rehearsals to lab-based experiments, it is important to break down the complete process into all methodically different learning phases. Concerning the OPTOTEACH optical teaching system, these phases are already known from the direct practical use of the system in various courses at Harz University:

- Repetition and solidification of theoretical knowledge
- Overview of and support during various lab experiments
- Gathering of measurement data and production of lab protocols

To decide on the ideal didactic concept for the teaching software, the authors extensively researched the various parallels between online collection of market research data, especially via online questionnaires, and lab and/or teaching software within the context of an augmented learning environment. Table 1 contains an excerpt from the list of researched parallels. Similarities were especially appearant concerning the somewhat limited user motivation, which is a problem for market researchers as well as for lab instructors. It is noteworthy that the solution to this problem consists – in both cases – in the introduction of an extrinsic motivational element into the situation, which is known as an incentive in market research terms – and as a grade for students. Both situations demand a certain level of focused mental concentration on the user side, in both cases data is collected and later analyzed and the exact technical configuration of the end unser terminals is unknown to the market research questionnaire designer as well as to the teaching software programmer. In both cases, no specific technological requirements (e.g. operating system, browser type, browser version or number of additional plugins needed) can be made without excluding potential users. Many more parallels can be found, e.g. concerning the average time needed to complete a typical online questionnaire or an average learning module.

Feature	Online Questionnaire	Lab / Teaching Software
Level of Motivation	Low or very low	Partially low
Source of Motivation	External (Incentives)	External (Grades)
Focus of Participants	Usually high	Mostly high
Data Analysis Method	Analysis of given answers	Evaluation / Grading
Programming	Java, HTML, CGI	Java, HTML, CGI
User-side IT Technology	Manifold technology	Manifold technology
Average Duration	20-30 Minutes	30-40 Minutes

Tab. 1: Parallels between the online collection of market research data through questionnaires and the use of teaching software within or outside an augmented learning environment (excerpt)

4 http://www.selfhtml.org
5 http://www.mikroo.de
6 http://www.makroo.de

Because of these parallels, it seems prudent to utilize already existing scientific research on the creation of ideal conceptual designs for market research questionnaires, especially the existing Best Practice frameworks, in the development of teaching software. A thorough review of contemporary online market research methodology also confirms other findings about the ideal design of teaching software: direct feedback and a high degree of interactivity can trigger a heightened involvement on the user side, the (careful and spare) use of high quality multimedia elements helps to keep up the user's attention and the best possible solution to present a larger number of questions (or other content) is splitting them up in screen-sized information modules.

The application of the most important guidelines in contemporary online market reasearch questionnaire design (especially the research of [Te00], [Dr03], [Bö99] and the most recent [We05]) lead to the four basic software modules pictured in fig. 7.

These four modules are: The continuous repetition and cementation of theoretical knowledge about various aspects of optical technology, the user-controlled exploration and self-testing of this theoretical content utilizing interactive graphs and modules such as multiple-choice questionnaires, the customisable help and support of lab experiments and the option of generating and saving PDF[7] protocols with measurement data and student answers to theoretical questions as a data base which can be utilized by the lecturer for grading purposes.

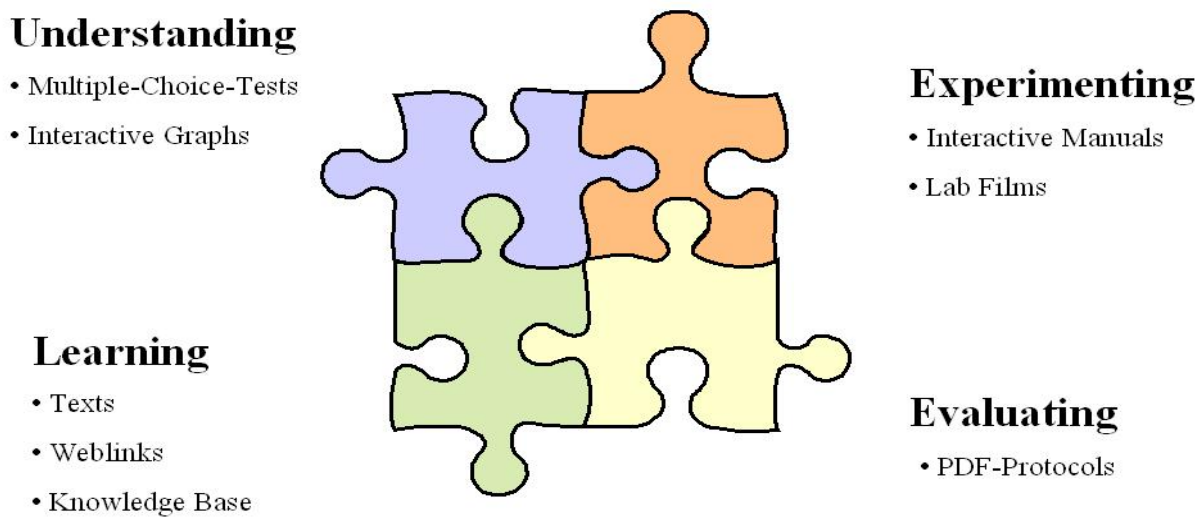

Fig. 7: Overview of the four OPTOTEACH basic software elements

The repetition and consolidation of theoretical knowledge is not confined to one theoretical module which students have to complete before a lab experiment can begin, instead, theoretical knowledge is repeated throughout the entire experimentation process and the interpretation of resulting measurement values. The hypertext-character of HTML allows the implementation of this idea into the software, because students can use embedded hyperlinks on important science terms to jump to corresponding theoretical context and then back to the current experiment. A permanently accessible glossary with an integrated search function makes it even easier for students to gain access to important theoretical knowledge. The synergy-effect that results from the interconnection of hands-on experimental lab work and understandable overviews of theoretical basics can thus be utilized most efficiently.

Because the overall design (the single information screen model mentioned above) allows the easy implementation of interposed control questions, this additional control method, which is typically not part of typical educational lab work programmes, can be integrated into the experimental workflow. It is up to the lecturer or lab administrator to decide, whether these knowledge checks are mandatory or optional for students.

The chaperonage of the individual student during lab experiments – the only part of the teaching software that is currently still under development – forms the core of the augmented learning environment. Parallel to the actual experimental performance students will be able to inform themselves about the general layout of the experiment,

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[7] PDF (Portable document File) is a registered trademark of Adobe Inc.

get work instructions from the computer and enter their measurement data, whereas average measurement data and other intermediate results provide the opportunity to continuously check whether the experiment is conducted correctly. Thus, students will be enabled to detect any discrepancies in their measurement data at an early stage and therefore check their own results, which is almost impossible to realize in a traditional lab environment. In the event of perceptible deviations of the experimental results from the ideal results, a set of multiple-choice questions will allow the student to identify probable causes of the discrepancy and gather instructions for correcting any possible mistakes. The lecturer only has to get involved into a particular experiment if this help system does not provide the solutions needed to achieve the expected results.

The heightened level of autonomy alleviates student-controlled lab work and supports the pedagogical concept behind of enabling students to advance their practical skills as well as their theoretical knowledge more or less autonomously in a self-controlled environment.

The acquisition of measurement data and the compilation of lab protocols will also be implemented, whereas the software covers all four learning phases. Via a HTML form field, students can enter measurement data as well as textual answers to theoretical questions and questions about completed experiments. This does not only represent a significant assistance for students but also for lecturers and lab administrators who will be disburdened from deciphering bad handwritings and searching for lost sheets of paper.

4.2 Dimensions of Teaching Software

Teaching software, like the OPTOSOFT software presented in this paper, is basically defined through the three dimensions of interactivity, adaptivity and controllability [DE01].

According to [Ke98], interactivity can be seen as a mostly technical dimension: When working in an interactive medium, the user – in this case the optics student – has unrestricted and self-controlled access to multimedia information. The interactivity allows the active processing of teaching content by the student, who has the ability to influence the selection and the sequence of content at least partially [Ja00]. Within OPTOTEACH, interactivity is provided via the easy-to-use navigation, which allows almost unrestricted access to all content modules. Students can forgo the recommended "learning path" and navigate freely through the software.

Adaptivity is defined as the extent to which users are allowed to customize any given software [DE01]. OPTOSOFT allows students to adjust the software to the preferred working speed, repeat complex passages at will or self-check the comprehension via multiple choice questions. When the software is used as a lab companion, the speed of instructions and recommendations is adjustable to the actual experimental progress, likewise in the acquisition of measurement data and the compiling of lab protocols, meaning the dimension of adaptivity is distinctive throughout all four phases described in 4.1.

According to [DE01], controllability does not refer to the control of the lecturer or lab administrator over the student but to the control of the student over the learning process. In computerized learning environments, the controllability increase with the extent to which non-linear navigation is implemented, meaning the less restricted the user is, the higher is the controllability of the software [Ne00]. Because the technical basis of OPTOSOFT is HTML, the hypertext-functionality allows a nearly completely unrestricted navigation throughout most of the learning modules. The only restrictions will be implemented into the lab protocol compilation process, because the electronic documents generated in this process may provide a basis for student grading.

Because of that, students will only be able to access the protocol editor after an experiment has been completed instead of being able to directly jump into the protocol compilation process. Furthermore, the PDF files generated by OPTOSOFT will exhibit a time stamp unchangeable by student changes in the protocol editor.

5 First Experiences

At present, more than half of the teaching software is completed, with the theoretical modules being already fully functional. The software will soon be undergoing vigorous beta testing at the Harz University photonics labs. The first student and lecturer feedbacks have been unanimously positive, welcoming the introduction of the multimedia element and the easy-to-navigate glossary to the lab. Several technical problems have been asserted and will be rectified before the release of the pre-beta-version.

One of the more interesting results of the first feedback evaluation is the clear demand for more multimedia elements to be included in the final version, directly connected to the general wish for a more colourful and less conservative visual design. While these wishes can certainly be implemented in the pre-beta-version, it is important not to overload the software with colours and multimedia elements, preserving the scientific image.

6 Conclusion and Outlook

At this stage, the fully functional OPTOSOFT version 1.0 is expected to be complete in late 2007, so that universities and vocational schools can start using the software in class and lab work not later than early 2008. The current version already includes the complete theoretical learning modules, the knowledge base, the link list, most of the multiple choice tests and interactive modules as well as some of the lab companion modules. Other lab companion modules, lab movies and a fully functional version of the protocol generator are still in development. The OPTOTEACH lab teaching system also described in this paper, has already been successfully introduced to the German education market and, as of early 2007, is being used in more than half a dozen universities nationwide.

Because the adoption of the augmented learning idea to photonics lab work is new and untested, the authors are very curious about the feedback of the first classes and lecturers that will start working with the software in early 2008. A quality feedback system, that will allow students and lecturers alike to communicate their experiences and critique points, is already in an early set-up phase. Aside from the mostly subjective impressions of students and lecturers, this feedback system will also gather more objective data such as average grading before and after the introduction of the software as well as the results of the teaching quality evaluation during the introductory period. A quality control and a version management system will ensure, that didactic and technical change requests are collected, evaluated, implemented or not implemented and archived for further evaluation.

The continuous further development of teaching system and teaching software as well as the complete documentation of this development process will result in a comprehensive catalogue of specifications and problems in the practical use of an interactive and multimedia lab companion software in the context of a photonics augmented learning environment. The authors expect to publish a revised edition of this catalogue as a basis for discussion about the optimal way of introducing augmented learning to photonics training.

All public and private institutions of vocational and higher education are invited to participate in this project.

7 Acknowledgement

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III.

MOTO:
a Matlab Object-oriented programming Toolbox for Optics

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The ray optics is the branch of optics in which all the wave effects are neglected: the light is considered as travelling along rays which can only change their direction by refraction or reflection. On one hand, a further simplifying approximation can be made if attention is restricted to rays travelling close to the optical axis and at small angles: the well-known linear or paraxial approximation introduced by Gauss. On the other hand, in order to take into account the geometrical aberrations, it is sometimes necessary to pay attention to marginal rays with the aid of a ray tracing procedure. This contribution describes a toolbox for the study of optical systems which implements both approaches. It has been developed in the framework of an educational project, but it is general enough to be useful in most of the cases.

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1. Introduction

Within the frame of the linear approximation, the properties of the rays travelling through an optical system can be treated with an elegant and powerful matrix formalism [1, 2]. The transfer matrix between two conjugate planes is obtained with the product between elementary matrices which account for propagation through an homogeneous medium and refraction (or reflection) at an interface. When studying optical systems within the Gauss approximation, it is sometimes necessary to determine the location and the size of the image of an object given by the optical system. This can be done in a geometrical manner by considering particular rays. However, the power and the cardinal elements, which are easily obtained from the transfer matrix, provide an accurate way to reach this goal. The Newton and the Descartes relations suffer from a restricting assumption: the optical system should be a focal one (otherwise the cardinal elements would not be defined). This is not the case of the homographic relation which is still valid for non-focal optical systems.

When studying complex optical systems, it is necessary to determine the path of the light with a greater accuracy than that obtained in the paraxial approximation. This may be done with the aid of elementary geometry, by successive application of the Snell-Descartes laws of refraction (or reflection). This method, which is known as ray tracing, is intensively used in the practical study of complex optical instruments. Since in an ideal system all rays that form an image are concurrent at the same image point, only two rays need to be traced to determine the image point. However, because of geometrical aberrations, marginal rays are not concurrent at a single point, whereas paraxial ones are. This is why ray tracing is the only way to properly take into account aberrations in an optical system without referring to Seidel or Zernike polynomials. Indeed, whatever the order used, these polynomials provide only an approximation of the geometrical aberrations while ray-tracing, which could be implemented for any interfaces (plane, spherical, parabolical,...), gives the true vision of the propagation through the optical system.

Both approaches have been implemented in Matlab with the aid of the Object Oriented Programming (OOP) facilities of this language [3]. This work has led to the development of a toolbox for Matlab which provides a quick and easy way to manipulate both dioptric and catadioptric systems, to study them interactively in the paraxial approximation (whether they are focal or non-focal) and also with attention paid to marginal rays (whether they propagate in homogeneous media or not). The toolbox conforms to Matlab for both programming rules and inline help [4]. High level functions are supported by graphical user interfaces. This toolbox, which will be made available to the public, may facilitate the education and training of students from college to university and of professionals like those in the medical field for example. Moreover, it may also be used as a scientific research tool since the ray tracing approach gives a significant improvement and could be very helpful for a better understanding of optical systems, like the eye for example.

2. Elementary objects and functions

The Object Oriented Programming (OOP) capabilities of MATLAB are used for implementing elementary classes which contains all the necessary characteristics of elementary optical systems. These elementary classes are used for computing the cardinal elements and the transfer matrices within the GAUSS approximation, but also for drawing the path of rays travelling throught an optical system whatever their inclination with the optical axis. Such an optical system is a vector which contains the individual elements. This vector is returned by the `sysopt` function which accepts a variable number of arguments and compiles/checks them in order to build the complete optical system.

2.1. Elementary objects

The file `dioptre.m` in the directory `@dioptre` contains the definition of the classe named `dioptre`. It is used for implementing refracting interfaces which are characterised by their location on the optical axes, their radius of curvature and the refractive indexes of the two media. Likewise, the file `mirror.m` in the directory `@mirror` contains the definition of the classe named `mirror`. It is used for implementing reflecting interfaces which are characterised by their location on the optical axes, their radius of curvature and the refractive index of the media. Finally, the file `diaphragm.m` in the directory `@diaphragm` contains the definition of the classe named `diaphragm`.
The functions defined in the private directories perform elementary actions on the corresponding optical subsystem like setting some characteristics, returning the transfer matrix $\mathcal{R}$ or the propagation one $\mathcal{T}$, computing the intersection of a ray with the interface, ...

2.2. Transfer matrix

When considering complex optical system consisting of regions of free space with a constant refractive index separated by spherical refracting/reflecting surfaces between the input and the output front planes, Exy and Sxy, the optical system is homogeneous step by step. Propagation through this system can be treated with the elementary matrices $\mathcal{R}$ and $\mathcal{T}$ corresponding to the refraction/reflection at an interface and to the propagation through free space [1]. The product of these elementary matrices, *written from right to left* following the path of the light, is the transfer matrix of the optical system within the GAUSS approximation:

$$T_{ES} = \mathcal{T}(\overline{S_pS})\mathcal{R}(S_p)\cdots\mathcal{T}(\overline{S_1S_2})\mathcal{R}(S_1)\mathcal{T}(\overline{ES_1}).$$

The function `matrix` returns in the variable `T` the transfer matrix T_{ES} of the optical system between the input plane Exy and the output plane Sxy:

```
T = matrix(soc{2});
for k=3:length(soc)
  T = matrix(soc{k-1},soc{k})*T;
  T = matrix(soc{k})*T;
end
```

The vector `soc` contains the individual elements of the optical system. Since the first cell of `soc` is used for storing the positions of the input and output planes Exy and Sxy as well as the refractive indexes n_o and n_i of the initial and final media, `T` is initialized with the transfer matrix of the first element reached by the light, here stored in the second cell. Then, products with propagation and transfer matrices are used up to the last element to obtain the final transfer matrix between Exy and Sxy.
The function `power` returns the opposite of `T(2,2)` which is by definition the refractive power V of the optical system.

2.3. Cardinal elements

The function `focal` returns in the two variables `fo` and `fi` the object and image focal lengths $f_o = -n_o/V$ and $f_i = n_i/V$:

```
fo = -No/V;
fi =  Ni/V;
```

where `No` and `Ni` are the refractive indexes n_o and n_i of the initial and final media, and `V` is the power V of the optical system as returned by the `power` function.

The function `cardinal` returns in the six variables `EFo`, `SFi`, `EHo`, `SHi`, `ENo` and `SNi` the location of the focal planes ($\overline{EF_o}$ and $\overline{SF_i}$), the principal planes ($\overline{EH_o}$ and $\overline{SH_i}$) and the nodal points ($\overline{EN_o}$ and $\overline{SN_i}$) with respect to the input and output planes Exy and Sxy:

```
EFo = fo*T(2,2);     EHo = fo*(T(2,2)-1);     ENo = fo*(T(2,2)-Ni/No);
SFi = fi*T(1,1);     SHi = fi*(T(1,1)-1);     SNi = fi*(T(1,1)-No/Ni);
```

where `T` is the transfer matrix T_{ES} of the optical system returned by the `matrix` function.

2.4. Algebraic determination of an image point within Gauss approximation

The function `homographic` returns in the variable `SAi` the position $z_i = \overline{SA_i}$ of an image A_i:

```
SAi = Ni*(T(1,1)*(EAo/No)-T(1,2))/(-T(2,1)*(EAo/No)+T(2,2));
```

where `EAo` is the position $z_o = \overline{EA_o}$ of the object A_o. The function `invhomographic` performs the reverse operation:

```
EAo = No*(T(2,2)*(SAi/Ni)+T(1,2))/(T(2,1)*(SAi/Ni)+T(1,1));
```

These two functions also return in the three variables `Gt`, `Ga` and `Gl` the transversal, angular and longitudinal magnifications G_t, G_a and G_l:

```
Gt = TaoAi(1,1);     Ga = TaoAi(2,2)*No/Ni;     Gl = Gt/Ga;
```

where `TaoAi` is the transfer matrix between the conjugate planes A_oxy and A_ixy:

```
TAoAi = [1 SAi/Ni; 0 1]*T*[1 -EAo/No; 0 1];
```

and is easily derived from the transfer matrix T_{ES} of the optical system and the transfer matrices describing the propagation between the front planes A_oxy and Exy on one hand, Sxy and A_ixy on the other hand.

The function `descartes` returns in the variable `HiAi` the position $p_i = \overline{H_iA_i}$ of an image A_i computed with the aid of DESCARTES's relation with regards to the principal points:

```
HiAi = Ni*/(V+No/HoAo);
```

where `HoAo` is the position $p_o = \overline{H_oA_o}$ of the object A_o. The function `invdescartes` performs the reverse operation:

```
HoAo = No*/(Ni/HiAi-V);
```

In addition, these functions also return the three magnifications:

```
Gt = (No/Ni)*(HiAi/HoAo);     Ga = HoAo/HiAi;     Gl = Gt/Ga;
```

Finally, the `newton` function returns in the variable `FiAi` the position $\sigma_i = \overline{F_iA_i}$ of an image A_i computed with the aid of NEWTON's relation with regards to the focal points:

```
FiAi = -(No/Ni)/V^2/FoAo;
```

where `FoAo` is the position $\sigma_o = \overline{F_oA_o}$ of the object A_o. The function `invnewton` performs the reverse operation:

```
FoAo = (No/Ni)/V^2/FiAi;
```

In addition, these functions also return the three magnifications:

```
Gt = -(V*FiAi)/Ni;     Ga = -No/(V*FiAi);     Gl = Gt/Ga;
```

or

```
Gt = No/(V*FoAo);     Ga = (V*FoAo)/Ni;     Gl = Gt/Ga;
```

2.5. Graphical determination of an image point within Gauss approximation

The function plotcardinal plots the position of the cardinal elements on an optical axis where the input and output planes Exy ans Sxy of the optical system are also drawn.
For a given object A_oB_o at a distance $z_o = \overline{EA_o}$ from Exy and for the corresponding image A_iB_i located at a distance $z_i = \overline{SA_i}$ from Sxy, the function plotgaussrays plots the three particular rays:

- the ray entering the system from B_o parallel to the optical axis emerges from the system by crossing the image focal point F_i towards B_i,
- the ray entering the system from B_o and crossing the object focal point F_o emerges parallel to the system towards B_i,
- the ray entering the system from B_o and crossing the object nodal point N_o emerges parallel to its incident direction and crossing the image nodal point N_i towards B_i.

2.6. Ray tracing

When propagating within the optical system, the rays are refracted/reflected by the successive interfaces. Between these interfaces, light is travelling in straight line in an homogeneous media. The corresponding rays are characterized by a set of coordinates (z, xy) (namely the coordinates of the intersection point with each interface) and by an inclination angle α with the optical axis which are computed with the aid of SNELL-DESCARTES laws. The function rays returns in the variables z, xy and a the successive locations and inclinations of these rays:

```
for k=2:length(soc)
  [z(k),xy(k),a(k)] = ray(soc{k},z(k-1),xy(k-1),a(k-1));
end
z(k+1) = ze;
xy(k+1) = xy(k)+tan(a(k))*(ze-z(k));
a(k+1) = a(k);
```

The function ray is a private function of the elementary classes described in section 2.1 which propagates the ray though each individual element of the optical system soc. The function rays is ended by computing the propagation of the ray after the optical system up to a plane, namely a virtual screen.
Finally, the path of the rays can be plotted with the function plotrays.

3. Application in homogeneous media

The functions described in the previous section are used here for studying a complex optical system, namely the human eye. The dimensions of the eye and the characteristics of its optical components vary greatly from person to person, and some further depend upon accommodation level, age and certain pathological conditions. Despite these variations, average values have been used to construct representative or schematic eyes. The standard model used for this work is the LE GRAND model [5] which is a four interfaces model: the two first interfaces correspond to the cornea, the two last ones constitute the lens. The function LeGrand returns all the elements of this model when it is relaxed:

```
cornea1 =   dioptre('cornea',0.00E-03, 7.80E-03,1.0000,1.3771);
cornea2 =   dioptre('cornea',0.55E-03, 6.50E-03,1.3771,1.3374);
iris    = diaphragm('iris'  ,3.60E-03,10.20E-03,6.00E-03);
lens1   =   dioptre('lens'  ,3.60E-03,10.20E-03,1.3374,1.4200);
lens2   =   dioptre('lens'  ,7.60E-03,-6.00E-03,1.4200,1.3360);
```

or when it accommodates. However, in the present study, we will concentrate on the relaxed eye:

```
>> eye = LeGrand('relaxed');
```

3.1. Gauss approximation

The transfer matrix is easily obtained with the matrix function:

```
>> T = matrix(eye)
T =  0.7446    0.0054
   -59.9404    0.9044
```

Then the focal distances are returned by the `focal` function:

```
>> [fo,fi] = focal(eye)
fo = -0.0167
fi =  0.0223
```

Finally, the cardinal elements are computed with the `cardinal` function:

```
>> [EFo,SFi,EHo,SHi,ENo,SNi] = cardinal(eye)
EFo = -0.0151
SFi =  0.0166
EHo =  0.0016
SHi = -0.0057
ENo =  0.0072
SNi = -0.0001
```

and they represented in Fig. 1 with the `plotcardinal` function:

```
>> figure(1); plotcardinal(eye);
```

The total power of the eye is returned by the power function:

```
>> V = power(eye)
V = 59.9404
```

It can be checked that approximately two third of this power is due to the cornea:

```
>> cornea = LeGrand('relaxed','cornea');
>> V1 = vergence(cornea)
V1 = 42.3564
>> lens = LeGrand('relaxed','lens');
>> V2 = vergence(lens)
V2 = 21.7787
```

The optical distance e between the cornea and the lens can therefore be computed with the aid of GULLSTRAND's formula. Indeed, since the refractive index of the aqueous, the medium between the posterior face of the cornea and the anterior face of the lens, is 1.3374, we have:

```
>> e = 1.3374*(V1+V2-V)/(V1*V2)
e = 0.0061
```

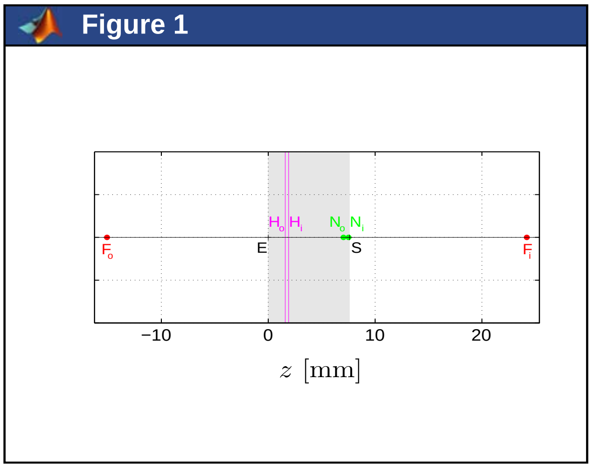
It can be verified that e is equal to the distance between the image principal plane of the cornea and the object principal plane of the lens by computing the cardinal elements of these two optical subsystems.
The iris is the aperture stop of the eye. The position EP_e of input pupil P_e with respect to the input plane Exy can be obtained with the aid of the `invhomographic` function:

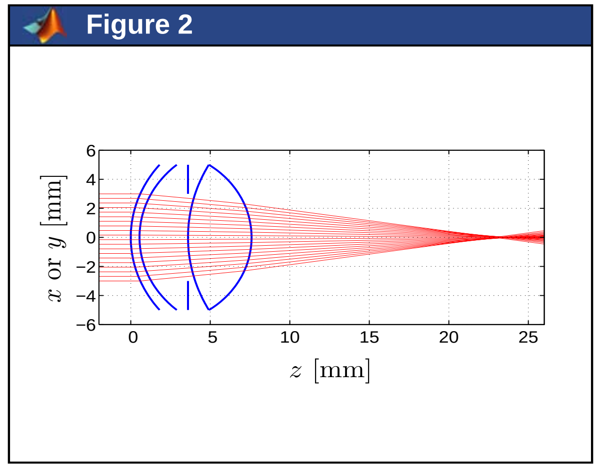
```
>> [EPe,Gt] = invhomographic(cornea,3.05E-03)
EPe =  0.0030
Gt  =  0.8841
```

since it is the conjugate point of the aperture stop given by the optical elements in front of the latter (i.e. here the cornea). It is located 3.04 mm behind Exy, that is to say 0.56 mm in front of the iris. Taking into account the transversal magnification, its diameter is equal to 6.78 mm. Likewise, the location of the output pupil P_s with respect to the output plane Sxy is obtained with the aid of the `homographic` function:

```
>> [SPs,Gt] = homographic(lens,0.00E-03)
SPs = -0.0039
Gt  =  1.0411
```

since it is the image of the aperture stop given by the optical elements behind the latter (i.e. here the lens). It is located 3.92 mm in front of the output plane Sxy, that is to say only 0.08 mm behind the iris. Accounting for the transversal magnification, its diameter is equal to 6.25 mm.





3.2. Ray tracing and aberrations

We now consider an incident beam of 20 rays parallel to the optical axis. The diameter of this beam is, for example, 6 mm, and the path of the rays will be plotted from a plane located 2 mm in front of the cornea to another plane 26 mm behind it in the vicinity of the retina:

```
>> [z,xy,alpha] = rays(eye,-2E-03,linspace(-3E-03,3E-03,20),0,26E-03);
```

The result is represented on Fig. 2 with the aid of the `plotsysopt` and `plotrays` functions:

```
>> figure(2); plotsysopt(eye,5.0E-03); plotrays(z,xy);
```

It can be observed that the eye is not an optical system which can be only studied within the GAUSS approximation. For example, the localization of the retina, that is to say the localization of the image focal plane, requires a ray tracing procedure. From the final coordinates and inclination of the rays when they hit the plane located 26 mm in the back of the cornea, the equation of the rays emerging from the lens can be computed:

```
>> a = tan(alpha(:,end));
>> b = xy(:,end) - a.*z(:,end);
```

Then, the distance $z = -b/a$ from the origin where the rays cross the optical axis is computed:

```
>> z = -b./a;
>> r = abs(xy(:,1));
```

The variations of the radius of the incident beam r wrt. z are shown on Fig. 3:

```
>> figure(3); plot(z*1.0E+03,r*1.0E+03);
```

This figure illustrates the fact that incident rays parallel to the optical axis are all the more convergent when they are far from the optical axis. Moreover, all the rays cross the optical axis before the image focal plane whose location in the GAUSS approximation is 24.2 mm from the anterior face of the cornea. Finally, the diameter d of the spot in a plane located at a given distance z from the anterior face of the cornea can be computed:

```
>> z = (21:0.01:26);
>> for k=1:length(z), d(k) = 2*max(a*z(k) + b); end
```

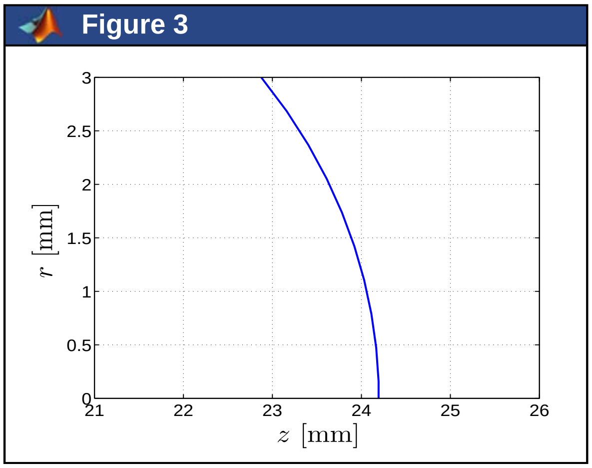
The variations of d wrt. z are shown on Fig. 4:

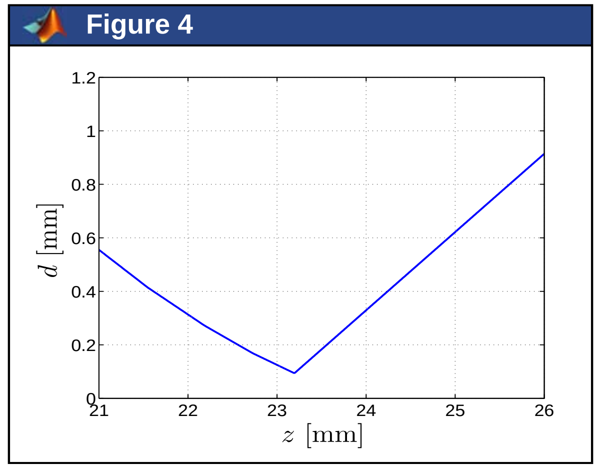
```
>> figure(4); plot(z*1.0E+03,d*1.0E+03);
```

It can be observed that the smallest spot, whose diameter d is here about 0.1 mm, is not in the focal plane but in a plane which is 1 mm in front of it:

```
>> [dmin,k] = min(d);
>> [d(k)*1E+03, z(k)*1E+03]
ans = 0.0948 23.1900
```

since it is located 23.2 mm behind the anterior face of the cornea compared to 24.2 mm in the GAUSS approximation.
The following figures show that the localization of the retina is not a matter of GAUSS approximation but requires a ray tracing procedure since it is always over-estimated by the former approach.





3.3. LASIK

Nowadays, some ametropias of the eye (myopia and hypermetropia) could be corrected by means of a modification of the shape of the anterior face of the cornea. A photo-ablation of a small piece of the cornea is obtained with the aid of an excimer laser. After cicatrizing, the radius of curvature of the anterior face of the cornea is modified. The refractive power of the cornea is changed accordingly, and the ametropic eye becomes emmetropic. This surgical technique is knows under the acronym LASIK which stands for Laser ASsisted In-situ Keratomileusis. One of the problems encountered in practice is to evaluate the amount of cornea removal in order to give to the cornea the expected refractive power [6]. We show in this section that a ray tracing approach could be very helpful to achieve this goal since it is the only way to properly take into account aberrations of the cornea [7].
The free parameters for the photo-ablation of a piece of cornea are the thickness ε of the corneal tissue which is burned as well as the diameter D of the surgical field. The goal is to change the radius of curvature R of the anterior face of the cornea so that, after cicatrizing, the new radius of curvature R' leads to a better focussing of the rays on the retina. Both radii are related to each other with the following equation [1]:

$$R' = \frac{(h-\varepsilon)^2 + (D/2)^2}{2(h-\varepsilon)} \quad \text{with} \quad h = R - \sqrt{R^2 - (D/2)^2}.$$

Measurements of keratometry and pachymetry of an eye suffering from myopia have led to the following numbers:

```
>> cornea1 =   dioptre('cornea',0.00E-03, 7.25E-03,1.0000,1.3771);
>> cornea2 =   dioptre('cornea',0.41E-03, 5.25E-03,1.3771,1.3374);
>> iris    = diaphragm('iris'  ,3.45E-03,10.33E-03,6.00E-03);
>> lens1   =   dioptre('lens'  ,3.45E-03,10.33E-03,1.3374,1.4200);
>> lens2   =   dioptre('lens'  ,7.60E-03,-6.17E-03,1.4200,1.3360);
>> eye     = sysopt(cornea1,cornea2,iris,lens1,lens2);
```

The diameter of the surgical field D has been fixed to 6 mm. The radius of curvature of the reshaped anterior face of the cornea R' is here computed for different values of the thickness ε:

```
>> D = 6.00E-03;
>> R = 7.25E-03;
>> h = R - sqrt(R^2 - (D/2)^2);
>> e = (0:150)*1.0E-06;
>> R = ((h-e).^2 + (D/2)^2)./(2*(h - e));
```

The variations of R' wrt. ε are represented on Fig. 5:

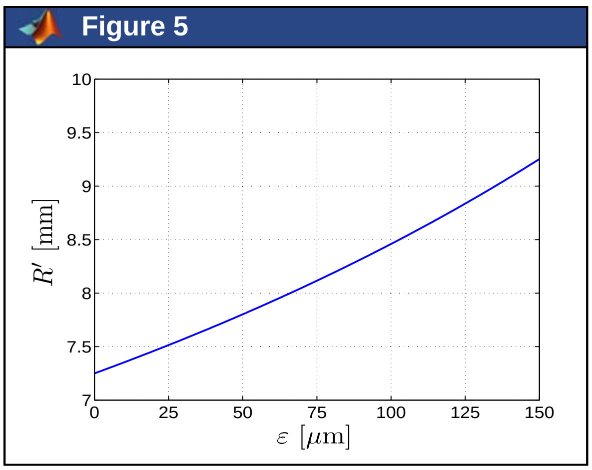
```
>> figure(5); plot(e*1.0E+06,R*1.0E+03);
```

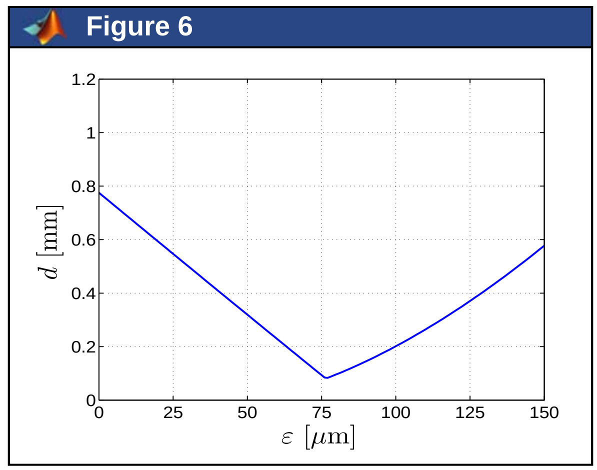
Measurements have shown that the retina is located 17.2 mm behind the posterior face of the lens, that is to say 24.8 mm behind the anterior face of the cornea. The diameter d of the spot on the retina is computed for an incident beam of 20 rays parallel to the optical axis. The width of this beam is taken equal to D:

```
>> for k=1:length(e)
>>   eye{2} = set(eye{2},'Position',e(k),'Curvature',R(k));
>>   [z,xy,alpha] = rays(eye,-2.0E-03,linspace(-D/2,D/2,20),0,26.0E-03);
>>   a = tan(alpha(:,end));
>>   b = xy(:,end) - a.*z(:,end);
>>   d(k) = 2*max(a*24.8E-03 + b);
>> end
```

The variations of d wrt. ε are represented on Fig. 6:

```
>> figure(6); plot(e*1.0E+06,d*1.0E+03);
```





The thickness of the tissue to be burned corresponds to the value of ε for which d is minimal:

```
>> [dmin,k] = min(d);
>> [e(k)*1.0E+06, d(k)*1.0E+03, R(k)*1.0E+03]
ans = 77 0.0829 8.1424
```

These values can be compared to those before correction, namely those for $\varepsilon = 0$:

```
>> [e(1)*1.0E+06, d(1)*1.0E+03, R(1)*1.0E+03]
ans =  0 0.7754 7.2500
```

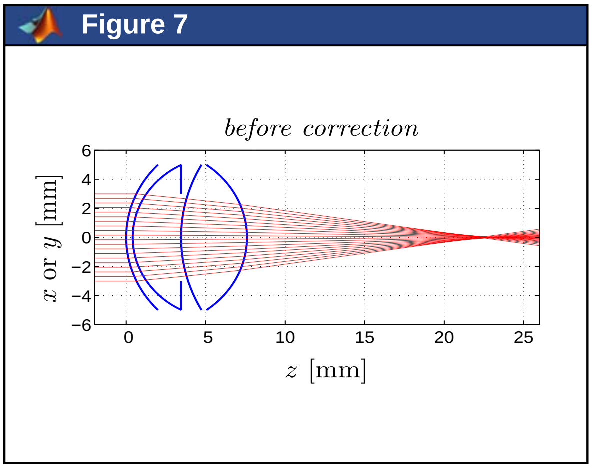
The thickness of the corneal tissue to be burned is $\varepsilon = 77\ \mu$m in the simulated surgical conditions. The diameter of the spot in the retina plane is therefore reduced from $d = 0.78$ mm down to less than $d = 0.09$ mm. To reach this goal, the radius of curvature of the anterior face of the cornea has increased from $R = 7.25$ mm up to $R' = 8.14$ mm.

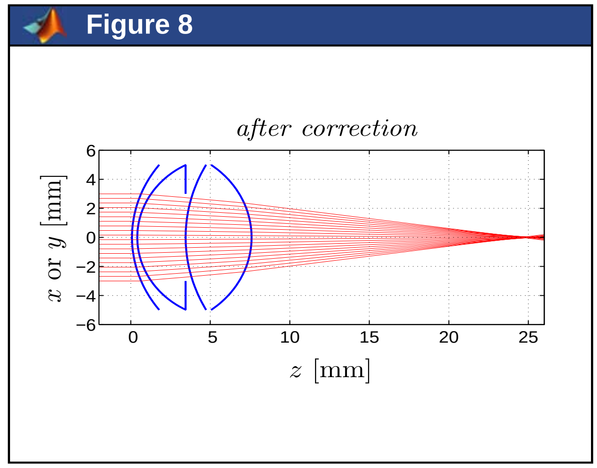
The consequence of this change of the radius of curvature is illustrated in Figs. 7 and 8 where the path of rays are plotted before and after corneal tissue removal:

```
>> eye{2} = set(eye{2},'Position',e(1),'Curvature',R(1));
>> [z,xy,alpha] = rays(eye,-2.0E-03,linspace(-D/2,D/2,20),0,26.0E-03);
>> figure(7); plotsysopt(eye,5.0E-03); plotrays(z,xy); title('before correction');
>> eye{2} = set(eye{2},'Position',e(k),'Curvature',R(k));
>> [z,xy,alpha] = rays(eye,-2.0E-03,linspace(-D/2,D/2,20),0,26.0E-03);
>> figure(8); plotsysopt(eye,5.0E-03); plotrays(z,xy); title('after correction');
```

Paying attention to the path of the rays close to the retina plane located 24.8 mm behind the anterior face of the cornea, it is observed that after correction the rays are converging on the retina whereas they were converging before the retina plane before correction since the eye was suffering from myopia.

The same simulation can be conducted with different values for the diameter D of the surgical field. The corresponding numbers show that, like expected, the thickness ε of the corneal tissue to be burned for reaching the same goal is an increasing function of D.





4. Application in non-homogeneous media

The capabilities of MATLAB to solve ordinary differential equations (ODE) is used here for studying the propagation of light in non-homogeneous media. The ODE which describes the path of the light is:

$$\frac{\mathrm{d}}{\mathrm{d}s}\left(n\frac{\mathrm{d}\mathbf{r}}{\mathrm{d}s}\right) = \mathbf{grad}\, n,$$

where $\mathbf{r}$ denotes the position vector of a point on the ray which is a function of the length of arc s of the ray [1,2]. For the numerical implementation of a ray tracing procedure, it is convenient to set $\mathrm{d}l = \mathrm{d}s/n$ [1] so that the previous ODE reads:

$$\frac{\mathrm{d}^2\mathbf{r}}{\mathrm{d}l^2} = \frac{1}{2}\mathbf{grad}\, n^2.$$

In this study, light is propagating in a plane. In cartesian coordinates x and y, the previous vector equation reduces to a system of two equations of second order:

$$\begin{aligned}\frac{\mathrm{d}^2x}{\mathrm{d}l^2} &= \frac{1}{2}\frac{\partial n^2}{\partial x},\\ \frac{\mathrm{d}^2y}{\mathrm{d}l^2} &= \frac{1}{2}\frac{\partial n^2}{\partial y}.\end{aligned}$$

Since MATLAB can only solve ODE of the first order, the previous system of second order has to be rewritten:

$$\begin{aligned}\frac{\mathrm{d}p_x}{\mathrm{d}l} &= \frac{1}{2}\frac{\partial n^2}{\partial x},\\ \frac{\mathrm{d}p_y}{\mathrm{d}l} &= \frac{1}{2}\frac{\partial n^2}{\partial y},\end{aligned} \quad \text{with} \quad \begin{aligned}\frac{\mathrm{d}x}{\mathrm{d}l} &= p_x,\\ \frac{\mathrm{d}y}{\mathrm{d}l} &= p_y.\end{aligned}$$

In this study, the refractive index of the non-homogeneous media satisfies the law [8]:

$$n^2(\rho) = 1 + \frac{\rho_0^2}{\rho^2} \quad \text{with} \quad \rho = \sqrt{x^2+y^2}.$$

The region where the media is non-homogeneous will be restricted to a disk with radius $R > \rho_o$. Outside this disk, n will be supposed to be uniform and equal to $n_i = \sqrt{1+\rho_o^2/R^2}$, so that no discontinuity occurs at the boundary. If this were not the case, SNELL-DESCARTES laws would be applied at the boundary where the refractive index may vary.
Within the non-homogeneous media, the gradient of n^2 can be written also in cartesian coordinates:

$$\begin{aligned}\frac{\partial n^2}{\partial x} &= -\frac{2x\rho_0^2}{(x^2+y^2)^2},\\ \frac{\partial n^2}{\partial y} &= -\frac{2y\rho_0^2}{(x^2+y^2)^2}.\end{aligned}$$

The function `ode2D` contains the final definition of the problem under study: in vector `f` are stored the values of x, y, p_x and p_y for a given value of l, whereas the vector `df` returns the values of p_x, p_y, $\mathrm{d}p_x/\mathrm{d}l$ and $\mathrm{d}p_y/\mathrm{d}l$ for the same value of l.

```
function df=ode2D(l,f,ro)
x = f(1);  px = f(3);
y = f(2);  py = f(4);
dpxdl = 0.5*(-2*x*ro^2/(x^2+y^2)^2);
dpydl = 0.5*(-2*y*ro^2/(x^2+y^2)^2);
df = [px; py; dpxdl; dpydl];
```

Before solving the ODE described in function `ode2D` it is necessary to precise the initial conditions of the problem. We consider here an incident ray hitting the boundary of the disk at a point $M_i(x_i, y_i)$ on the circle with radius R making an angle α with Ox axis. In the neighbourhood of M_i, we have: $\mathrm{d}x = \mathrm{d}s\cos\alpha$ and $\mathrm{d}y = \mathrm{d}s\sin\alpha$. Since at any point on the ray path $\mathrm{d}l = \mathrm{d}s/n$, we therefore have:

$$(\mathrm{d}x/\mathrm{d}l)_i = n_i\cos\alpha \quad \text{and} \quad (\mathrm{d}y/\mathrm{d}l)_i = n_i\sin\alpha.$$

The radius of the disk is set, for example, to $R = 4\rho_o$ with $\rho_o = 1$. For clarity reasons, we will restrict the study to incidents rays parallel to Ox axis, at a distance h from this axis, so that $\alpha = \pi$.

```
>> ro = 1;
>> R = 4*ro;
>> h = 2*ro;
>> Xi = sqrt(R^2 - h^2);
>> Yi = h;
>> Ni = sqrt(1 + (ro/R)^2);
>> alpha = pi;
>> dXidl = Ni*cos(alpha);
>> dYidl = Ni*sin(alpha);
```

After point M_i, the light propagates in the non-homogeneous media and the resulting path is the solution of the ODE described in the function `ode2D`. This equation is solved here with the aid of the function `ode45` whose integration scheme is based on a fifth order Runge-Kutta approach:

```
>> options = odeset('Stats','on','RelTol',1E-12,'AbsTol',1E-12);
>> [l,f] = ode45('ode2D',[0:0.1:10],[Xi Yi dXidl dYidl],options,ro);
>> X = f(:,1);  Y = f(:,2);  dXdl = f(:,3);  dYdl = f(:,4);
```

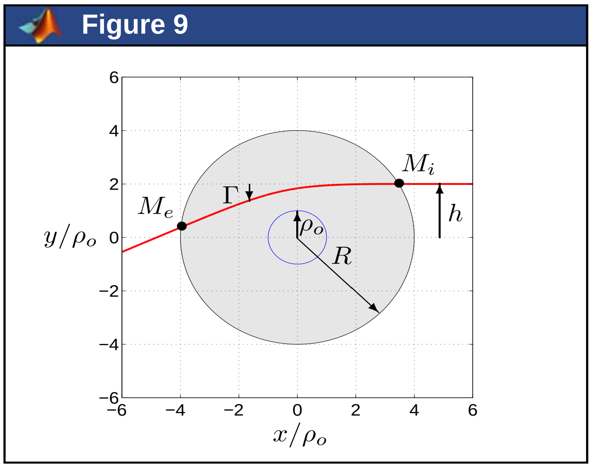
The values of the solutions x, y, $p_x = \mathrm{d}x/\mathrm{d}l$ et $p_y = \mathrm{d}y/\mathrm{d}l$ along the ray path in the disk are returned in the array `f`. For convenience reasons, they are written in separates vectors `X`, `Y`, `dXdl` and `dYdl`.
The ray emerges from the disk at a point $M_e(x_e, y_e)$ on the circle with radius R with an inclination angle β with the Ox axis. The coordinates (x_e, y_e) are computed with the aid of a simple linear interpolation between two points lying on each side of the boundary. The tangent of β is equal to the ratio $(\mathrm{d}y/\mathrm{d}x)_e$ which is computed from the derivatives $(\mathrm{d}y/\mathrm{d}l)_e$ and $(\mathrm{d}x/\mathrm{d}l)_e$ obtained again after a linear interpolation.

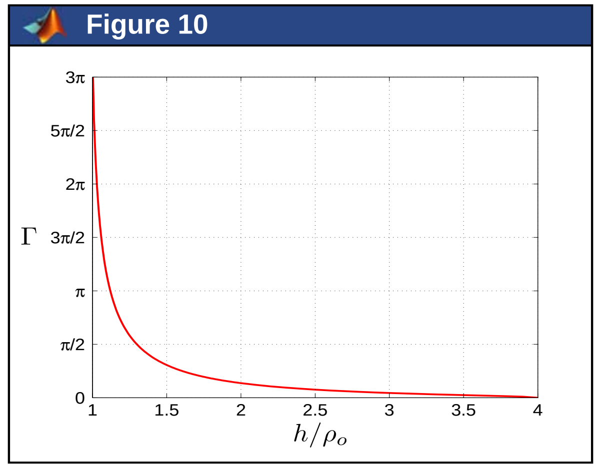
```
>> k = max(find((X.^2+Y.^2) < R^2));
>> le = interp1([X(k)^2+Y(k)^2,X(k+1)^2+Y(k+1)^2],[l(k),l(k+1)],R^2,'linear');
>> Xe = interp1([l(k),l(k+1)],[X(k),X(k+1)],le,'linear');
>> Ye = interp1([l(k),l(k+1)],[Y(k),Y(k+1)],le,'linear');
>> dXedl = interp1([l(k),l(k+1)],[dXdl(k),dXdl(k+1)],le,'linear');
>> dYedl = interp1([l(k),l(k+1)],[dYdl(k),dYdl(k+1)],le,'linear');
>> beta  = atan2(dYedl,dXedl);
```

The complete path of the ray is represented on Fig. 9:

```
>> figure(9); plot([X(1:k); Xe]/ro,[Y(1:k); Ye]/ro);
```

Up to M_i and beyond M_e the light is travelling in straight line since the media is homogeneous with uniorm refractive index n_i. On the contrary, from M_i to M_e, in the disk of radius R, the path is curved since the light is here travelling in a non-homogeneous media.
The curvature of the path is oriented towards the center of the disk, that is to say towards the direction of **grad** n. The ray continuously tends towards the center without reaching it and moves away in a symetric manner with respect to the location where the distance from the center of the disk was minimal.

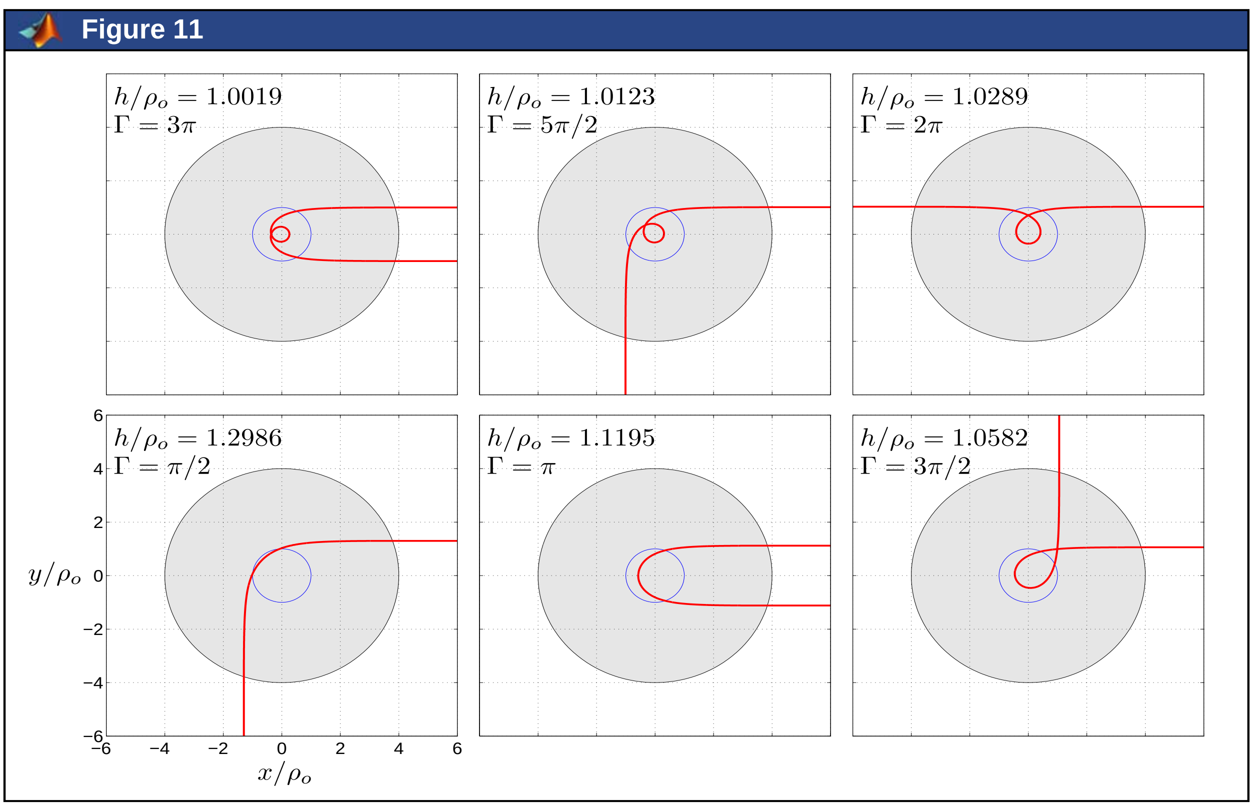




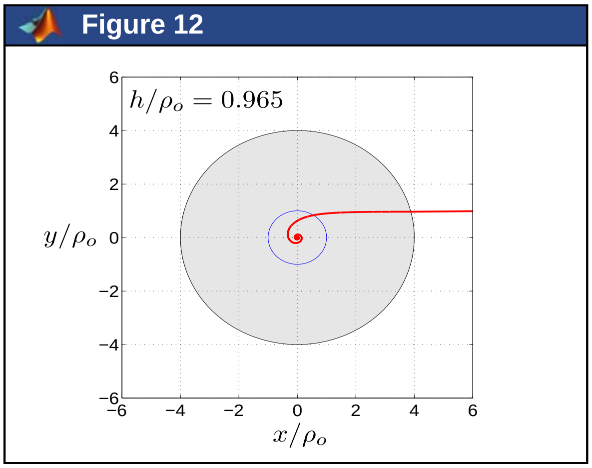
According to Fig. 9, the deviation angle Γ after travelling through the disk is equal to $\beta + \pi$:

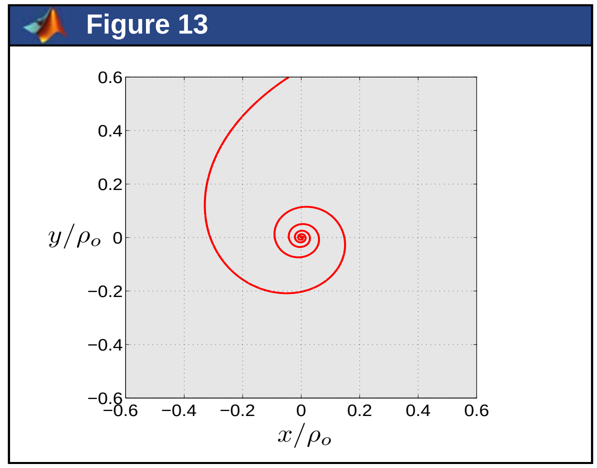
```
>> gamma = beta+pi
gamma = 0.4288
```

Here, for $h = 2\rho_o$, the deviation is about 25° with respect to the incident direction. As shown in Fig. 10, Γ varies in a non-linear manner provided that h does not go below a limit h_ℓ which depends on ρ_o, R and α. Values of Γ greater than $\pi/2$ correspond to rays which make a half turn, or even more than a complete turn, before leaving the disk. Some particular situations are shown in Fig. 11 for different values of the ratio h/ρ_o.



One can think that the light can make a large number of turns before leaving the disk. On the contrary, below the limit h_ℓ, the path of the light identifies to that of a spiral: the ray seems to be attracted by the discontinuity of the refractive index of the non-homgeneous media for $\rho = 0$ and does not emerges from the disk. Such a situation is illustrated in Figs. 12 and 13 for $h = 0.965\rho_o$:





These simulations illustrate the results, sometimes amazing, of the propagation of the light in a non-homogeneous medium.

5. Conclusion

This contribution has described a MATLAB toolbox for the study of optical systems. Thanks to the Object Oriented Programming (OOP) capabilities of MATLAB, this toolbox provides a quick and easy way to manipulate both dioptric and catadioptric systems, to study them interactively in the paraxial approximation (whether they are focal or non-focal) and also with attention paid to marginal rays (whether they propagate in homogeneous media or not).
Two illustrations in both homogeneous and non-homogeneous media have demonstrated the capabilities of this toolbox for the education and training of students from college to university and for professionals like those in the medical field for example.

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IV.

Nonlinear Optics Mathcad Exercise for Undergraduate Students

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Abstract: An educational experience in numerical modeling for physics majors at Virginia Military Institute has been created as part of the undergraduate research learning paradigm. As part of the independent project course required of all physics majors at VMI, those joining the thin films research group are taught the various stages of numerical modeling applied to complex problems (such as optical limiting) as a precursor to experimental work. Students are introduced to a realistic method of research involving open-ended experiments by this exercise. By teaching students how to design, create, and test a complex numerical model, they gain insight into how an experiment is set up and executed as well as what results can be anticipated. We present an exercise in which undergraduate students use Mathcad in their modeling and calculations.

1. Introduction

The paper describes the work derived from a specific independent project class required for Physics majors. The main motivation for this project is that optics is such an important scientific field with numerous applications in consumer technologies, telecommunications, medicine, health, defense, to mention just few. Physics majors at VMI are required to take optics and this is a good opportunity for them to further expand their knowledge and appreciation of the field. In addition, our department has a strong optics background through faculty expertise and research areas: laser spectroscopy, statistical optics, nonlinear optical properties of organic materials and thin films, and observational astronomy. As part of their curriculum, physics majors learn Mathcad and are also required to take an Independent project course which is two semesters long during their junior year. For this particular independent project students combine concepts from optics with Mathcad and further expand to nonlinear optics (NLO), specifically optical limiting (OL). This was done as a precursor to experimental work on OL properties of fullerene materials.

2. Theoretical Concepts

Step 1 – Basic optics (transmission, Beer's law)

At the beginning of the project the student is reminded of basic concepts of optics[1], including index of refraction, intensity of light, and propagation of light waves in a dielectric. The concepts that are reviewed also include the expression of the energy flux density through a dielectric, given by:

$$I = I_0 e^{-\alpha z}$$

where $\alpha = 2k_I$ is the absorption coefficient of the medium. This means that increased incident intensity linearly increases the output intensity. The polarization of a linear medium by an electric field $\vec{E}$ is usually written as $\vec{P} = \varepsilon_0 \chi \vec{E}$, where ε_0 is the vacuum permittivity and χ is the susceptibility of the medium.

Step 2- Introduction to nonlinear optics

Next, the student is introduced to nonlinear optical phenomena. The polarization of a nonlinear medium by an electric field $\vec{E}$ is

$$P = \varepsilon_0(\chi_1 E + \chi_2 E^2 + \chi_3 E^3 + ...) = P_1 + (P_2 + P_3 + ...)$$

where χ_1 is the linear susceptibility and χ_i (with i >1) represent the nonlinear susceptibility coefficients of the medium. The first term P_1 represents the polarization of the linear medium (described by linear optics), while the higher order terms only appear in nonlinear optical media, when the intensity of incident light is very high. For this project we are interested in optical limiters for which the transmittance decreases with increased incident light intensity. This particular class of materials has potential applications for eye and sensor protection.[2] There are several mechanisms[3] of achieving optical limiting, one of them being reverse saturable absorption (RSA), where the absorption of the material increases with light level. Reverse saturable absorption occurs when the excited states have absorption cross sections larger than that of the ground state. In order for the students to understand the reverse saturable absorption mechanism they use Mathcad to analyze the linear, the three level, and the five level model of an optical limiter.

Step 3 – Fullerene materials and basic properties related to OL (electron affinity, five level model reduced to three level model)

One class of materials that exhibit promising optical limiting properties is the fullerenes. Fullerenes represent a third allotropic form of carbon, besides graphite and diamond. Their existence was first demonstrated[4] in 1985. Since then, other fullerene materials besides C_{60} have been created: higher cages (C_{70}, C_{76}, C_{84}), endohedral metallofullerenes, and various derivatives. The unique nonlinear optical properties of fullerenes are due to the highly polarizable conjugated π-electrons which are delocalized over the surface of the carbon cage. One of the properties of these materials that has been studied extensively is the optical limiting effect, first reported[5] in C_{60} and C_{70} at 532 nm and later measured at longer wavelengths and demonstrated for other fullerene materials[6]. As in any other RSA materials, fullerene materials have the same requirements[7]: small, but finite ground state absorption and large excited state absorption; often these materials exhibit intersystem crossing to triplet manifold. To best describe the behavior of RSA materials under nanosecond pulses a five level model is usually employed.

The five levels include the ground state S_0, the first excited singlet state S_1, the next higher excited singlet state S_2, the lowest T_0 and higher T_1 triplet states. The incident laser beam excites the molecules from the ground state S_0 to one of the many vibrational levels of state S_1, which relaxes very fast (~ps) to the equilibrium singlet-state S_1. From this excited singlet state the molecules can relax to the ground state, with rate $1/\tau_0$, or, through a process called intersystem crossing (ISC) they can be transferred to a lower triplet state T_0, from where they can undergo transitions to higher triplet state T_1, upon absorption of another photon. The ISC crossing is fast (650 ps – 1.2 ns), with a quantum efficiency close to unity. Although by subsequent absorption of photons the molecules in S_1 and T_0 can be further excited to S_2 and T_1, respectively, they relax rapidly (less than ps) back to S_1 and T_0, and therefore there is no decrease in S_1 and T_0 populations during the duration of the nanosecond laser pulse. In addition, in RSA materials, the lifetime of T_0 is large (~ 100 μs to 100 ns) compared to the temporal width of the pulse. The rate equations that describe the above five-level model are:

$$\frac{dS_0}{dt} = -\sigma_{01} S_0 \phi + k_{10} S_1 + k_{30} T_0$$
$$\frac{dS_1}{dt} = \sigma_{01} S_0 \phi - \sigma_{12} S_1 \phi - (k_{10} + k_{13}) S_1 + k_{21} S_2$$
$$\frac{dS_2}{dt} = \sigma_{12} S_1 \phi - k_{21} S_2$$
$$\frac{dT_0}{dt} = -\sigma_{34} T_0 \phi - k_{30} T_0 + k_{13} S_1 + k_{43} T_1$$
$$\frac{d\phi}{dz} = -\sigma_{01} S_0 \phi - \sigma_{12} S_1 \phi - \sigma_{34} T_0 \phi$$

When RSA is dominated by the excited triplet state absorption, the model can be reduced to a three level model which includes the ground state, the first excited singlet state, and the first excited triplet state, which has a long lifetime.

$$\frac{dS_0}{dt} = -\sigma_{01} S_0 \phi + k_{30} T_0$$
$$\frac{dT_0}{dt} = \sigma_{01} S_0 \phi - k_{30} T_0$$
$$\frac{d\phi}{dz} = -\sigma_{01} S_0 \phi - \sigma_{34} T_0 \phi$$

These are the three equations students use to model in Mathcad the OL behavior of the material, as described in the next section.

3. Mathcad modeling and computation

Step 4 – Set-up problem in Mathcad

Linear absorption can be described by the reduction of light intensity *dI* after an incident beam of photons I_0 crosses a linear dielectric of length *l* with absorption coefficient α and is given by

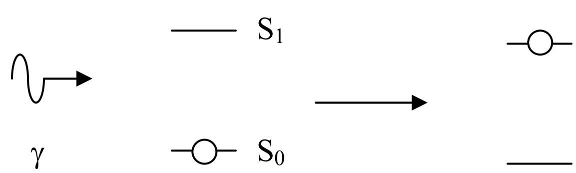
$$dI = -\alpha I dz$$

where the distance is integrated until *l* is reached. Likewise, the equation above can be turned into a time integral by noting that $dz = cdt$ and writing

$$dI = -\alpha I c dt = \alpha' I dt$$

where α' is a redefined absorption coefficient and we have assumed the velocity of light in the sample is the speed of light *c*. Simple integration yields, $I = I_0 e^{-\alpha' t}$. This equation simply states that the longer the beam takes to cross the sample, the greater the reduction in the incident intensity. The crossing time can be converted into a thickness by multiplication of the *c* but the point is clear enough that students can grasp this simple concept.

If asked to determine the transmitted intensity, the student will most likely solve the final equation above. If asked to graph the function, he/she will simply do so by having Mathcad compute the transmitted intensity *I* over a certain time domain *t*. However, if the student considers the problem from the atomic point of view and is asked to show how one arrives at linear absorption, he/she is likely to be befuddled and not know where to start. The best place to have him/her start is to consider a simple absorption process where an electron in the ground state absorbs a photon from the beam. In doing so the electron jumps to a higher energy state and does not return to populate the ground state. This is shown in the diagram below.



The student then reasons that the ground state will be depopulated at a certain rate and the excited state populated at the same rate. He/she should then reason that the ground state depopulation rate should depend on the incident intensity (or photon flux), the number of electrons in the state, and the ground state cross section. The rate equation for the ground state becomes

$$\frac{dS_0}{dt} = -\sigma_{01} S_0 \phi$$

where S_0 is the population of ground state, σ_{01} the ground state absorption cross section, and ϕ the incident photon flux. Next, the student has to reason that the excited state level is populated at the exact same rate (since we are not allowing for the possibility of the electron relaxing to the ground state). This lets him/her write a second equation as

$$\frac{dS_1}{dt} = \sigma_{01} S_0 \phi \, .$$

The third equation the student needs to reason out will be the reduction in the number of photons after the beam has crossed the material (or how many remain after a certain time period, which represents crossing the material). In terms of the rate at which photons are being removed from the beam, the reduction is simply,

$$\frac{d\phi}{dt} = -\sigma_{01} S_0 \phi$$

which shows that the photons are being absorbed at the same rate as electrons are being promoted to the excited state. This gives the student three equations which describe linear absorption. Now he/she is asked to determine the photon flux (which relates to I) using the three equations. This is where he/she uses Mathcad to solve this system of three linear first order differential equations.

In this Mathcad program the subscripted variable is x and it describes quantities S_0, S_1, and ϕ as follows: $x_0 \rightarrow S_0, x_1 \rightarrow S_1, x_2 \rightarrow \phi$. The first derivatives need to be written in the matrix form with these variables which means the student has to convert the equations as follows

$$\frac{dS_0}{dt} = -\sigma_{01} S_0 \phi = -\sigma_{01} x_0 x_2$$
$$\frac{dS_1}{dt} = \sigma_{01} S_0 \phi = \sigma_{01} x_0 x_2$$
$$\frac{d\phi}{dt} = -\sigma_{01} S_0 \phi = -\sigma_{01} x_0 x_2$$

A matrix *D(t,x)* is defined that contains the three converted equations and in Mathcad is written as

$$D(t,x) := \begin{pmatrix} -x_0 x_2 \\ x_0 x_2 \\ -x_0 x_2 \end{pmatrix}$$

where the equations have been scaled by σ_{01} since it is contained in each term. This matrix is then passed to the Mathcad differential equation solver *rkfixed* which uses a fourth order Runge-Kutta method to solve the system of equations. It must also have the endpoints of the interval over which the equations are solved, the number of points the equations are solved at between those endpoints, and the initial conditions. Here the student chooses a time between 0 and 0.1 seconds with the initial conditions that S_0 = Nm, S_1 = 0 and ϕ =Nγ where Nm is the number of molecules and Nγ is the number of incident photons. The output of *rkfixed* is a matrix that has 4 columns where the number of rows equal the number of steps specified in the call to *rkfixed*. The first column is the time interval with a step size equal to the difference between the two endpoints divided by the number of steps. The second, third, and fourth columns give the values of S_0, S_1, and ϕ respectively at those times.

The student then considers the transmitted flux at a certain point in time and runs the routine for an incident flux that doubles, that is Nγ = 2,4,8,… up to 512. He/she runs the program and plots the transmitted photon flux as a function of incident flux. The result is shown in the graph below (Figure 1) for Nm = 100. The result shows a linear behavior - as the incident flux increases so does the transmitted flux in direct proportion.

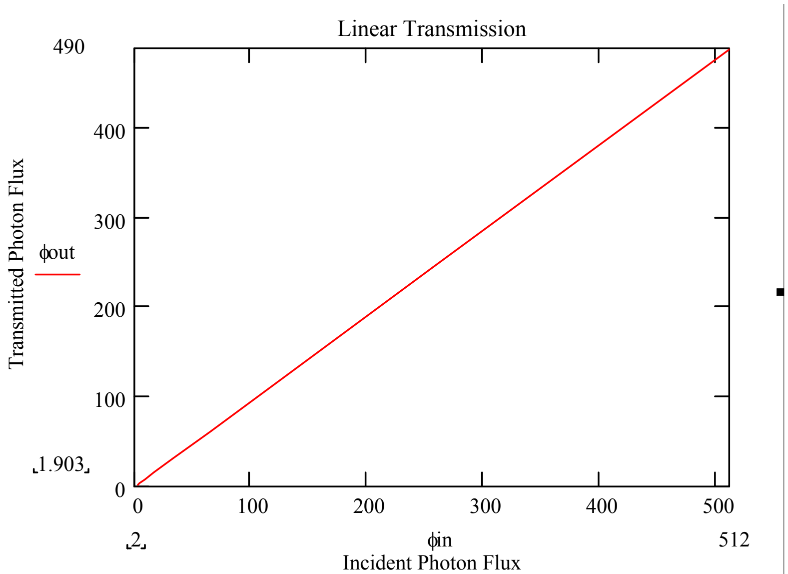


Figure 1. Linear dependence of transmittance.

<u>Three level model</u>.

Having learned how to model and solve the three equations for linear absorption the student is now ready to move on to the three level model for an optical limiter. Using the linear model explained above, the student now considers the possibility that the electron in the excited state can either return to the ground state by relaxation from the S_1 state, or by intersystem crossing it can go to the T_0 state and then return to the ground state. The equations that govern this process are converted into Mathcad as the following

$$D(t,x) := \begin{pmatrix} -\sigma_{01}S_0\phi + k_{30}T_0 = -\sigma_{01}x_0x_2 + k_{30}x_1 \\ \sigma_{01}S_0\phi - k_{30}T_0 = \sigma_{01}x_0x_2 - k_{30}x_1 \\ -\sigma_{01}cS_0\phi - \sigma_{34}cT_0\phi = -\sigma_{01}cx_0x_2 - \sigma_{34}cx_1x_2 \end{pmatrix}$$

where $x_0 \to S_0, x_1 \to T_0, x_2 \to \phi$. Similarly as before, the matrix is passed to a first order differential equation solver, but this time the Rkadapt routine is used. This method also uses the fourth order Runge-Kutta method, but allows the step size to vary in smaller steps where the solution is changing rapidly and larger steps where the change is smoother.

The student uses the ground state cross sections and rate constants for C_{60} from the literature[8] and considers a 10 ns pulse with 500 iteration steps. He then considers the output a specific time and runs the model again for a series of incident fluxes that doubles. The result is shown below (Figure 2) for Nm = 10^{18} and where $N\gamma = 2,4,8,\ldots \times 10^{23}$ up to 512×10^{23}. The nonlinear behavior is clearly seen - as the number of incident photons increases, the transmitted flux does not double but starts to show optical limiting.

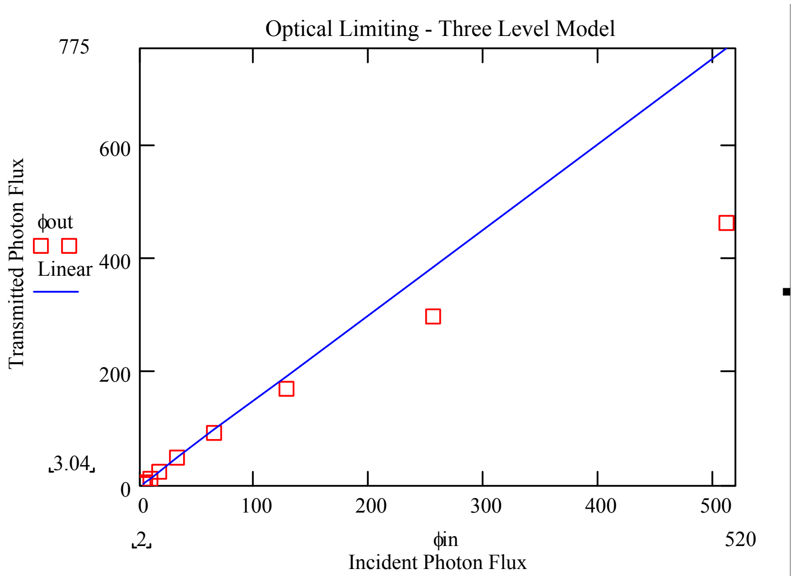


Figure 2. Optical limiting effect.

Step 5 – Future work related to modeling and experimental work

This project introduces students to numerical methods in nonlinear optics using Mathcad and forms a basis from which he/she can expand into future projects, specifically the incorporation of the five level model, numerical studies of C_{60} as well as other RSA materials, and experimental studies (including verifying the validity of the models) of C_{60} and other fullerenes (higher empty cages and endohedral metallofullerenes) using a pulsed nanosecond, Q-switched Nd:YAG laser.

4. Conclusion

This Mathcad exercise was aimed at introducing students to one aspect of the field of nonlinear optics through analyzing the three level model of an optical limiting material. The students use the knowledge learned in optics class and perform the computation with Mathcad.

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Virtual Holographic Laboratory

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Abstract: In this work we present a Virtual Holographic Laboratory for educational purposes. This project is edited on DVD support and it has been designed to be interactive: schemes, pictures, videos in order to clarify the theoretical description of the phenomena improving the understanding of its fundamental concepts. We believe that this project is helpful for undergraduate and graduate students in physics and engineering to obtain the solid knowledge about holography and to prepare for practical lessons on holography or partially substitute the lasts in the case of absence of appropriated technical base at a specific university level.

1. Introduction

Nowadays holography is playing an important role in science and technology. Holographic recording and reconstruction of an object is probably the most illustrative example of various optical phenomena and concepts such as interference, diffraction, coherence, etc. Moreover holography is very attractive to the students and therefore to motivate them toward to the entire area of optics and photonics. These are the main reasons which yield to including the holography in the curriculum of many universities over the world. Certainly the practical lessons on holography are needed for deeper understanding. Nevertheless some universities in the developing countries cannot afford them. We have recently created a computer assisted course[1] dedicated to analogue and digital holography which can partially substitute the practical lessons. The course edited on DVD (HTML-based) is written in Spanish and its contents correlate with the Master courses on Statistical Optics and Holography given at the Faculty of Physics of Complutense University of Madrid (UCM).
The DVD contains:

- Historical introduction to holography, including links to the Nobel Prize lecture of its founder D. Gabor.
- Fundamentals of holography where the phenomena of interference and diffraction as well as concepts of coherence are discussed.
- Description of various schemes and methods for holographic recording and reconstruction.
- Special section dedicated to digital holography where digital writing and reading processes are discussed.
- Description and classification of materials and devices for holographic recording.
- Discussion of application of holography in science, technology and every day life.
- Three designed practical lessons, corresponding to the course of Statistical Optics at UCM.

– References and links.

In the following section we present a brief resume of the contents of the Project by enhancing the principal objectives.

2. Overview of the project

The edition of this Project is under HTML format and multimedia contents as Flash-Video, then allowing its use in the most popular operative systems: MS Windows, Mac OSX and Linux. This design provides a complete integration with the common web navigators (Web Browser) and at the same time it turns out to be quite familiar to the user. This allows also to incorporating various links to scientific papers via Internet. The various menus have been designed to perform a quick and easy access to the various DVD's sections and contents.

The previous use of this material in practical courses has demonstrated to be a tool of great applicability at the time to afford the preparation of the undergraduate students for laboratory interaction as well as being quite useful for concepts assimilation.

2.1 Historical introduction to holography.

The reader has access to each one of the sections in an independent manner and without the requirement to accomplish a predetermined order. However, it is advisable, and in particular in the case of fresh students, to follow the proposed sequence of sections, as indicated in the menu in order to assure a sequential logical and gradual learning.

The first section is dedicated to a historical introduction of the holography as well as a presentation of the importance and technological impact of this science. As well as for the rest of the sections and at the end, it is facilitated a number of bibliographic references to orient those students interested in a deeper approach of the subject. This section then is also an introductory basis to the most characteristic aspects of the holography.

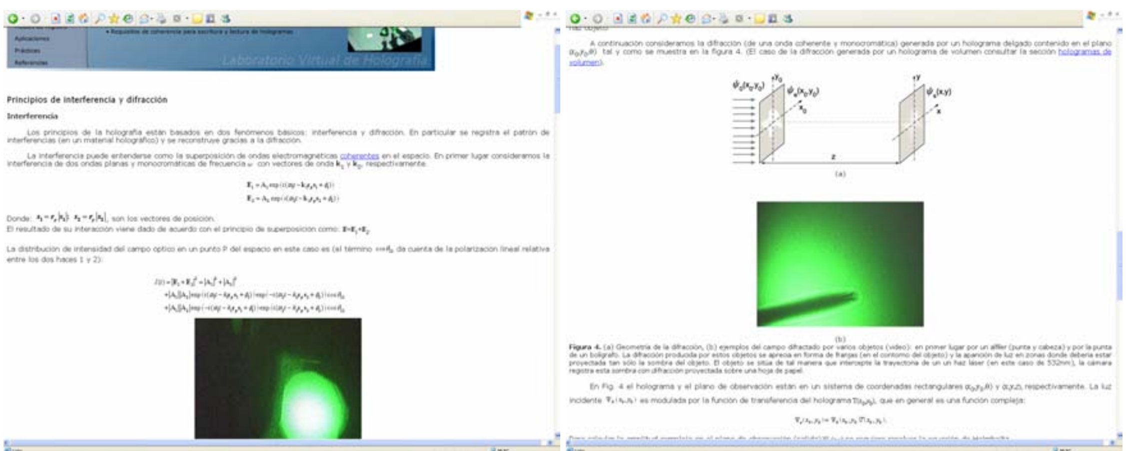
Figure 1 (color on line).- Screenshot corresponding to the historical introduction to holography.

2.2 Fundamentals of holography

The objective of this part of the project is to facilitate to the student the assimilation on the main processes characterizing the recording and reading of a hologram. Concepts such as real and virtual images of the holographically recorded object are usually not very well understood and introduce some confusion in the interpretation by fresh students. Therefore, these concepts are specially treated and illustrated with profusion of pertinent graphics and schemes (as it is done for the rest of the sections).

This section is divided into three parts clearly differentiated: an introduction to the principles of interference and diffraction of light, definition and types of holograms and finally the requirements of coherence of light for the recording and reading of holograms.

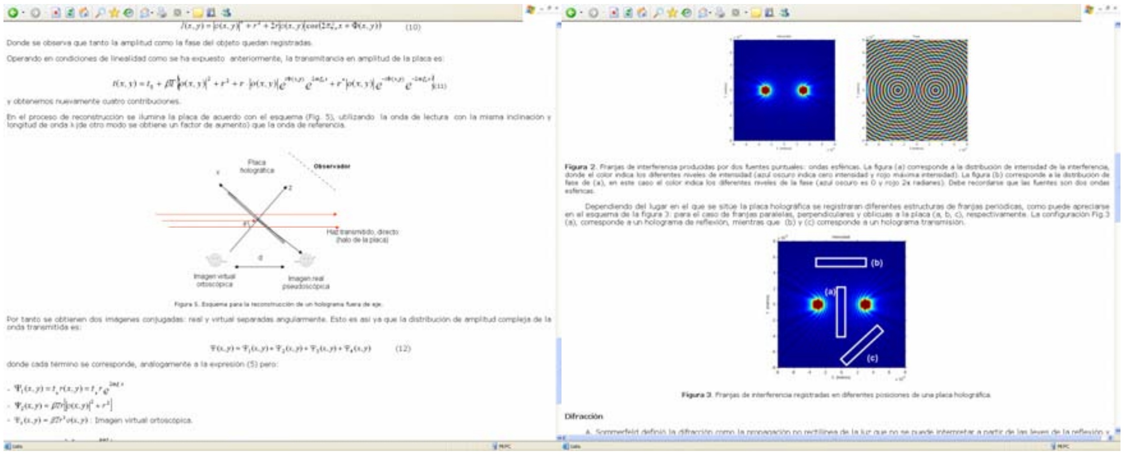
In each one of these parts it is presented a well detailed and concise explanation of the key aspects involved in the recording and reading of a hologram. Interactive videos demonstrating phenomena such as interference and diffraction of light by various objects are available and help to illustrate the basic concepts to the student. Usually, in a room lecture, students are affording the typical mathematical description, so that these multimedia materials are interesting complements to the teacher. Figure 2 shows some of these illustrations.



(a) (b)

Figure 2 (color on line).- Interference (a) and diffraction (b) sections where different examples are introduced. Flash videos for these examples are also displayed.

Accordingly, the mathematical description describing the various processes for the recording and reading of the hologram is introduced as well. Various schemes for the study of the various types of holograms, say, for example, reflection and transmission ones are also displayed (see Figure 3).



(a) (b)

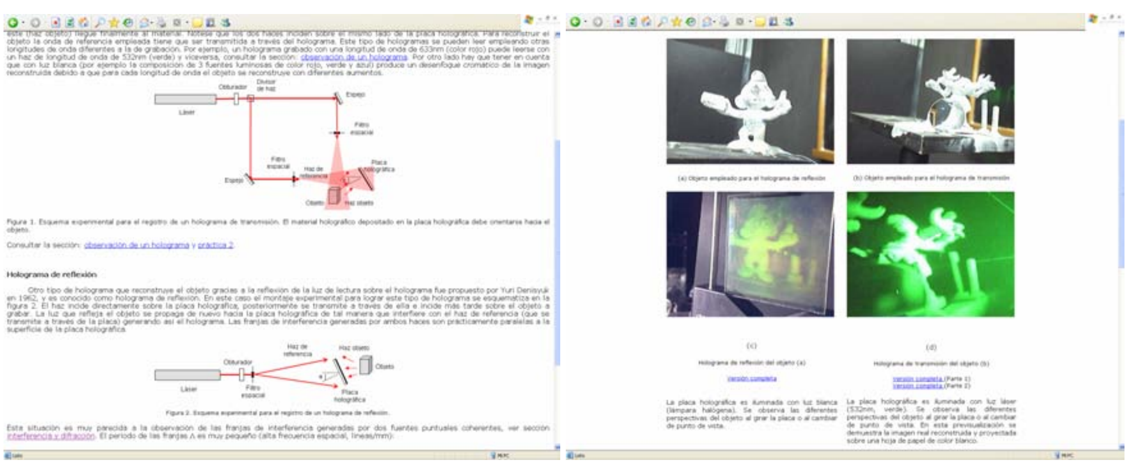
Figure 3 (color on line).- Transmission and reflection holograms illustrated by means of different figures, for instance (a) and (b).

Moreover, it is provided a mathematical description of the differences arising between real and virtual images at the time of reading the hologram. These concepts are treated as well in the following sections and providing interactive videos. Finally, it is discussed the requisites regarding the spatial and temporal coherence of the optical beam, as key factors for obtaining high quality holograms.

2.3 Holography: recording and reading schemes, types of holograms, observation and hologram quality.

As explained above, one of the main objectives is that the student be capable to distinguish the various types of holograms and the differences arising between real and virtual images regarding the kind of contained information. This section reinforce the knowledge previously introduced and by mean of practical examples.

The section presents various schemes for the recording and reading procedures (see Figure 4) as well as the definition of thick and thin holograms, respectively.



(a) (b)

Figure 4 (color on line).- (a) Schemes and methods for holographic recording and their experimental implementation are discussed. The hologram reconstruction is shown as a Flash-Video for different points of view, (b).

More insights are given in Figure 4(b) with the aim to illustrate the differences between real and virtual images. Here the interactive multimedia provides a direct observation of both images. This is indeed a very useful tool for the understanding of concepts then facilitating the student task.

2.4 Digital holography: digital writing and reading processes.

One of the main objectives of the present project is to afford the introduction of advanced concepts and techniques that are being currently applied in current research subjects. This is part of a new and attractive work planning to the student. In particular, in this section it is studied with detail the techniques for the recording and reading of 2-D digital holograms (see Figure 5). Moreover, the various experimental schemes to be used for this task are displayed with an emphasis on the characteristics of Spatial Light Modulators (SLM), CCD cameras and CMOS. The section is devoted as well to the study of the technical aspects that correspond to the specifications of these devices. The 3-D holographic technique is presented by including an up dated list of references.

(a) (b)

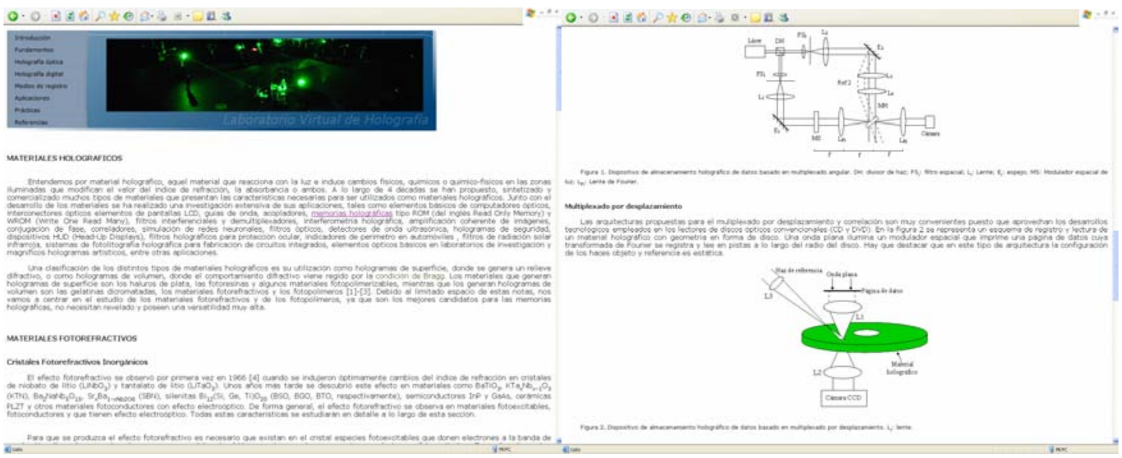
Figure 5 (color on line).- Digital hologram section, (a). Spatial Light Modulator and CCD devices are also introduced in this section, (b).

The section devoted to 2-D digital holography includes the concepts of recording and reading of Fresnel holograms: computer generated and optically reproduced via SLM. Also, the optically recording procedure is explaining with the use of the CCD and post computational reproduction. To complete with the study various schemes are displayed as well as numerical computation results. It is introduced practical work as for example the reconstruction of different parts of a digital interferogram with the aim to show the contained codified information.

2.5 Description and classification of materials and devices for holographic recording.

An important aspect to introduce is the classification of the various types of holographic materials as well as its technological applications. In particular, it is presented a detailed discussion of the most relevant current holographic materials and the advantages presented in its used (see Figure 6). It is mentioned the organic and inorganic photorefractive materials as well as the photopolymerizables glasses, originally synthesized in our laboratory[2].

Foundations of the techniques such as multiplexing and concepts such as scattering are studied as well. As a technological application we have included a detailed description of the holographic data storage (see Figure 6(b)).

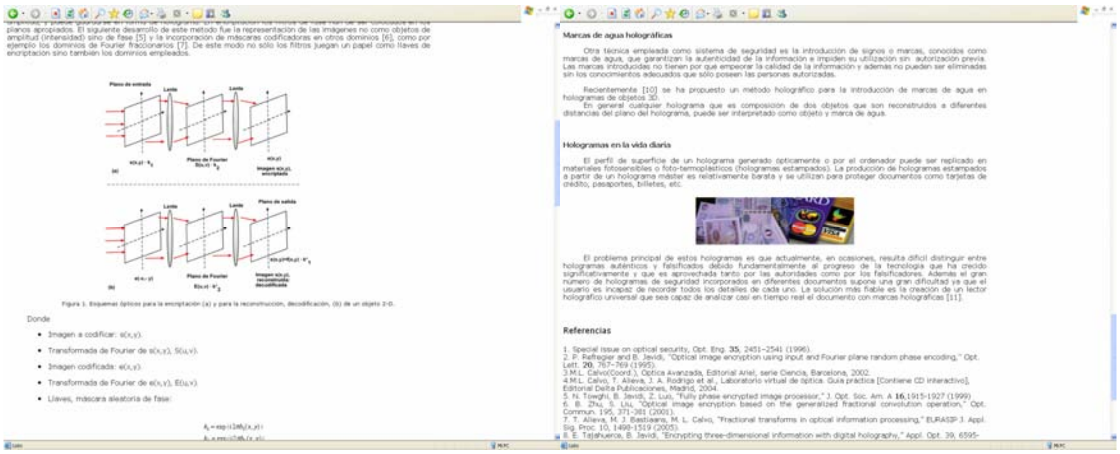


(a) (b)

Figure 6 (color on line).- Description and classification of different holographic materials are presented, (a). Applications such as holographic data storage are also discussed, (b).

2.6 Discussion of application of holography in science, technology and every day life.

In this section it is described some of the most relevant and appealing technological applications of holography in science and daily life. It includes cases as encryption systems (see Figure 7 a-b) as well as applications in biomedicine.



(a) (b)

Figure 7 (color on line).- Conventional encryption techniques (a) as well as different holographic applications in biomedicine, technology and security systems are discussed (b).

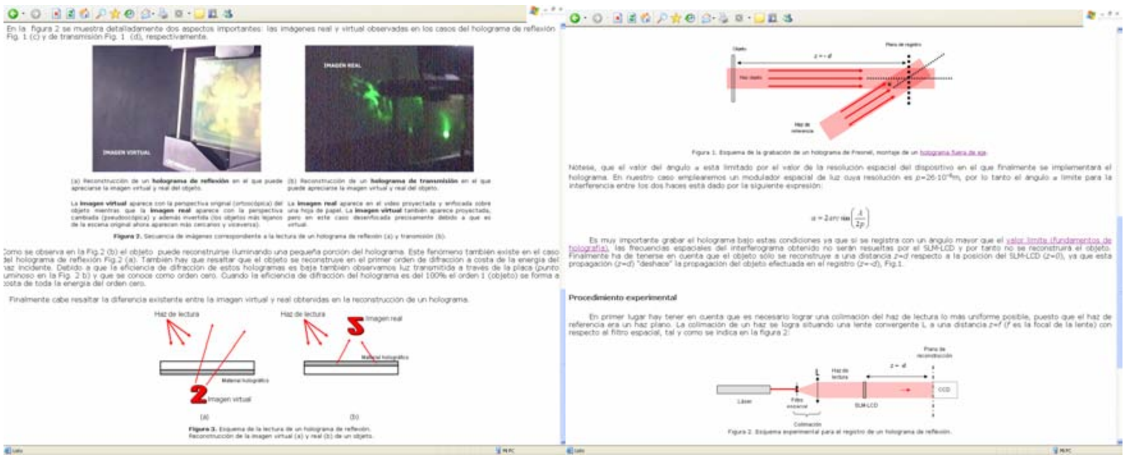
We believe this constitutes a good example to the student on the various nowadays perspectives of holography development.

2.7 Laboratory practical lessons: reflection and transmission holograms recording and numerical simulation of 2-D digital holograms.

In the precedent sections we have presented a brief description of the contents of the project. The last section is dedicated to the proposal of three practical experiences in the laboratory with the aim to introduce to the student on the various technical procedures for recording and reading of holograms in both aspects analogical and digital, respectively.

The basic idea is to give to the students a series if instructions so that they can be ready to afford their personal work in the laboratory. Thus, the various experimental set-up are displayed, interferometers, spatial filtering and chemical procedure for developing the BB-640 holographic plates used for the practical work.

One important aspect included as well is the mentioning of all the security rules to be applied regarding the use of a laser beam and chemical products. The student has to be able to record reflection and transmission holograms and object reconstruction (see Figure 8.).



(a) (b)

Figure 8 (color on line).- Practical lessons for analogue and digital holography, (a) and (b) respectively.

In the practical work for 2-D digital holography the student has to perform various Fresnel holograms with the use of a personal computer and reconstruct it optically via SLM. The multiplexing techniques in digital holography are proposed to the student as an advanced problem.

We stress that the presented guide is useful for both students and teachers since it contains general and detailed information on practical holography that can be afforded as well by amateurs.

2.8 References and links.

The guided ends with a list of references organized in categories as: text books, scientific articles and links to web sites dedicated to holography.

3. Conclusion

The structure of the project has been oriented to obtain a gradual assimilation of concepts by the student. Also, it has been introduced in a detailed way so that advanced readers can also benefit of the contents. The multimedia material included is an important tool for a dynamical learning. Special emphasis is dedicated to carefully designed schemes (recording and reading), types of analogical and digital holograms, described in a very concise fashion. The physical concepts as diffraction of light and interferences are studied in detail. The discussion on the various current technological applications, holographic materials as well as optoelectronic devices (SLM, CCD, etc.) provides to the student and completes knowledge and enhances the motivation.

The proposed guide has been used during the academic course 2006/2007 in the Holographic Laboratory associated to the Statistical Optics subject. This is part of subjects studied by undergraduate students in fundamental physics (fourth course). A total number of thirty six students divided into ten groups were working in practical holography. The results were indeed a great success showing the great acceptation of this kind of didactical method. Some of these students are now pursuing advanced subjects in holography under the guidance of the teachers of this project.

Acknowledgements

This Project has been financed by the Vice-Rectorate of Innovation and European Space of High Education Degrees, Office of European Convergence, Complutense University of Madrid (Project 303/2005).

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ETOP 2007

The NEMO educational kit

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Abstract

NEMO is the European "Network of Excellence on Micro-Optics". One of the objectives is to disseminate knowledge on micro-optics. Therefore NEMO plans to inform pupils about the crucial role of micro-optics This is done through the distribution of an educational kit to their physics/technology teachers. This kit has been realized through a cooperative action of different partners of the NEMO-network all over Europe. It contains a variety of replicated micro-optical refractive and diffractive components, and a semiconductor laser source. The kit is supplemented with a CD-ROM which explains the basic concepts and describes possible experiments and experimental setups. It contains also a computer tutorial which simulates the optical processes of image formation.

It is hoped that this will encourage interest in optics and, more generally, in science as an area of future study and as a possible career choice.

At the conference the realization and the lay out of the EduKit will be commented and a demonstration will be given.

The NEMO educational kit

H. Thienpont[1], J. Mohr[2], M. Kujawinska[3], M. R. Taghizadeh[4], A. J. Waddie[4], T. Mappes[2], F. Wyrowski[5], E. Stijns[1]

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1. Introduction

NEMO is the "Network of Excellence in Micro-Optics" constructed under the European "Sixth Framework Programme". It aims at providing Europe with a complete Micro-Optics food-chain, by setting up centers for optical modeling and design, measurement and instrumentation, mastering, prototyping and replication, hybrid integration and packaging, reliability and standardization. More than 300 researchers from 30 groups in 12 countries participate in the project.

One of the objectives of NEMO is to spread excellence and disseminate knowledge on micro-optics and micro-photonics. Therefore NEMO plans to inform pupils, already from secondary school level onwards, about the crucial role of light and micro-optics and the opportunities this combination holds. This is be done through the distribution of a user-friendly and well illustrated educational kit to their physics/technology teachers. The latter contains a variety of replicated micro-optical refractive and diffractive components, fabricated with the aid of the network technology centers, a semiconductor laser source and a clear and instructive manual for basic experiments. The kit is packed in a box, paid by SPIE-Europe. It is self-consistent: schools with no optical instrumentation are able to use it for basic demonstrations. However it is also possible to use the elements in more complicated set-ups to be constructed by the users themselves.

2. The realization of the Educational Kit

The EduKit consists of a DVD-box with:
- a laserpointer
- a piece of plastic optical fibre
- a CD-ROM with the necessary explanation
- a plastic card with refractive and diffractive optical components.

Those components were designed in the group of Mo Taghizadeh in the Heriot-Watt University, Scotland, UK., and replicated by the group of Juergen Mohr in Karlsruhe, Germany[(1)]. The layout is shown below.

On a small plastic card (see figure 1) you find the different diffractive optical elements or DOEs, and also arrays of micro-lenses.

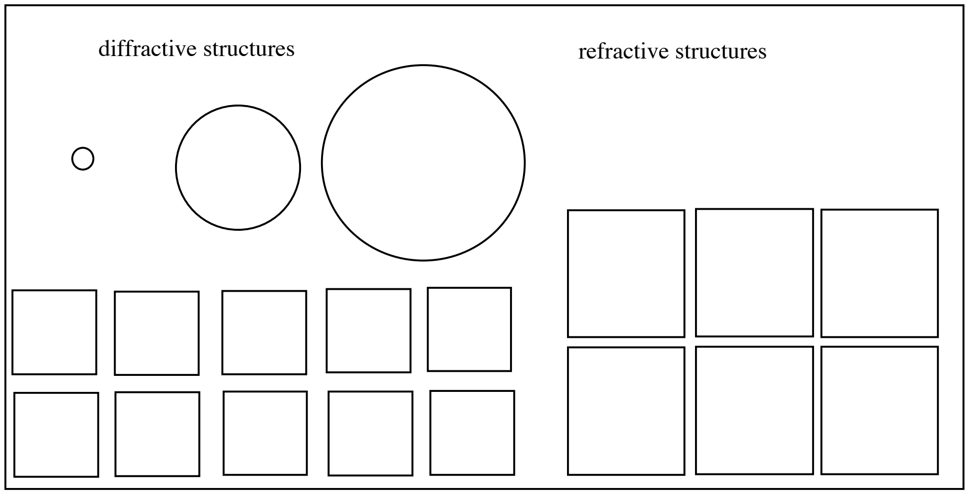


Figure 1: lay out of the plastic card with optical elements

On the left you find the diffractive elements or DOEs. There are two simple *linear gratings*, with a pitch of about 60 lines per millimeter (lpmm) respectively about 30 lpmm; they give a row of equidistant points on the projection screen.
The card contains also two *crossed grating*, once again with spatial frequencies of 60 respectively 30 lpmm; their far-field diffraction pattern consists of a regular square grid of points.
Next there is a set of PF-DOE's (= Pattern Forming Diffractive Optical Elements), which produces the following patterns:
- two array generators or "fan-out" elements which split the incident laser beam into a regular square grid of 4x4 respectively 8x8 points of equal intensity.
- there are also two flattop generator: one on-axis and one off-axis
- the next PF-DOE gives a square grid
- finally the last two FP-DOE give the logos of the NEMO network and a European flag.

Moreover on the card you find also three FZP or Fresnel Zone Plate's with focal distances of respectively 10, 50 and 250 mm.

Finally the refractive elements (on the right side of the card) are arrays of very small lenses, so-called *micro-lenses*: two *square* arrays of micro-lenses, two arrays of *cylindrical* lenses, and two *hexagonal* arrays of micro-lenses. The distances between neighbouring lenses are either 0,1 mm or 0,05 mm.
The companion CD-ROM gives not only information about the experiments to be performed with the Kit (see next section), but gives also background information about the NEMO-network, and also examples of the uses of diffractive elements in actual instrumentation. Moreover you find explanations about the basic concepts of light rays, waves, diffraction and interference.
On the CD-ROM you also find a "tutorial" which simulates the basic experiment of diffraction, i.c. Young's interference experiment; you can change the distance between the slits and/or the wavelength, and look at the changing image on the screen. There is also a computer program included, realized by LTG[(2)], which calculates the light distribution behind the diffractive elements as a function of variable parameters.

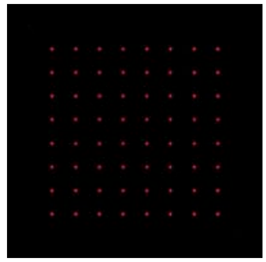
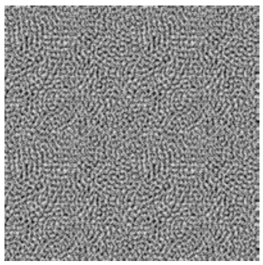
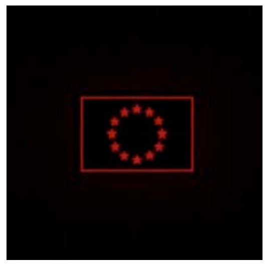
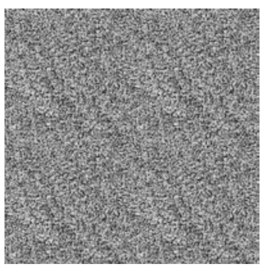
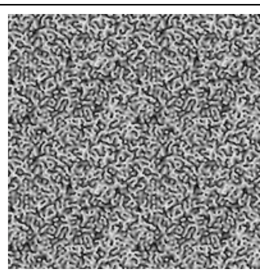
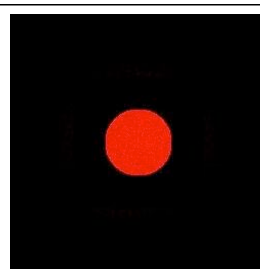
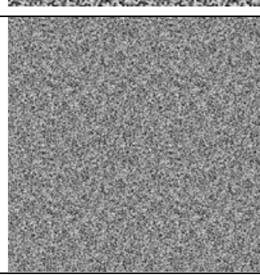
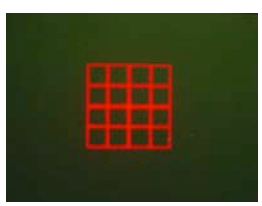
Element Name	Phase Profile	Output Profile	Description
8x8 PF2			Increased fan-out element – binary EOM with grating period of 256μm.
EU outlie PF6			16 phase level pattern formation DOE (PF-DOE) generating the outline of the EU flag. Grating period is 512 μm.
NEMO outline PF5			16 level PF-DOE generating the NEMO logo. Grating period is 512μm. Experimental result.
On-axis Flattop PF3			On-axis flattop generator. 16 phase levels, period = 512μm.
Grid PF4			16 level PF-DOE which generates a grid pattern. Period = 512μm. Experimental result.

Figure 2: picture of some DOEs (left) and their projection on a distant screen (right).

3. The use of it

In the most simple experiment, you shine directly with a laser (-pointer) through the diffractive elements, and look at the image on a distant screen, see figure 3.
The included CD-ROM also explains which images you can expect for each of the elements, when using the plastic card in this simple projection set up.

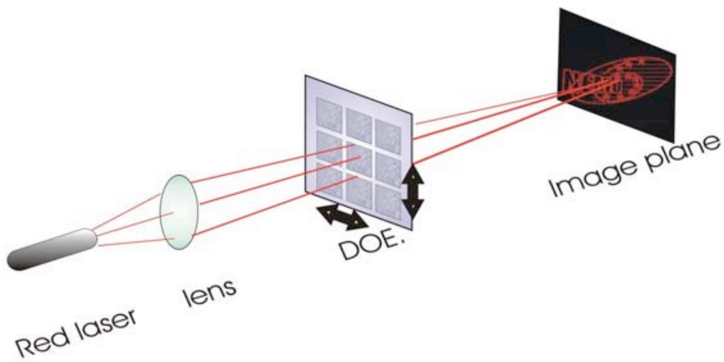


Figure 3: realization of the far-field diffraction pattern by simple projection

However, the same plastic card with DOEs can also be used for much more complicated set ups, if you have more optical hardware available. You can experimentally produce a Fourier transform, or even build a 4-f processor for optical filtering. It is clear that the latter experiments require a deeper theoretical knowledge, and so they are reserved for higher schools or even universities.
There is also a section included on laser safety.

4. How is it distributed and used?

The EduKit was designed and produced within the framework of the NEMO-network, a project sponsored by the European Commission. This sponsoring allows for a free distribution of the EduKit to teachers of secondary schools in Europe. It is expected that they use it in their lessons on physics or technology. Afterwards, they fill in an "evaluation form", so that a next and improved/extended edition can be produced.
More information is to be found at www.micro-optics.org .

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(2) LightTrans GmbH, Jena, Germany: (www.lighttrans.com)

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I.

A Photonics Masters Program at a Regional Metropolitan University

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Many Physics students opt for a master's degree in Physics without plans for pursuing a doctorate in the future. These students typically wish to find jobs in industry after receiving the M.S. degree. The traditional Physics master's degree program, with courses mirroring those of the first year of a program leading to a Ph.D., is not addressed to the needs of many of these students. On the other hand, offering broad and extensive training for a variety of careers in industry may place burdens on the resources of smaller graduate programs. In this presentation, we describe a new Optics-Photonics program and course sequences developed for a small graduate Physics department at a regional metropolitan university (Southern Illinois University Edwardsville) which has successfully placed students in rewarding careers in industry that heavily utilize their Physics training.

II.

Photonics: Challenging Diverse Students in a Flat World for Emerging Careers

Joyce Hilliard-Clark et al
North Carolina State University Imhotep Academy
Raleigh, NC

The Photonics program addresses the question of how does one integrate scientific content, student encouragement, and parental support to engage minority high school students to experience success in areas of a national need? Historical data indicates that ethnically diverse students, (African Americans), do not take advanced mathematics and science, (physics), courses in high school. Therefore, we propose using a variety of strategies for providing instruction in leadership, experimentation, research writing, communication and scientific presentation to work with students, families and teachers in promoting success and academic achievement in challenging science courses. Seventy-five African American students are participating in a year-round Photonics (physics of light) program at NC State University. Students from fifteen counties in North Carolina learn about fiber optics, communications and the properties of light.

Objectives: Participants develop a deeper and richer understanding of science, technology, engineering and mathematics, to improve students' competencies in science and to nurture their interest in science, technology, engineering and mathematics (STEM) careers.

Methods: Photonics students investigate the technology they encounter routinely**.** Students built telescopes, laser diode circuits, electronic robots and carry out scientific research using lasers and other photonics devices in biweekly and monthly sessions.

Results: The program has done a stellar job of targeting minority students. Seventy-five percent African American, nine percent Asian/Pacific Islander, 14 percent Caucasian and two percent Hispanic are participants. Forty-six percent are male and 54 percent female. Ninety-one percent of the students experienced a successful encounter and have a better understanding of photonics according to *BWF SSEP Student Feedback Survey*.

Conclusion: Using qualitative data collected from surveys, focus group interviews, pre- and post- assessments guide our research approach. Participants, (88 percent), have improved in writing, presentation skills and physics knowledge. The Photonics program continues to guide and expose under-represented students into a discipline traditionally not experienced in the public school setting, by making physics and photonics concepts authentic and relevant through hands-on technology learning experiences. Students have explored the world of work in their job-shadowing experiences and have learned from scientists in the university and community. Parents, teachers, students and the general public benefits from the outcomes of this program.

III.

Losses Influence of a Fabry Perot resonator on the effect of the optical multistability in a laser saturable absorber with a homogenous widening

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Abstract:

Our work concerns the study of the effect of the optical bistability and multistability in a laser saturable absorber of a Fabry Perot resonator with a homogenous widening. We theoretically studied the influence of the losses of the resonators on the optical bistability by examining mainly the cases where the losses of the resonator depend on the position of the emitted mode of a frequency and the losses of the resonator depend on the density of photons We examined the influence of the physical parameters of laser saturable absorber such as the coefficient of saturation and pumping of the medium active and absorbing on the density of the photons for each loss We showed the effect of the optical bistability and multistability then we analyzed the linear stability of the solutions obtained.

Keywords: Optical bistability, Laser saturable absorber, homogenous widening, Losses of a resonator

IV.

Flexible Organic Temperature Sensors

Daniela Topasna et al
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Lexington, VA

The design and fabrication of thin film temperature sensors for various applications is an important and well established field. In order to gain familiarity with the design and fabrication of such devices, students at the Virginia Military Institute create and test their own thin film temperature sensors using organic polymers. The sensor is created by depositing a conducting polymer onto a flexible substrate with electrical contacts deposited by thermal evaporation. The resistance of the polymer as a function of temperature establishes a relationship that is then used to determine unknown resistances.

V.

A simple and effective ‘first’ optical image processing experiment

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Optical image processing experiments can contribute to an understanding of optical diffraction and lens image formation. We are trying to discover a highly effective way of introducing lens imaging and related topics, light scattering, point sources, spatially coherent light, image processing, in a laboratory-based holography-centered introductory optics course serving a mixture of physics, chemistry, and science education sophomores and juniors. As an early experiment in this course, a microscope slide bearing opaque stick-on letters forming a word such as PAL is back-lighted by a point source of laser light. The surround for the letter A is transparent, while the surround for the letters P and L is made translucent with Scotch MAGIC™ tape. A 20-cm focal length converging lens forms a bright image of PAL on a screen, and also an image of the laser point source in a (transform) plane between the lens and the screen. Students are startled when they see that they can choose to pass only the image of the letter “A” or only the images of “P” and “L,” by very simple manipulations in the transform plane. The interpretation of these experiments is challenging for some students, and the experiments can lead to a significant amount of discussion. Useful explanatory ray diagrams will be presented. Many demonstrations of optical image processing require long focal length lenses and precise manipulation of somewhat complex passing/blocking filters. In contrast these experiments are easy to set up and easy to perform. Students can fabricate the required objects in a matter of minutes. The use of zero-order laser light helps students discover the essential simplicity of the ideas underlying image processing. The simultaneous presence of both scattered (spatially incoherent) and not scattered (spatially coherent) laser light is thought provoking. Current explorations to further develop these and other closely-related experiments will also be described.

Supercontinuum Generation in Photonic Crystal Fibers for Undergraduate Laboratory

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Abstract

The nanotechnology field is currently undergoing an exciting period of discoveries. It is necessary to bring nanotechnology to physics students. However, there is a lack of nanotechnology experiments developed for the undergraduate labs. By coupling high peak power laser pulses to a highly nonlinear photonic crystal fiber, supercontinuum generation and characterization are incorporated into nanotechnology education in undergraduate physics labs. Because of the fast advance and truly interdisciplinary nature of nanotechnology, the supercontinuum generation in photonic crystal fiber experiment gives physics undergraduate students an opportunity to work with high power lasers, to gain hands-on experience with state-of-art test and measurement equipment, and to access research projects in fiber optics, laser applications and nanotechnology.

1. INTRODUCTION

A supercontinuum is a broad spectrum beyond all visible colors with the properties of a laser. In other words, a supercontinuum is coherent white light. The first observation of a supercontinuum generated in a photonic crystal fiber (PCF) dates back to 1999 by Ranka et al. [1]. The progress in photonic crystal fibers [2] makes the supercontinuum generation relatively simple. As one of the most successful examples in nanophotonics, their applications have been reported ranging from sensors to lasers and to different types of passive and active waveguide devices.

The physics behind the process of supercontinuum generation in photonic crystal fibers has been studied. The dominant nonlinear effects responsible for the continuum generation are stimulated Raman scattering [3], four-wave mixing [4] and self-phase modulation [5], solitons [6], etc. The objective of this work is to generate and characterize supercontinuum in a highly nonlinear photonic crystal fiber pumped with femtosecond and picosecond laser pulses, and to study the effects of pump laser power, and pump wavelength on the supercontinuum generation.

2. PHOTONIC CRYSTAL FIBERS

Conventional optical fibers consist of a cladding and a core. The refractive index of a

* Undergraduate student.

core is slightly higher than that of the cladding. Light propagates within the core of an optical fiber due to the total internal reflection. In recent years, rapid progress has been made in photonic crystal fibers and photonic crystal fiber devices. There are two basic types of photonic crystal fibers, namely, hollow core PCFs [7] and solid core PCFs. PCFs exhibit a novel cladding structure which is formed by a periodic pattern of air-holes around the central core. The air-holes lower the effective refractive index of the cladding. Hence, coupled light is guided within the core due to reflection from the core and cladding interface.

The photonic crystal fiber used in this work was from Thorlabs (Parts number: SC-5.0-1040). The fiber has a solid core of 4.8 μm in diameter, surrounded by a periodic pattern of air-holes. Fig. 1 is a SEM image from the manufacturer that shows the central part of the fiber cross section. The outer diameter of the photonic crystal fiber is 125 μm. The PCF has a zero dispersion wavelength of 1040nm.

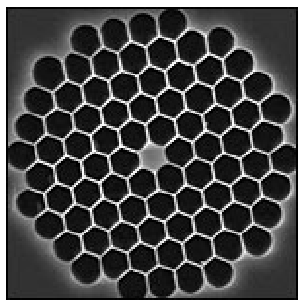

Fig. 1 SEM image of PCF cross section. The solid core is surrounded by a periodic pattern of air-holes (provided by Thorlabs).

3. EXPERIMENT SETUP

Both a femtosecond Ti:sapphire laser and a picosecond Nd:YAG laser were used as the source to generate the supercontinuum in the fiber. The energy per pulse E_p and peak power P_p from a mode-locked laser can be calculated by

$$E_p = \frac{P_{av}}{f_r} \text{ and } P_p = \frac{P_{av}}{T_{FWHM} f_r}$$

where P_{av} is the average power from the laser; f_r is the laser repetition rate; T_{FWHM} is the full-width half-maximum (FWHM) of the laser pulses. For a 1 kHz repetition rate, 200 fs laser pulses at an average power of 20 mW from a Ti:sapphire laser, the calculated peak power is 100 MW. The energy per pulse is 20 μJ. Similarly, for a 10 kHz repetition rate, 10 ps laser pulses from a mode-locked Nd:YAG laser at 1.06 μm with an average power of 20 mW, the calculated peak power is 200 kW and energy per pulse is 2 μJ.

The experimental setup of the supercontinuum generation in a PCF pumped by ultrashort pulses is illustrated in Fig.2. The TEM_{00}-mode linearly polarized ultrashort pulses from a mode-locked laser first passed through a variable optical attenuator consisting of a half-wave plate, a polarization cube beamsplitter and a neutral density filter. Then the laser pulses were coupled into the PCF using a 20X objective lens having a numerical aperture of 0.4. The PCF used in the experiment had a length of 18 meters. The fiber ends were carefully stripped of its polymer coating, cleaned and cleaved to avoid any possible contamination. One end of the fiber was inserted into a fiber chuck which was mounted on a fiber coupler assembly with x, y, z and angle adjustments. The far end of the cleaved fiber was inserted into the bare fiber adapter for easy connection with the receptacles of a commercial optical power meter and an optical spectrum analyzer (OSA). The fiber coupler assembly with PCF was placed after the objective lens and aligned properly to obtain the best coupling of laser into the PCF.

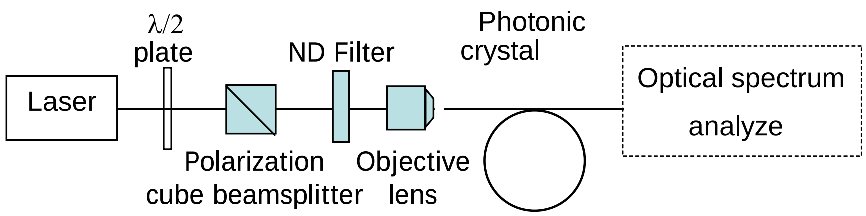

Fig. 2 Schematic drawing of the experimental setup for supercontinuum generation in a photonic crystal fiber pumped with ultrashort laser pulses.

Before the PCF was properly aligned, laser pulses with average powers of less than 1 mW were used to prevent any possible damage of the fiber end. Once the alignment and optimization were completed, the input power from a laser was gradually increased. The average power of the laser beam was measured using a Newport 1830-C Picowatt Digital Optical Power Meter with an 818-ST detector and an OD 3 calibrated optical attenuator (883-SL). The fiber coupling efficiency was measured to be approximately 30%, although it could be further optimized by varying the objective lens magnification or the antireflection coatings. The spectrum from the PCF output was investigated with an optical spectrum analyzer (Ando AQ-6310B) which has a full spectrum range from 400 nm to 1750 nm with a resolution of 0.1nm.

4. SUPERCONTINUUM GENERATION

The interaction of ultrashort pulses with a nonlinear PCF leads to spectral broadening. The properties of the resulting supercontinuum depend primarily on the input pulse and PCF parameters. When the generated supercontinuum covers the whole visible spectral region, it appears as white light as shown in Fig. 3.

(a) (b)

Fig.3 The supercontinuum shown on a screen; when the PCF was pumped with 775 nm, 200 fs pulses at (a) 10 mW; and (b) 50 mW.

The evolution of the pump pulse spectrum into a supercontinuum in an 18-meter long photonic crystal fiber was studied by gradually increasing the pump pulse power. Figure 4 shows the measured spectra when the input laser power was 2 mW, 5 mW, 15 mW and 20 mW, respectively, with the x-axis being the wavelength and the y-axis spectral density (a.u.) in log scale. Because the pump wavelength of 775 nm was shorter than the PCF zero dispersion wavelength of 1040 nm, in the region of normal dispersion, the measured spectrum broadening was relatively narrow and most of the energy was concentrated around the pump wavelength. At higher pump power, the spectra were further broadened and the input energy converted to three visible bands around 580 nm, 660 nm and 750 nm. The total spectral range was approximately over 500 nm.

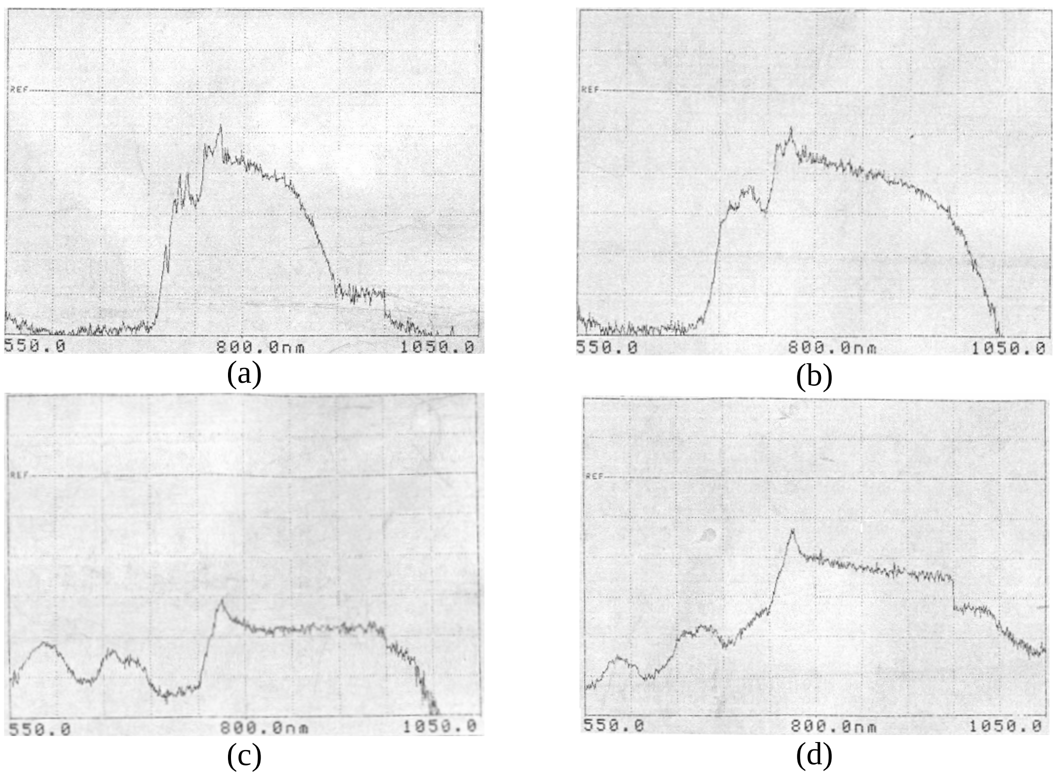

Fig. 5 The spectra evolution with the increase of input laser power: (a) 2 mW; (b) 5 mW; (c) 15 mW; (d) 20 mW. The x-axis is the wavelength ranging from 550 nm to 1050nm, and the y-axis the spectral density (a.u.) in log scale.

The resulting supercontinuum was also observed and measured when the same fiber was pumped with 10 picosecond pulses at 1.06 μm wavelength from a mode-locked Nd:YAG laser operated at a 10 kHz repetition rate. Fig. 6 shows the measured spectra when pumped at 1 mW, 10 mW and 20 mW. There was no supercontinuum observed when pumped at 1 mW. At 15 mW input power, the spectrum was extended over the whole spectrum range limited by the instrument, but the initial laser input pulse was still visible. Since the PCF has a zero dispersion at 1.04 μm, the supercontinuum generated by 1.06 μm ultrashort laser pulses has a much broader spectrum range, as expected. At 20 mW input power, the PCF provides a relatively flat and very broad spectrum that covered the entire visible and near IR spectrum range from 400 nm to 1750 nm limited by the optical spectrum analyzer.

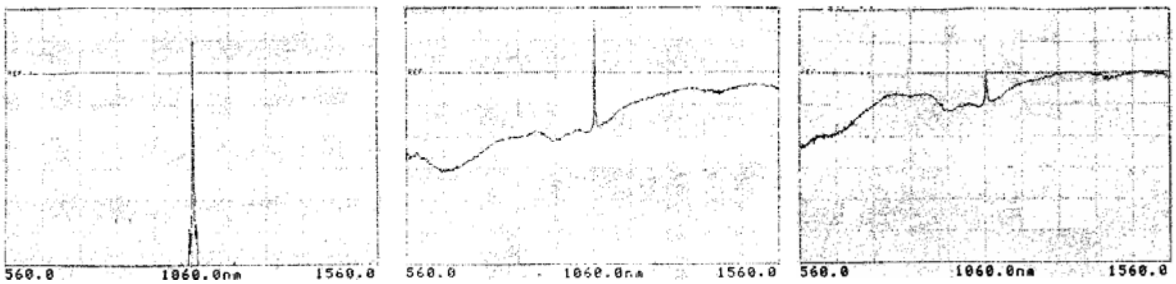

Fig. 6 The measured spectra pumped with 1.06μm, 10 ps pluses at (a) 1 mW; (b) 15 mW and (c) 20 mW average power. The x-axis is the wavelength ranging from 560 nm to 1560nm, and the y-axis the spectral density (a.u.) in log scale.

5. CONCLUSIONS

In this work, supercontinuum generation from a photonic crystal fiber has been implemented using femtosecond and picosecond laser pulses for undergraduate physics labs such as fiber optics, lasers and spectroscopy. The use of an 18-meter long photonic crystal fiber made the supercontinuum generation possible at input power levels of only a few mW. The evolution of the supercontinuum was investigated and the effects of pump power on the generated supercontinuum were measured with an optical spectrum analyzer. Because of the zero dispersion at 1040 nm wavelength, the input laser pulses at 1.06 μm wavelength created a flat and broad supercontinuum over 1000 nm wide, limited only by the instrument, ranging from the entire visible spectrum to the near-IR.

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VII.

Virtual Researcher on Call: "Encouraging the youth of today to become the researchers of tomorrow"

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Virtual Researcher On Call (VROC) is an educational initiative of Partners In Research and was created as an opportunity to connect current research and researchers with high school students in grades 9 to 12 throughout Canada. The concept was to use a web-based interface to optimize time requirements for this connection through the use of videoconferencing technology. In addition, this program was thought to match the opportunity for researchers to explain and showcase their work, interact with students who may potentially become the next generation of researchers and to increase the knowledge of the general public about the advances being made by Canadian Researchers and the benefits to the Canadian Society, and by extension to the world at large.

For the Teachers, this program is a resource to enhance their curriculum content and also for them to see first hand, information that would not be available in text books, sometimes until years later. For the students, it was expected that this would be a rare opportunity not only to hear about new developments but for them individually to have dialogue with researchers who are involved in these new discoveries. For some this would be an opportunity to have some insight into what they were considering for a career choice. Indeed, it might lead to mentorship or even an opportunity for a job placement in a laboratory. For some students, it might provide information to assist them in deciding general areas of their schooling that they might pursue, and for others it might provide a rationale for them to finish their high school career.

VIII.

Putting the "Spark" into Physical Science and Algebra

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The presenters will describe a number of laboratory activities developed in collaboration with the Department of Electrical Engineering at the University of Delaware as part of their outreach program to help make math and science more authentic on the pre-college level. Lessons relating to electrical topics are often abstract and appropriate only for advanced students in math and science. We have devised lessons that rely on simple equipment. They promote skills that are included in National and State Standards. They emphasize the connections between math and science; they are appropriate for an algebra course, a physical science course, a PhysicsFirst course or a traditional physics course. Students benefit from seeing that what they learn in math and science courses can lead to cutting-edge work in areas such as passive wave imaging, photonics, wireless communication and high performance computing. The collaboration has been meaningful because it has motivated us to tailor our lessons to reflect what is happening in the research lab of our local university. Written materials for use in teacher training workshops will also be available.

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IX.

Optical Engineering: Learning by Design

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1. Background

This presentation will describe the issues associated with a design-based course in optical engineering. The original purpose of this course was to provide senior undergraduate and graduate students with a good foundation in free-space optics, including topics such as geometric aberrations, Gaussian beam theory, diffractive optics, interference filters and polarization. However in order to make the material more immediate and to help the students to integrate their knowledge, a design project component was introduced into the course several years ago. Over the succeeding years, the project component has become a more and more significant part of the course, so that it now forms the central component. Typical enrollment is 15-25 students. The class is typically 75% graduate students, with the remainder being senior undergraduates. 30% have previously taken an undergraduate optics class and around 30% are typically doing graduate/undergraduate research in photonics. A course in electromagnetic waves is a pre-requisite but for many of the students this is their first real ‘optics’ course. Therefore it is a significant challenge to present sufficient material that the students can do real work in their design projects without over-burdening them with new concepts. Most of the students (90%) attend McGill, with the remainder attending UQAM, Ecole Polytechnique or Concordia

3. Course structure

The lecture content of the course is reasonably typical of a free-space optics course. ‘Optics’ by E.Hecht is used as the course book, although additional material on Gaussian beams and sequential ray tracing is taken from other sources. In the first half of the course the students study geometric optics, aberrations, the ray matrix method, sequential paraxial ray tracing and Gaussian beams. They also study diffraction relatively early in the course so that they can understand the importance of diffraction-limited resolution. Once students have a basic knowledge of optical system vocabulary they are introduced to the optical design software (CodeV® from Optical Research Associates) via a series of tutorials. They are given homework assignments that contain a mixture of problems that require calculation and CodeV problems. At the beginning of the course, students are given a list of suggested projects, although they are also permitted to suggest their own. They then select a project in the 4^{th} week.

4. Design projects

A great deal of care goes into the design of the projects. It is important that they should be more than just case studies. Rather they should require real calculations, be open-ended, represent real-world challenges and must be doable with the knowledge, tools and time available to the students. Realistic specifications and performance objectives are given for each, although students are allowed to adjust the specifications if they can show that there is good reason to do so. Projects include a retinal scanner, a Blu-Ray disc pick-up head, grating-based demultiplexers, head-up displays and several others. By the mid-semester, students are required to submit a project outline that contains hand-calculations and discussion of the approach that they will follow. They then have an interview with the instructor where they are required to defend their choices. This is a very important part of the process since it is usually at this stage that the various misconceptions held by the students become evident and can be corrected. Students then continue with the project, whilst at the same time studying more advanced topics in lectures such as polarization and interference filters. In some cases they may need to study material outside the course syllabus in order to complete their projects. They then submit a complete report and also give a short presentation to the rest of the class.

4. Outcomes

In general this approach has brought very positive results. Students display a much better understanding of geometric optics concepts and more awareness of the diverse applications of optics and photonics. In particular it is possible to compare their performance with that of students in an undergraduate course in photonics which covers many of the same topics but without the design component, and the level of understanding is so much higher in the optical engineering course. More information on the benefits and challenges of this approach will be provided at the meeting.

Low-price Optical Microscope for School Science Education

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(Abstract)

In schools, scientific education with an optical microscope is popularly used. However, scanning apparatus for the microscope is very expensive such that the price is several times higher than the microscope itself. In order to activate children's interest in science, a low-price scanning and imaging function unit compatible to conventional optical microscopes used in schools was designed and manufactured using a personal computer (PC) used in all elementally and middle school education.

The designing of imaging apparatus includes two choices: (i) using imaging device (reflection-type), or (ii) using photo-sensor and scanning device (transmission-type). In this paper, the latter method is adopted, considering the educational effect using "Lambert-Beer's law".

This apparatus measures optical transmittance of modulated visible light with a photo-detector, and uses audio-input unit of PC as an A/D converter. Scanning unit with a pair of pulse motor drives was also used. Control software was built on Knoppix (an operating system based on freeware Linux), however it is very easy to rewrite to Windows application. By these reasons, this apparatus is low-price (less than microscope price) so that it is one of the best candidates for science education application in schools. As a biological specimen, a wing of spider wasp (Pompilidae) was used. Measured region was 10mm×10mm and the resolution was 100×100 pixels. The photograph of original specimen and the obtained image were shown in Figures (a) and (b), respectively. The obtained image showed a well-resolved detailed structure of the wing. Scanning was done by an external scanning apparatus. However, feeding of scanning pulses through printer port to stepping motor will be available based on the same method.

1. Introduction

In schools, scientific education with an optical microscope is popularly used for science education. Everybody can recognize the importance of visual stimulation in elementary and middle school education so that the importance of low-price image capturing has increased.

However, scanning apparatus for the microscope is very expensive such that that price is several times higher than the microscope itself. For example, a scanning apparatus prepared for an optical microscope manufactured for educational purpose about $100 will cost more than $400 to $500.

In this study, a low-price scanning and imaging function unit compatible to conventional optical microscopes used in schools was designed and manufactured using a personal computer (PC) used in all elementally and middle school education to activate children's interest in science.

2. Imaging scheme and principle.

As imaging scheme, transmission-type imaging and reflection –type imaging exist. In addition, the designing of imaging apparatus includes two choices: (i) using imaging device such as CCD camera, or (ii) using photo-sensor and scanning device with point-to point detection. For the first case, the digital microscope is sold on many countries (with a price about \$400-\$1000). However, for the developing countries, it is very difficult to realize for every schools to purchase enough number of CCD imaging apparatus. In addition, scanning of digital microscope for educational purpose is preformed by manual scanning almost all countries because of its high price of scanning apparatus.

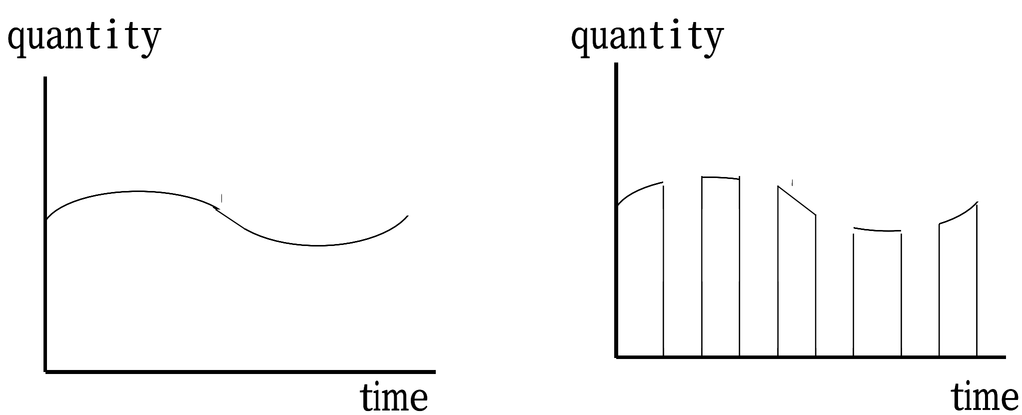
In this paper, the point -to-point (P-P) detection scheme is adopted, which is based on the "Lambert-Beer's law".

$$I(x,y) = I_0 \cdot \exp[-\alpha(x,y) \cdot L\} = I_0 \cdot \exp[-A(x,y)] \qquad (1)$$

where I_0 is a constant in light intensity incident to the sample, α(x, y) and A(x, y) are absorption coefficient and absorbance at the scanning position (x, y) of the sample with the length L.

The P-P detection scheme is detect a transmitted light intensity by a photodetector for every point of scanning at position (x, y), and reconstruct image of it. For the reflection-type detection, the P-P detection scheme is similar. It detects reflected light intensity at every point of scanning and reconstruct image of a sample.

The basic principle of A/D conversion of this measurement method is schematically shown in Fig. 1(a) and (b) in time domain. The conventional A/D converter shown in Fig. 1(a) works as signal converter in the frequency region from direct current (DC) to the maximum frequency determined by the sampling frequency. On the other hand, audio inputs are DC-isolated so that they cannot sample DC or lower frequency signal as they are. Therefore if we modulate optical source at audio frequency as shown in Fig. 1 (b), the generated



(a) (b)

Fig. 1 (a) Conventional A/D converter (left), (b) A/D conversion of the present study; modulated signal behaves like a "sound"[1,2].

signal with the same frequency behaves like “sound” so that it can be converted to digital signal by audio input unit, which is attached to every PC as a PC standard device! According to the knowledge of Fourier transform, the modulation of optical source will shift signal sideband to modulation frequency from DC. This scheme is shown in frequency domain in Fig. 2[1,2].

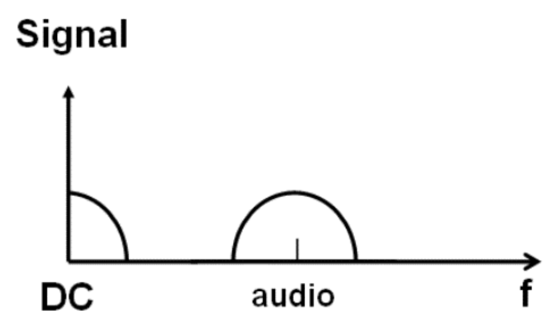


Fig. 2 Frequency shift scheme in utilizing sound input/output devices as A/D and D/A converters.

Furthermore, printer port, standard utility for PCs is also one candidate of driving tool for scanner of a sample set on a slide glass. A line printer working by a LPT port or serial (RS232C or USB) port is a powerful candidate of scanning apparatus.

For a system design, there are many selection of combination of i) detection (CCD or photodiode+sound input), ii) scanning (printer port or sound output drive, independent mechanical movement), etc,

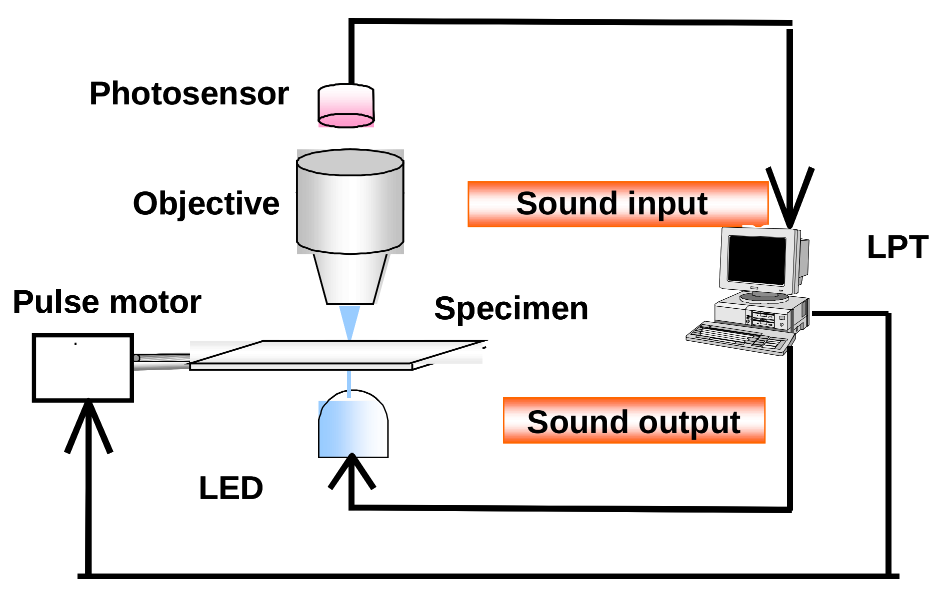


Fig. 3 The expected experimental setup of the low-price optical microscope (transmission-type)

LabVIEW™ supplied by National Instruments offers various “vi (virtual instrument)” subroutines, such as sound acquisition, sound generation, etc. And the compiled program can run under a free supporting utility called “runtime engine”. These are also good candidates for low-price optical microscope for school science education.

The proposed low-price optical microscope is conceptually shown in Fig. 3. This apparatus utilizes sound input/output and printer port (LPT/serial) as control devices. Furthermore, its ability in audio range is comparable to that with conventional A/D and D/A input/outputs facility and scanning devices.

The reason why this microscope does not require lock-in amplifier is that 1) it detects peak-to peak of alternative current (AC) signal generated by the modulated transmitted light intensity, or that 2) it multiplies modulation reference signal with detected electrical signal generated by the transmitted light intensity and detects DC component using software. The detection is performed if we denote sampled signal carrying the information of optical image as e[k] (k=1 to n), n is the number of short time sampling,, and detected sine and cosine components as I_s and I_c as,

$$I_s = \sum_{k=1}^{n} e[k] \cdot \sin(2\pi f k T)$$
$$I_c = \sum_{k=1}^{n} e[k] \cdot \cos(2\pi f k T) \qquad (2)$$

where f and T mean modulation frequency and sampling period, respectively. The detected optical signal is calculated from sine and cosine components as

$$I = \sqrt{I_s^{\ 2} + I_c^{\ 2}} \qquad (3)$$

The time needed for image acquisition by calculating DC component depends upon the audio sampling rate or the performance of the PC.

3. Experimental Apparatus

3.1 First-stage experiment

In this study, the P-P scheme was adopted. This apparatus measures optical transmittance of modulated visible light with a photo-detector, and uses audio-input unit of PC as an A/D converter. Scanning unit with a pair of pulse motor drives was also used. The basic setup is similar to Fig. 3. An optical source is a conventional halogen lamp (50W) with a DC power supply that is with an infrared (IR) absorber plate (Edmund Optics, 45648-E) attached on it. The output is modulated by a mechanical chopper, a fan driven by a DC motor with a stabilized DC power supply. Modulation frequency was changed about 20Hz-300Hz. Transmitted light is detected by a photodiode (Toshiba TPS501) and an additional detector circuit. The output is connected to sound input.

In the first-stage experiment to verify the A/D conversion ability of the audio input device, the scanning apparatus was replaced by a linear motor stage and the control software was made by LabVIEW™ The basic program was that made for a photoacoustic microscope fabricated by the research group of the first author

(TH)[3-5].

Two experiments were compared at this stage: 1) A/D converter unit called DAQ (data acquisition) supplied by National Instruments combined with a lock-in amplifier (NF Circuit Block, LI-5610B) was used, and 2) the sound input and peak-to peak detection of an electrical signal was performed by the software without lock-in amplifier was performed with a similar method described in [3]. Time needed to get images with resolution of 50 x 50 pixels were thirty minute.

3.2 Second-stage experiment

We would like to describe road map to reach the final version of low-cost optical microscope. In the second-stage experiment, detection and scanning procedure was separated for the more actual trial to realize low-price scanning apparatus. RGB color LEDs driven by a drive circuit are manufactured by electronic parts and driven by audio output of a PC. Frequency domain discrimination is done by changing modulation frequencies of R-, G- and B-colored LEDs, ratio of which are 2:3:5, respectively. Control software is made with language C running on Knoppix (an operating system based on freeware Linux), however it is very easy to rewrite to Windows application.

By the reasons described above, this apparatus is low-price (less than microscope price) so that it is one of the best candidates for science education application in schools.

4. Specimens

As a specimen, a slide glass painted by a black paint was used. The paint was cross-shaped with a length and width of 12 mm and 3 mm, respectively. A wing of spider wasp (*Pompilidae*) was used as a biological specimen. The photographs of two specimens are shown in Figures 4 (a) and (b).

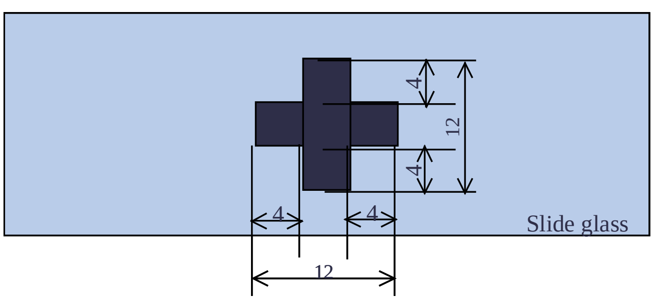


Fig. 4

(a) Black paint painted on a slide glass (left)

(b) wing of Spider wasp (*Pompilidae*) (right)

5. Experimental Results

For the painted color paint specimen, measured region was 15mm×50mm and the resolution was 50×50 pixels. On the other hand, the measured region was 10mm×10mm and the resolution was 100×100 pixels. For the biological specimen (wing of spider wasp), the image obtained by sound input experiments are shown in

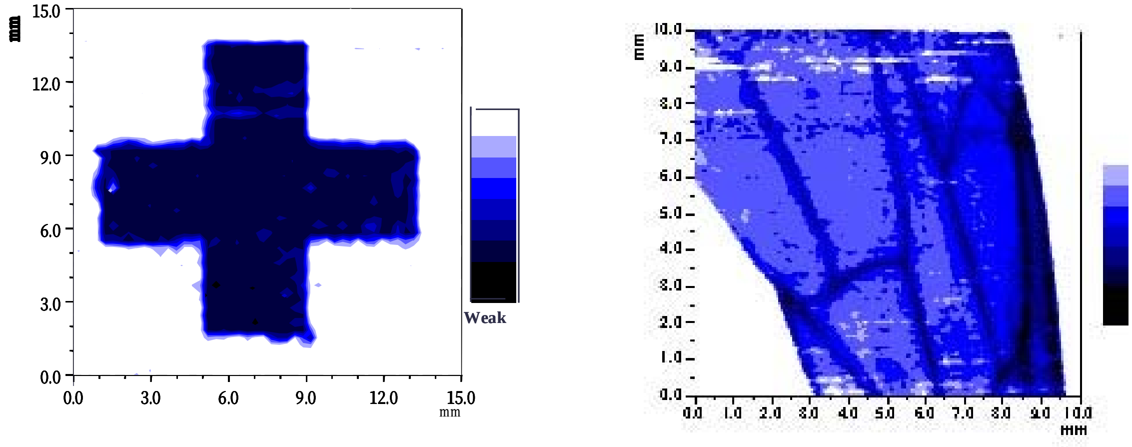


Fig. 5 (a) obtained transmitted image of a painted slide glass (b) obtained transmitted image of a spider wasp

Figures 5 (a) and (b), respectively. The quality of both images obtained for painted color paint and a spider wasp show good quality.

For comparison, the image for painted color paint obtained by a DAQ and lock-in amplifier was shown in Fig. 6. The reason why the image shows more noise is caused by not because the performance of the DAQ input apparatus but the fluctuation of a hand-made chopper.

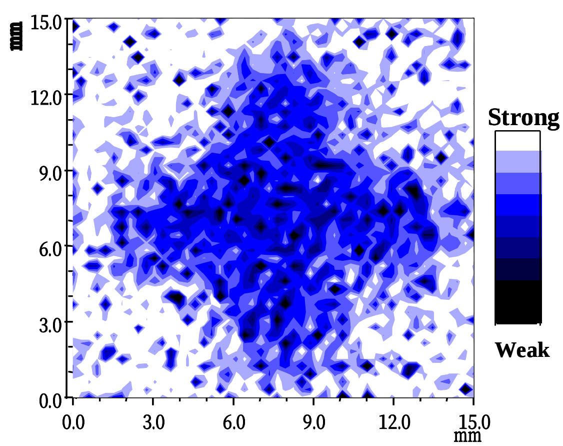


Fig. 6 Image obtained by DAQ and lock-in amplifier

6. Discussions

On the colored imaging (second-stage experiment), RGB drive method is in progress. Modulation of RGB LEDs is realized with three different frequencies, the modulation frequency ratio of R, G, and B LEDs are 5; 3; 2, respectively. The scanning apparatus using pulse motor drive is working with a speed of 5 mm x 5 mm 25 round-trip scans for 50 x 50 pixels with 8 seconds. The scanning time limits the minimum time of image capture so that the time (8seconds) is short enough to wait until image appears. Thirty minutes needed for linear-motor drive case (first-stage experiment) is too long time for children to wait. The integration of detection part and scanning part is in progress. The modulation/ detection program and the scanning program are both written in language C running on Knoppics.

For the other candidate of the software for this low-cost optical microscope apparatus, sound acquisition-vi and sound generation-vi supplied by LabVIEW™ are good subroutines, which are easy to be programmed with GUI (graphical use interface). These programs are also in progress, and will be supported in a web by the first author (TH) in the future. The compiled program will run under a runtime engine, which is a free program package downloadable from the site of National Instruments.

7. Conclusion

In this study, it is verified that it is possible to use PC sound input /output to use A/D and D/A converter if we modulate light source and detect the signal at audio frequency range. Image reconstruction was succeeded for reflection-type monochrome imaging. Color imaging system using RGB photodiodes modulated at different frequencies is being fabricated and in progress.

The problem to determine which selection is the best candidate of the control software of a low-price optical microscope system, C running on free Unix or LabVIEW™ with runtime engine under Windows, was left as the problem in the future. Subjects to fabricate a reflection−type imaging device and the attempt to integrate this scheme and CCD capture method in a unified optical microscope was also unresolved.

The goals of the present study in the future are; 1) to realize low-price (<$100) optical microscope imaging apparatus, and 2) to establish a center of software download (FREE or at extremely low-price) for microscope application (we would like to contribute to this web site).

For the children's scientific education, the authors would like to realize and deliver low-price optical microscope imaging apparatus to everywhere in the world!

Acknowledgments

The authors are grateful to undergraduate students Mr. Y. Terasawa and Mr. K. Ono of Tohoku Gakuin University for their contributions to fabrication of the apparatus of the present study.

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XI.

Nonlinear Optics MathCAD Exercise for Undergraduate Students

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An educational experience in numerical modeling for physics majors at Virginia Military Institute has been created as part of the undergraduate research learning paradigm. As part of the independent project course required of all physics majors at VMI, those joining the thin films research group are taught the various stages of numerical modeling applied to complex problems (such as optical limiting) as a precursor to experimental work. Students are introduced to a realistic method of research involving open-ended experiments by this exercise. By teaching students how to design, create, and test a complex numerical model, they gain insight into how an experiment is set up and executed as well as what results can be anticipated. We present an exercise in which undergraduate students use MATHCAD in their modeling and calculations.

XII.

Biophotonics Master studies: teaching and training experience at University of Latvia

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Biophotonics is a subject related to photonic phenomena in biological media, e.g. living tissues; it can be regarded as a parallel term to “Biomedical Optics” or “Bio-optics”, also frequently used in scientific community.

A Master level sub-program “Biomedical Optics” was originally developed at University of Latvia and started in Faculty of Physics and Mathematics in year 1995. The Curriculum (total 80 credits) includes special subjects “Biomedical Optics – 1” (tissue optics and optical bio-sensing), “Biomedical Optics – 2”(lasers in medicine), “Medical Lightguides”, “Anatomy”, “Physiology”, “English Terminology of Biomedical Optics” etc., as well as laboratory training (6 student labs) and Master project. The studies take four semesters – three for lectures and practical training, and one for the Master project. Details of the study programs and the practical experience gained over 12 years will be discussed in this presentation.

The main conclusions are:

- Biophotonics is a rapidly developing area, therefore every-year updates of the program content are necessary;
- The students are enthusiastic about their studies, but the lack of any textbook in this field makes studies difficult; considerable self-efforts of the students are requested;
- Internet resources may be useful in many cases; however, some of the Biophotonics items are presented there incompletely or even totally wrong; how to get rid of them?
- WebCT has proved to be a useful tool for Biophotonics studies;
- Specialized student laboratories are very helpful, but expensive; the experience gained so far indicates to need of a professional inter-university metodology;
- More efficient international collaboration in the field of education and training on Biophotonics is needed in future.

XIII.

Report on an Optics Outreach Program in Montréal

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Introduction

In accordance with its mission, the Student Chapter of the Optical Society of America (OSA) in École Polytechnique de Montréal organises numerous outreach activities to trigger the interest of students with 6-17 year of age in optics. In the last two years, these workshops have attracted over 450 students.

Methods

Two of the outreach activities organised have received particular acknowledgements from the target audience: the Extreme Microwave demonstration and the gelatine telecommunication hands-on activity. Extreme Microwave is a spectacular presentation, appreciated by both students and parents, in which the amazing optical properties of the common kitchen microwave oven are showcased. The gelatine-telecommunication workshop, a hands-on activity intended for middle and high school students, teaches the principles of total internal reflection, light propagation in bent waveguides and optical couplers using a laser pointer as source and gelatine as waveguide. The participants then complete their study by assembling an optical telecommunication setup used to transmit music, for which they connect the electric circuitry and align the laser pointer towards the receiver.

Results

Last year, 97% of the participants rated these activities ‘very’ or ‘extremely’ interesting, while finding the workshops to be captivating, complete and instructive. Some even affirmed that they now seriously consider pursuing studies in optics. The demonstrations and hands-on activities helped them gain confidence in their skills and realise that physics could mean more than equations.

Conclusion

The described outreach activities have fulfilled the Chapter’s objectives while providing an opportunity for students to interact with scientists and presenting optics concepts which may not be part of the students’ regular school curriculum, leaving them with a human and attractive image of the field of optics.

XIV.

Photonics Teaching Development at California Polytechnic State University

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California Polytechnic State University (Cal Poly) is one of 23 campuses comprising the California State University, the nation's largest four-year comprehensive public undergraduate university system. Cal Poly has a photonics program, photonics student club, and photonics laboratory within the Electrical Engineering Department that dates back to 1985. This laboratory is dual-use for both teaching and as a photonics center of excellence for the newly established Project-Based Learning Institute (PBLI) (http://pbl.calpoly.edu/). Our photonic education program at Cal Poly emphasizes four main educational tools. **A.** Lecture Classes. **B.** Photonics Laboratory Classes **C.** Student Photonics Club, and **D.** PBLI Design Projects. In this paper, we will describe the above four aspects with emphasizing on our new initiatives for part B and D.

Tool A, Lectures: We adopt multimedia course material in the lecture to match current fiber optic technology development.

Tool B, Photonics Laboratory Initiatives: Our primary goal in improving this laboratory was to replace old equipment (such as fusion splicer, ILX current sources), introduce modern components (e.g. SFP pluggable transceivers, Optical Amplifiers) and systems (1Gigabit Ethernet multimode and single mode links) to the fiber optic communication portion of the laboratory. We also are tightly linking hardware experiments with photonics simulation CAD tools (RSOFT product in our case). The lab instruction videos are also developed through out the years. These efforts demonstrate a more modern photonic lab experiments and meet current education goal.

Tool C, Student Photonics Club: Sponsored by SPIE since 1985, the club hosted the technical seminar given by both students and the outside speaker. It also organized field trip to Jet Propulsion Laboratory (JPL) in Jan 2007.

Tool D, PBLI Initiatives: The College of Engineering has formalized a mechanism that facilitates industrial and government sponsorship of engineering projects primarily for undergraduate students (PBLI). Through the PBLI program, students work with sponsor companies (such as Agilent and JDSU), internal or external research funding, and oversea research institute (Peking University, Beijing, China) under the guidance of professors. This paper will describe those photonics projects associated with PBLI and the benefits they provide to photonics education at the undergraduate level.

XV.

OPTICS LABORATORY EXPERIMENTS WITH LASER-HEATED SAMPLES OF CRUDE OILS AND OIL-IN-WATER EMULSIONS

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The aim of the present paper is to describe incorporation of basic industrial research results into current University study programs in Physics and Optoelectronic Engineering. The Laboratory of Optics and Fluids (LOF) of University Simon Bolivar (USB) leads a research program on applications of Photonics technology in the Petroleum Industry. More precisely, the main research subject at the (LOF) is development of optical procedures allowing determination of conditions of stability of oil-in-water emulsions. In several countries (for example, Canada and Venezuela) there exist important reservoirs of heavy crude oils, whose high viscosity impede their transportation through pipelines. Therefore, emulsions of heavy oils in water were developed in order to allow their commercialization. Though those emulsions are stable in current environmental conditions, high temperature or velocity gradients frequently provoke their coalescence. In typical experiments conducted at the (LOF) temperature gradients are induced in oil-water emulsions and in crude oil samples by irradiation with a CW laser beam. In crude oil samples the strong dependence of the liquid surface tension and refractive index on the local liquid temperature gives rise to long-range deformation of the liquid free surface. The latter cited thus behaves as an interferometrically smooth liquid mirror, which gives rise in turn to phase and intensity variations in the reflected light beam. In emulsion samples the inhomogeneous heating gives rise to thermoconvective flow, which is clearly observed as a moving speckle pattern in the reflected light beam. These are typical phenomena of self-interaction of a laser beam incident upon a material medium. In the present paper we discuss these optical phenomena, first studied in a basic research context, from an educational viewpoint. Simple experimental setups based in these principles are currently used in Physics and Engineering laboratory courses at the USB. The following experiments are discussed in detail:

a) Obtention of a liquid mirror with shape determined at will by the light intensity distribution in a laser beam incident upon a crude oil sample.

b) Study of statistical properties of laser speckle patterns resulting from scattering of laser beams incident upon oil-in-water emulsion samples.

c) Development of optical techniques allowing real time measurement of crude oil refractive index as a function of the liquid temperature.

XVI.

Applying the Principles of Augmented Learning to Photonics Laboratory Work

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Abstract: Most modern communication systems are based on opto-electrical methods, wavelength division multiplex (WDM) being the most widespread. Likewise, the use of polymeric fibres (POF) as an optical transmission medium is expanding rapidly. Therefore, enabling students to understand how WDM and/or POF systems are designed and maintained is an important task of universities and vocational schools that offer education in photonics.

In the current academic setting, theory is mostly being taught in the classroom, while students gain practical knowledge by performing lab experiments utilizing specialized teaching systems. In an ideal setting, students should perform such experiments with a high degree of autonomy. By applying the principles of augmented learning to photonics training, contemporary lab work can be brought closer to these ideal conditions.

This paper introduces „OPTOTEACH“, a new teaching system for photonics lab work, designed by Harz University and successfully released on the German market by HarzOptics. OPTOTEACH is the first POF-WDM teaching system, specifically designed to cover a multitude of lab experiments in the field of optical communication technology.

It is illustrated, how this lab system is supplemented by a newly developed optical teaching software - „OPTOSOFT“ - and how the combination of system and software creates a unique augmented learning environment. The paper details, how the didactic concept for the software was conceptualised and introduces the latest beta version. OPTOSOFT is specifically designed not only as an attachment to OPTOTEACH, it also allows students to rehearse various aspects of theoretical optics and experience a fully interactive and feature-rich self-learning environment.

The paper further details the first experiences educators at Harz University have made working with the lab system as well as the teaching software. So far, the augmented learning concept was received mostly positive, although there is some potential for further optimisation concerning integration and pacing of various interactive modules.

1 Introduction

The demands on digital high-speed data communication equipment are increasing permanently and so are the demands on the maximum bandwidth of transmission media [Na00]. Modern communication systems need high-speed optical transmitters and receivers for Terabit data transmission rates. Most of these communication systems are based on advanced opto-electrical methods like wavelength division multiplex (WDM), which is one of the most widely used methods. Likewise, the use of polymer optical fibres (POF) as an optical transmission medium is expanding rapidly.

The POF is an optical waveguide consisting of a highly transparent polymeric material. A thin PMMA cladding with a lower refractive index encircles the PMMA core, causing a total internal reflection, an optical phenomenon, which always occurs when light strikes a medium with a lower refractive index and is reflected to almost full extent. Thus, light cannot leave the waveguide making POF usable for communication technology.

The current surge in POF uses in especially visible in market growth – compared to the market for glass optical fibres, the POF market is booming. While POF technology has been around since the late 70s, using polymer fibres for data communication has been a costly business until the turn of the century when prices for transmitter and receiver modules in the visible wavelength area (400nm to 800nm) declined, making a cost-effective use of POF possible [Da01].

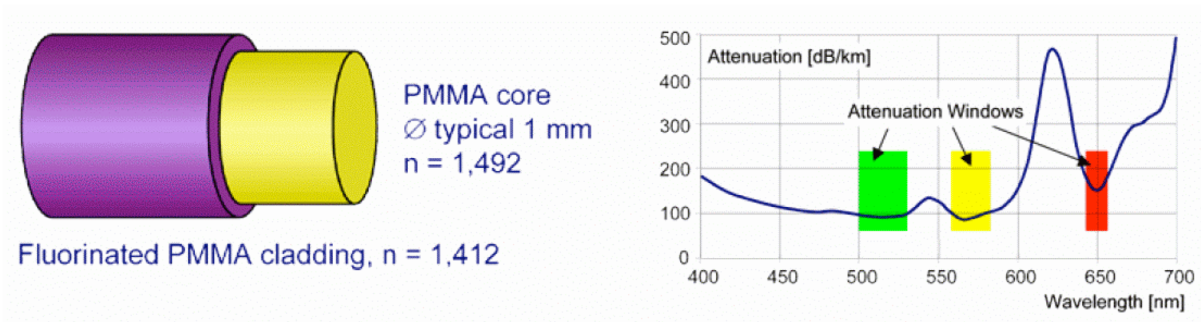

Fig. 1: General structure and of POF (left) and attenuation within the visible spectrum (right) [PO07]

According to a recent study by IGI Consulting [IGI06], the increased interest in POF is mostly due to several current developments in the technical area:

- The demand for cost-efficient high-speed communication technology is increasing
- European automakers have introduced the POF-based MOST-bus[1]
- The 1394b standard has been introduced, increasing the distance between communication nodes to 100m for 3,29 Gbps communication systems
- During the last years, several new POF application fields have been found, including home infotainment, industrial Ethernet, medical technology and sensor technology

Another recent market study, conducted by Harz University itself in 2005 among the members of OPTECNET – the German optical competence networks[2] – shows a clearly risen interest in POF technology. More than 50% of all companies polled are currently in the process of or preparing to expand the use of POF in their own production activities.

Aside from the automotive industry, the industry expected to most heavily shift to POF usage over the next years is the home entertainment sector. A recent market analysis [Ah07] confirms, that although wireless communication systems like WLAN or Powerline Communication have the advantage of relieving the home owner from actually passing any wires, their data rate as well as their technical stability compare to badly against the established Fast Ethernet to make both alternatives viable ones. Lightweight and transparent POF provide home owners an opportunity, to belatedly establish a 100MBit/s data connection without too much effort (because of the extremely simple handling) that is a lot less visible than regular copper cables. Thus, POF has become increasingly interesting for the so-called "last mile" – the last few meters from any city-wide broadband and glass fibre based network to the end user.

The increasing importance of POF and WDM systems makes enabling students and vocational trainees to understand how WDM and/or POF systems are designed, built and maintianed a paramount task for universities and other institutions of higher learning or expert vocational training that offer education in optical technology. This includes honing the practical skills of students and vocational trainees and introducing them to concepts such as WDM not only on a theoretical, but also on a practical, "hands-on" level.

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1 http://www.mostnet.com

2 http://www.optecnet.de

Fig. 2: As of 2004, the MOST bus has already been in use in some of the most recognized modern car types.

Fig. 3: In-house multimedia infrastructure using POF

In the current academic setting, theory is mostly being taught in the classroom while students gain practical knowledge by performing lab experiments, often using specially designed lab systems. During such experiments, supervising educators have to adapt to the individual learning progresses of single individuals or work groups. In the course of one lab experiment, it is often necessary to quickly and individually rehearse theoretical knowledge or to give problem-specific practical advice. This does not correspond with the idea that students should handle most lab work autonomously as part of the learning experience. By applying the principles of augmented learning to photonics training, contemporary lab work can be brought closer to these ideal conditions.

This paper introduces OPTOTEACH, a newly developed optical teaching system for photonics training in POF data communication and WDM methodology. The paper details the technical layout of the system as well as some of the design concepts behind it. It is then explained, how the system can be augmented with supplemental, interactive software and how this combination of lab system and software creates an effective augmented learning environment.

2 Optical Teaching System

OPTOTEACH is the first POF-WDM teaching system, specifically designed to cover a multitude of lab experiments in the field of optical communication technology, e.g. PI curve and bandwidth measurements or analysis of EMF influences. OPTOTEACH systems are exclusively built and distributed by HarzOptics, an optics think tank and research institute associated with the department of Automatation and Computer Science at Harz University in Wernigerode. OPTOTEACH systems are currently being used for educational lab work at Harz University, Braunschweig University, Dresden University, the University of Mannheim and the Federal Centre for Electronics Technology in Oldenburg.

OPTOTEACH systems consist of two video transmitters, one LED and one laser in cw mode and two receivers. The system enables students to transmit two analogous FBAS video signals or corresponding test signals with a maximum bandwidth of 10 MHz. Both transmitters operate within the visible wavelength, which does not only allow OPTOTEACH systems to be built and maintained at reasonable costs, but also provides students with an opportunity to visually experience the WDM effect first hand. The two signals are joined via a conventional Y-coupler developed by Ratioplast Optoelectronics GmbH[3], the separation is effected by a Ratioplast splitter in combination with red and blue colour filters. Signals can be transmitted over various fibre length, covering 5m up to 100m, whereas the fibre itself is interrupted by a micrometer stage, enabling the students to analyse coupling losses with cut or polished fibres as well as lateral and longitudinal misalignments. The general design of the system can be seen in figure 4.

The system gives students an opportunity to perform a multitude of experiments, e.g.:

- PI curve measurements
- Bit Error Rate measurement
- Signal quality tests (eye diagram)
- Measurement of bandwidth and S-parameter
- Analysis of EMF influence on the transmission
- Identification of modulation characteristics (AM, ASK, PCM)
- Attenuation measurements for different fibre lengths (1-100m)
- Attenuation measurements for different wavelengths (490/520/660nm)
- Analysis of the influence of lateral and longitudinal misalignments on the transmission

A more detailed description of the teaching system itself can be found in [Fi06] and [Re06].

3 http://www.ratioplast.com

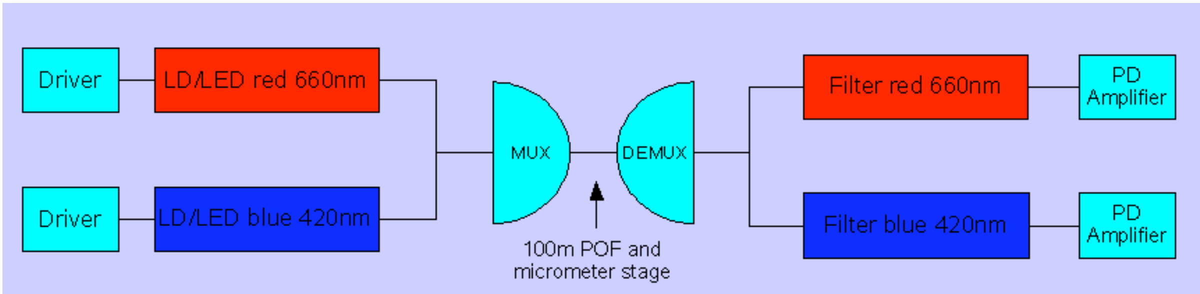

Fig. 4: General technical layout of the OPTOTEACH lab system [Re06]

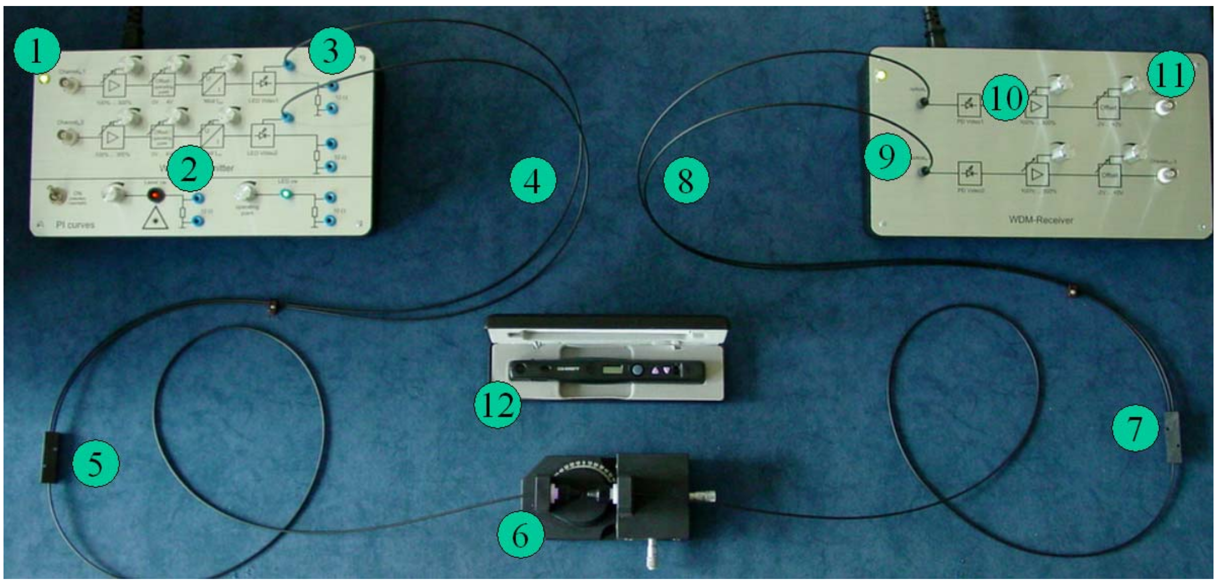

Fig. 5: OPTOTEACH Lab System with (1) BNC-Inputs (2) Potentiometer (3) Optical Outlets (4) Polymer Fiber (POF) (5) Multiplexer (MUX) (6) Shifting Table (7) Demultiplexer (DEMUX) (8) Polymer Fiber (POF) (9) Optical Outputs (10) Potentiometer (11) BNC-Outputs (12) Optical Powermeter

3 General Software Design

3.1 Basic Requirements

Two basic requirements can be determined for teaching software in general: platform independence and the integration of multimedia content.

The software designer has to make sure, that the software can be used independent from the technical equipment available in the universities or vocational schools. This implies, that platform independent technology such as Java or HTML has to be used at all stages of the software development process.

If HTML is used, if has to be considered, that the terminals used in the educational institutions will differ from each other in browser type and version as well as in screen resolution. Thus, the software has to be thoroughly tested and adapted to the various possible configurations before being released. The development of teaching software for any special combination of operating system, browser type and version as well as screen resolution is economically unsound, because the customers are forced to adapt their technology to the software requirements or be content with a lower quality or hardware-triggered software errors.

Integrating multimedia content into the software application is less of a technical and more of a didactic necessity. The contemporary software user generally expects content to be enhanced with multimedia features and the integration of video films or animations has long been known to be a good practice for activating the user's interest and for making teaching software more appealing [Te00]. Short video sequences and animations that depict can be used to visualize scientific theory as well as depicting actual lab work sequences or experiments. Thus, they can be seen as chapters in a “taped instruction handbook” and an amendment of textual descriptions of experimentation sequences or lab work instructions.

The OPTOTEACH software concept acknowledges these possible problems and depends solely on multimedia technologies, that do not require any plugins (such as animated GIFs) or standard plugins that can reasonably be expected on most of all currently used lab terminals (such as Macromedia Flash).

3.2 Navigation

The direct comparison of online questionnaires in market research and interactive teaching software reveals a common design problem: Should contextual information be placed on one scrollable page or should all content be split into smaller information units that can be displayed on one single screen each [Te00].

If at lot of information is displayed on one single page, the overall theoretical context can be compassed almost instantaneously by the student. This prevents any feelings of being confronted with a seemingly endless number of smaller information screens and allows students to get a quick overview of the entire content and to guess the approximate reading time. Such systems are much less complex – from the programmer’s point of view – and are therefore easier and quicker to realize than the programming of a more elaborate system of smaller information screens [Te00]. On the other hand, presenting the entire content of one chapter or the entire proceedings of one experiment can entice students into quickly scrolling through the entire text or completely skip the theory to start with the experiment right away.

The most fundamental benefit of smaller information screens is, that it spares students the discomfort of having to scroll through the information – the navigation is much more concise and brings about a more comfortable software handling. It is also possible to easily integrate interposed control questions between the information screens and to instantaneously validate any given answers, which not only enables the students to get an immediate feedback on their learning efforts but also makes it possible for the software to suggest the targeted repetition of certain theoretical aspects based on the direct evaluation of the answers given.

The information screen option therefore offers a higher level of interactivity as well as enhanced possibilities to evaluate student performance. These advantages and the consequential higher software quality and enriched learning experience outweigh the higher complexity in design and programming. To circumvent the aforementioned feeling of “endlessness”, a progress bar can be included, which indicates the remaining number of information screens. Additionally, the average time of completion can be shown at the beginning of each self-contained learning module.

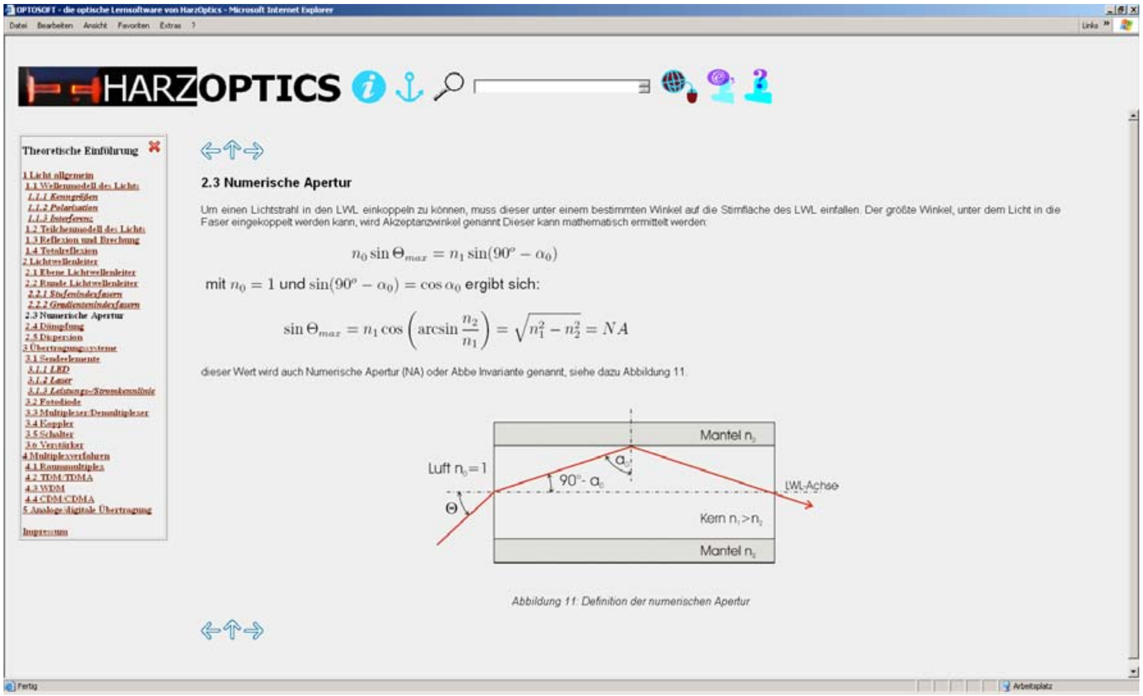

Fig. 6: Screenshot of the current OPTOSOFT beta version (in German language)

The navigation design should allow a comprehensive overview of the theoretical content and enable the student to jump back and forth between the theoretical chapters as well as follow an “ideal learning path”. A good example for a practical and concise navigation design is the popular SelfHTML HTML learning software[4]. Another exemplary navigation design can be found on the two online learning sites “Mikro Online”[5] and “Makro Online”[6], developed by Wilhelm Lorenz, professor of macroeconomics at Harz University.

After the navigation design is completed, a pre-test should be arranged along the lines of the conceptual design of any online market research questionnaire. The pre-test allows a testing of the navigation design as well as the general visual impression of the software during a phase of the software development process, in which changes in either the navigational design or the visual presentation are still possible. The basic procedure of such a pre-test can be adopted from market research online pre-testing processes and is described e.g. in [Po98].

4 Didactic Concept

4.1 Learning Phases

Because the software aims to support the entire learning process form theory rehearsals to lab-based experiments, it is important to break down the complete process into all methodically different learning phases. Concerning the OPTOTEACH optical teaching system, these phases are already known from the direct practical use of the system in various courses at Harz University:

- Repetition and solidification of theoretical knowledge
- Overview of and support during various lab experiments
- Gathering of measurement data and production of lab protocols

To decide on the ideal didactic concept for the teaching software, the authors extensively researched the various parallels between online collection of market research data, especially via online questionnaires,

4 http://www.selfhtml.org
5 http://www.mikroo.de
6 http://www.makroo.de

and lab and/or teaching software within the context of an augmented learning environment. Table 1 contains an excerpt from the list of researched parallels. Similarities were especially appearant concerning the somewhat limited user motivation, which is a problem for market researchers as well as for lab instructors. It is noteworthy that the solution to this problem consists – in both cases – in the introduction of an extrinsic motivational element into the situation, which is known as an incentive in market research terms – and as a grade for students. Both situations demand a certain level of focused mental concentration on the user side, in both cases data is collected and later analyzed and the exact technical configuration of the end unser terminals is unknown to the market research questionnaire designer as well as to the teaching software programmer. In both cases, no specific technological requirements (e.g. operating system, browser type, browser version or number of additional plugins needed) can be made without excluding potential users. Many more parallels can be found, e.g. concerning the average time needed to complete a typical online questionnaire or an average learning module.

Feature	Online Questionnaire	Lab / Teaching Software
Level of Motivation	Low or very low	Partially low
Source of Motivation	External (Incentives)	External (Grades)
Focus of Participants	Usually high	Mostly high
Data Analysis Method	Analysis of given answers	Evaluation / Grading
Programming	Java, HTML, CGI	Java, HTML, CGI
User-side IT Technology	Manifold technology	Manifold technology
Average Duration	20-30 Minutes	30-40 Minutes

Tab. 1: Parallels between the online collection of market research data through questionnaires and the use of teaching software within or outside an augmented learning environment (excerpt)

Because of these parallels, it seems prudent to utilize already existing scientific research on the creation of ideal conceptual designs for market research questionnaires, especially the existing Best Practice frameworks, in the development of teaching software. A thorough review of contemporary online market research methodology also confirms other findings about the ideal design of teaching software: direct feedback and a high degree of interactivity can trigger a heightened involvement on the user side, the (careful and spare) use of high quality multimedia elements helps to keep up the user's attention and the best possible solution to present a larger number of questions (or other content) is splitting them up in screen-sized information modules.

The application of the most important guidelines in contemporary online market reasearch questionnaire design (especially the research of [Te00], [Dr03], [Bö99] and the most recent [We05]) lead to the four basic software modules pictured in fig. 7.

These four modules are: The continuous repetition and cementation of theoretical knowledge about various aspects of optical technology, the user-controlled exploration and self-testing of this theoretical content utilizing interactive graphs and modules such as multiple-choice questionnaires, the customisable help and support of lab experiments and the option of generating and saving PDF[7] protocols with measurement data and student answers to theoretical questions as a data base which can be utilized by the lecturer for grading purposes.

[7] PDF (Portable document File) is a registered trademark of Adobe Inc.

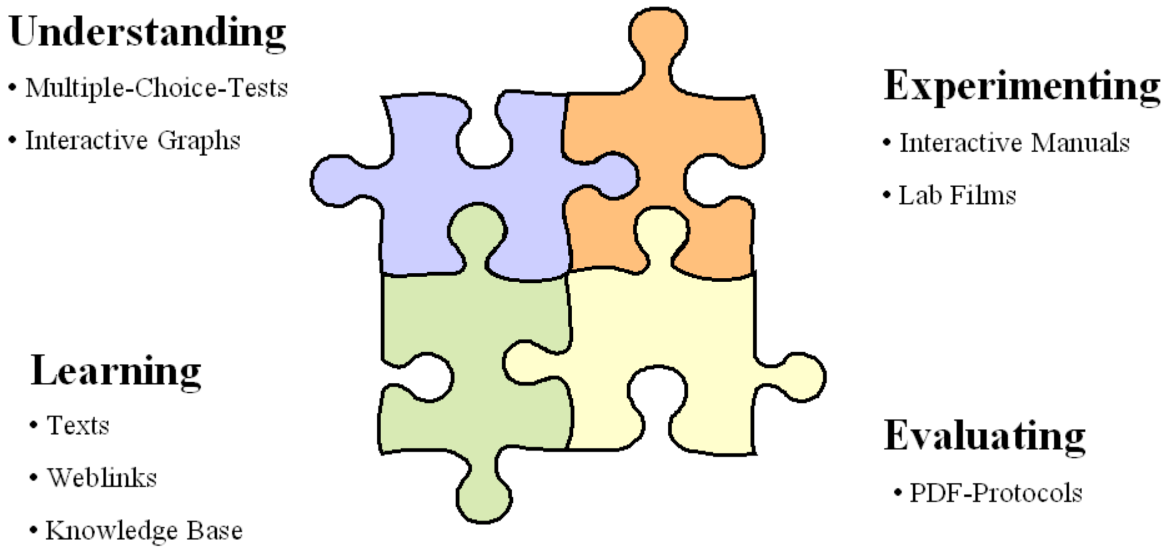

Fig. 7: Overview of the four OPTOTEACH basic software elements

The repetition and consolidation of theoretical knowledge is not confined to one theoretical module which students have to complete before a lab experiment can begin, instead, theoretical knowledge is repeated throughout the entire experimentation process and the interpretation of resulting measurement values. The hypertext-character of HTML allows the implementation of this idea into the software, because students can use embedded hyperlinks on important science terms to jump to corresponding theoretical context and then back to the current experiment. A permanently accessible glossary with an integrated search function makes it even easier for students to gain access to important theoretical knowledge. The synergy-effect that results from the interconnection of hands-on experimental lab work and understandable overviews of theoretical basics can thus be utilized most efficiently.

Because the overall design (the single information screen model mentioned above) allows the easy implementation of interposed control questions, this additional control method, which is typically not part of typical educational lab work programmes, can be integrated into the experimental workflow. It is up to the lecturer or lab administrator to decide, whether these knowledge checks are mandatory or optional for students.

The chaperonage of the individual student during lab experiments – the only part of the teaching software that is currently still under development – forms the core of the augmented learning environment. Parallel to the actual experimental performance students will be able to inform themselves about the general layout of the experiment, get work instructions from the computer and enter their measurement data, whereas average measurement data and other intermediate results provide the opportunity to continuously check whether the experiment is conducted correctly. Thus, students will be enabled to detect any discrepancies in their measurement data at an early stage and therefore check their own results, which is almost impossible to realize in a traditional lab environment. In the event of perceptible deviations of the experimental results from the ideal results, a set of multiple-choice questions will allow the student to identify probable causes of the discrepancy and gather instructions for correcting any possible mistakes. The lecturer only has to get involved into a particular experiment if this help system does not provide the solutions needed to achieve the expected results.

The heightened level of autonomy alleviates student-controlled lab work and supports the pedagogical concept behind of enabling students to advance their practical skills as well as their theoretical knowledge more or less autonomously in a self-controlled environment.

The acquisition of measurement data and the compilation of lab protocols will also be implemented, whereas the software covers all four learning phases. Via a HTML form field, students can enter measurement data as well as textual answers to theoretical questions and questions about completed experiments. This does not only represent a significant assistance for students but also for lecturers and lab administrators who will be disburdened from deciphering bad handwritings and searching for lost sheets of paper.

4.2 Dimensions of Teaching Software

Teaching software, like the OPTOSOFT software presented in this paper, is basically defined through the three dimensions of interactivity, adaptivity and controllability [DE01].

According to [Ke98], interactivity can be seen as a mostly technical dimension: When working in an interactive medium, the user – in this case the optics student – has unrestricted and self-controlled access to multimedia information. The interactivity allows the active processing of teaching content by the student, who has the ability to influence the selection and the sequence of content at least partially [Ja00]. Within OPTOTEACH, interactivity is provided via the easy-to-use navigation, which allows almost unrestricted access to all content modules. Students can forgo the recommended "learning path" and navigate freely through the software.

Adaptivity is defined as the extent to which users are allowed to customize any given software [DE01]. OPTOSOFT allows students to adjust the software to the preferred working speed, repeat complex passages at will or self-check the comprehension via multiple choice questions. When the software is used as a lab companion, the speed of instructions and recommendations is adjustable to the actual experimental progress, likewise in the acquisition of measurement data and the compiling of lab protocols, meaning the dimension of adaptivity is distinctive throughout all four phases described in 4.1.

According to [DE01], controllability does not refer to the control of the lecturer or lab administrator over the student but to the control of the student over the learning process. In computerized learning environments, the controllability increase with the extent to which non-linear navigation is implemented, meaning the less restricted the user is, the higher is the controllability of the software [Ne00]. Because the technical basis of OPTOSOFT is HTML, the hypertext-functionality allows a nearly completely unrestricted navigation throughout most of the learning modules. The only restrictions will be implemented into the lab protocol compilation process, because the electronic documents generated in this process may provide a basis for student grading.

Because of that, students will only be able to access the protocol editor after an experiment has been completed instead of being able to directly jump into the protocol compilation process. Furthermore, the PDF files generated by OPTOSOFT will exhibit a time stamp unchangeable by student changes in the protocol editor.

5 First Experiences

At present, more than half of the teaching software is completed, with the theoretical modules being already fully functional. The software will soon be undergoing vigorous beta testing at the Harz University photonics labs. The first student and lecturer feedbacks have been unanimously positive, welcoming the introduction of the multimedia element and the easy-to-navigate glossary to the lab. Several technical problems have been asserted and will be rectified before the release of the pre-beta-version.

One of the more interesting results of the first feedback evaluation is the clear demand for more multimedia elements to be included in the final version, directly connected to the general wish for a more colourful and less conservative visual design. While these wishes can certainly be implemented in the pre-beta-version, it is important not to overload the software with colours and multimedia elements, preserving the scientific image.

6 Conclusion and Outlook

At this stage, the fully functional OPTOSOFT version 1.0 is expected to be complete in late 2007, so that universities and vocational schools can start using the software in class and lab work not later than early 2008. The current version already includes the complete theoretical learning modules, the knowledge base, the link list, most of the multiple choice tests and interactive modules as well as some of the lab companion modules. Other lab companion modules, lab movies and a fully functional version of the protocol generator are still in development. The OPTOTEACH lab teaching system also described in this paper, has already been successfully introduced to the German education market and, as of early 2007, is being used in more than half a dozen universities nationwide.

Because the adoption of the augmented learning idea to photonics lab work is new and untested, the authors are very curious about the feedback of the first classes and lecturers that will start working with the software in early 2008. A quality feedback system, that will allow students and lecturers alike to communicate their experiences and critique points, is already in an early set-up phase. Aside from the mostly subjective impressions of students and lecturers, this feedback system will also gather more objective data such as average grading before and after the introduction of the software as well as the results of the teaching quality evaluation during the introductory period. A quality control and a version management system will ensure, that didactic and technical change requests are collected, evaluated, implemented or not implemented and archived for further evaluation.

The continuous further development of teaching system and teaching software as well as the complete documentation of this development process will result in a comprehensive catalogue of specifications and problems in the practical use of an interactive and multimedia lab companion software in the context of a photonics augmented learning environment. The authors expect to publish a revised edition of this catalogue as a basis for discussion about the optimal way of introducing augmented learning to photonics training.

All public and private institutions of vocational and higher education are invited to participate in this project.

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Teaching thin optical coating and optics education in developing country – a scenario in Bangladesh

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Abstract: Optics education is an essential ingredient in building modern science and technology. As the rate of technological change accelerates, continuing optics education becomes more important than other. This talk is an account of a successfully continuing professional-education course on optics and optical coatings in the Department of Applied Physics & Electronic Engineering, University of Rajshahi, - a scenario of optics education in Bangladesh. The foundation course on optics emphasizes in understanding of the basic principles of geometrical and physical optics through formal lectures and its practice through laboratory demonstrations. The Department of Applied Physics & Electronic Engineering usually do local fabrication/ assembling of optics laboratory teaching aids. Students and technical staffs under the guidance of a Faculty staff member do equipment fabrication and assembling. This article describes some of the project-type set ups for performing experiments on (i) wavelengths of various spectral lines determination (ii) determination of unknown solution concentration (iii) determination of thickness of thin optical coating as well as (iv) determination of various optical parameters such as refractive index, optical band gap through the measurement of transmission and reflection spectra.

OCIS codes: (000.2060) Education, (080.2740) Geometrical optics, optical design, 310.6860) Thin Films, Optical Properties

1. Introduction

Science and technology have a major role in the development of today's society and civilization. The science of optics includes light emission, transmission, absorption, reflection, detection and amplification of light by optical devices and instruments, laser, fiber optics, optoelectronic devices and related optoelectronics system of hardware and software [1]. In recent years, optics plays a significant role in the growth and development of high tech industry such as energy generation, telecommunications, information technology, detection & ranging, medical diagnostics and treatment, structure of health monitoring, quality control of products as well as in the environment control of our ambience [1].

Bangladesh is a country of about 140 million people and it has 16 public Universities and more than 50 private Universities. Most of these Universities have undergraduate and graduate programs in disciplines of Humanities, Social Sciences, Business Studies as well as Science & Engineering programs. In response to the growing importance of optics, education institute across Bangladesh including the Rajshahi University (RU), a very old University in the country established in 1952, has been offering optics course in the Department of Applied Physics & Electronic Engineering from the inception of the Department. The Department of Applied Physics & Electronic Engineering at RU was established in 1966 and initially it had started to offer a Master of Science education program. The Department had late offered an undergraduate program in 1973. Optics and optoelectronics courses at RU are part of a 4-year Bachelor of Science Honors in Applied Physics & Electronic Engineering degree program. A 2-credit project course is compulsory for all attending Honors graduate.

The main courses include Applied Optics, Basic and Advanced Electronics, Quantum Mechanics, Atomic & Nuclear Physics, Pulse & Switching, Instrumentation & Control Systems, Non Conventional Energy, Integrated Circuits (IC) Fabrication & Communication Electronics, Solid State Physics, Communication Engineering, Applied Geophysics, Medical Physics, Computer Architecture & Organization, Radio & TV Engineering, Telecommunication, Microprocessor & Microcomputer, Materials Science and Advanced Solid State Physics. The Honors degree program is 4 years duration, comprising 160 credits, where 128 credits are allocated for theory courses and 32 credits for practical classes with project works. The education of RU contains a formal lecture of 50 minutes duration and a laboratory session of 2 hours. The department offers a basic course of Applied Optics for the first year Honors students to have a fundamental knowledge in optics.

Optics and optoelectronic courses are embedded in Instrumentation & Control Systems, Non Conventional Energy, IC Fabrication & Communication Electronics, Solid State Physics, Communication Engineering, Materials Science and Medical Physics. In laser and fiber optics, students learn various aspect of laser such as principles of laser generation, laser resonator, beam properties, application in interferometry & holography and application in medical physics. Light guiding properties of optical fibers, dispersion, attenuation, applications of fiber optics in telecommunication and in Satellite Communication as well as laser in various sensor applications. Besides, basic optics principles and their use in optical equipments as well as in technical applications are taught through lectures and practices. Discussed topics include interfrometry, diffraction, polarization and their applications through a number of demonstration classes.

2. Project

The main concern in the undergraduate project work is the syntheses of the knowledge from all lectures that have been in the classroom and its application to solve real problems in practice. Components and instrumentations are needed to construct the necessary project to carry out its measurements and to exhibit its performance to the audience present. The following two typical illustrations are among 50-project work usually done in every year by the Honors students at the end of their 4^{th} year degree program. The project was based on electronics & optoelectronics with hardware and software design.

Design and construction of a microprocessor control four-way traffic signal system: Electronic auto traffic signal system is very useful for developing country like Bangladesh. It has very important role to make discipline in vehicle communication in a busy road. A microprocessor-based system is controlled by software; therefore it controls the duration of light ON/OFF to make order of the traffic systems.

Carbon dioxide gas detector: Whenever CO_2 gas is passed through a fresh colorless lime water $Ca(OH)_2$, it is turned milky in color due to its white precipitation of calcium carbonate ($CaCO_3$).

Colorless limewater + Carbon dioxide gas ↔White precipitated of Calcium Carbonate + Water.

Therefore, CO_2 gas changes the optical transparency of the limewater. Their changes in transparency can be measured by using optoelectronic circuit and detect the presence of CO_2.

3. Examples of experiment for basic understanding

The objective of running optics laboratory class is a provision of practical experience to supplement and illustrate concepts developed and discussed during formal lectures. With this in mind, various laboratory works are organized for the first, second, third and fourth year students. In the first year level, the courses are not very specialized so that the laboratory experiments involve certain common components and instruments. Exchange and reallocation of the equipments are possible during the execution of the yearly program. The motivating factors for local fabrication/assembling of optics experiments are: (i) to have fundamental knowledge in education (ii) cost-effectiveness (iii) easy maintenance and (iv) easy duplication, upgrading or modification. The exercise involves teaching staff members, technical staff members and the students also. Five sets of optics experiments are illustrated below which have been set for demonstration for students from the first year level to 4^{th} years.

3.1 Phenomena of interference of light.

Measurements of radius of curvature of a lens by Newton's ring: The set up is developed in the laboratory and is depicted in Figure 1(a). When a plano-convex lens L of large radius of curvature is placed on a glass plate G, a thin air film of progressingly increasing thickness in all direction from the point of contact between the lens and glass plate is formed. The air film thus possesses a radial symmetry about the point of contact. When it is illuminated normally with monochromatic light, an interference pattern consisting of a series of alternate dark and bright circular rings concentric with the point of contact is obtained.[2, 3, 4] and it is shown in Figure 1(b).

Students usually measure the diameter of the lens and calculate the diameter, D, of dark and bright rings by using of microscope. By plotting a graph of the square of the diameter as the ordinate and number of rings as abscissa, the calculated result gives a straight line and it then determines the radius of the curvature of the lens by using the following equation

$$R = \frac{\left(D_{n+m}^2\right) - D_n^2}{4m\lambda} \quad (1)$$

Where, λ is the monochromatic light wavelength n & m are the number of rings, respectively.

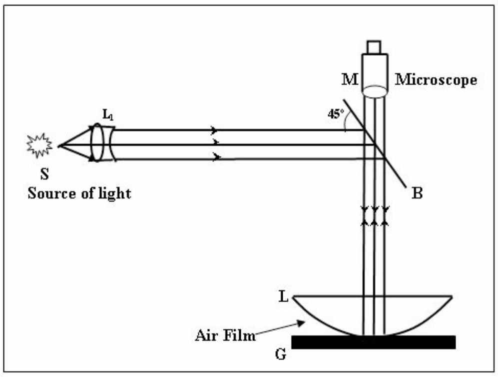

Fig. 1(a). Experimental set up of interference of light

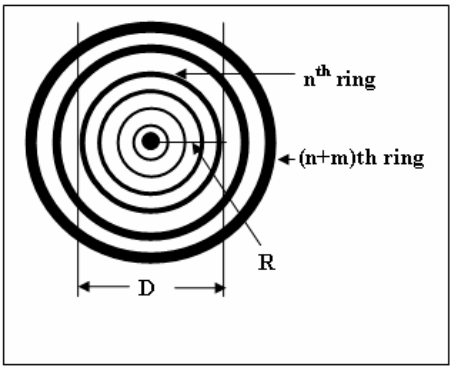

Fig. 1(b). Interference pattern

3.2 The phenomena of diffraction of light

Determination of the wavelengths of various spectral lines by spectrometer using plane diffraction grating: The laboratory experiment is summarized schematically as in Figure 2. If a monochromatic light of wavelength λ falls normally on a plane diffraction grating placed vertically on a Prism Table, a series of diffracted image of the collimator slit will be seen on both sides of direct image [2, 3, 4]. Using the equation

$$N = \frac{\sin\theta}{n\lambda} \quad (2)$$

Where, N is grating constant, n is the number of the image and θ is the deviation angle of light.

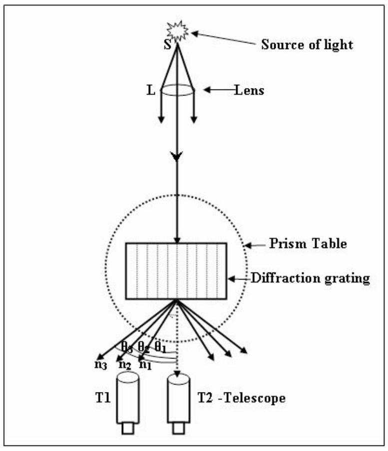

Fig. 2. Illustrates the diffraction phenomena of light.

The students usually do the experiment with sodium light of known wavelength and then the value of N is determined first. From the knowledge of N, the wavelength of any unknown light can be found with the help of Equation (2).

3.3 Phenomena of polarization of light

Determination of the specific rotation of a sugar solution by polarimeter: Figure 3 illustrates the schematic set up of the experiment to have a basic understanding of the polarization of light. The angle of rotation of the plane of vibration produced by a substance, in solution or otherwise, is proportional to (i) the thickness of medium (solution) (ii) the concentration of the solution or the density of the active substance in the solvent and (iii) the nature of the substance.

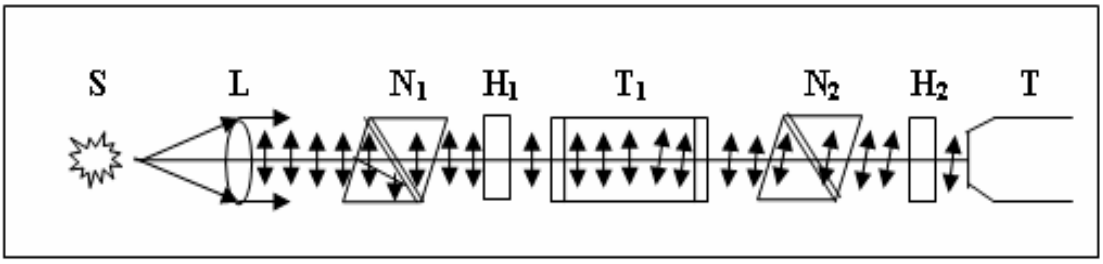

Fig. 3. Schematic diagram of the experiment of polarization of light

If l = 1 decimeter and c = 1gm/cm^3, then specific rotation may be defined as the rotation produced while traversing a path of one decimeter (10 cm) length in the solution containing 1 gm of the optically active substance per cm^3 of the solution.

The specific rotation = (rotation produced by 1 decimeter length of the solution)/(density of the solution in gm c.c.)

The amount of the rotation is usually determined from the experiment by the students and the rotation depends on the temperature as well as wavelength of the light used. The angle of rotation vs. their corresponding concentration of the solution yields a plot of straight line and it then determines the unknown concentration of the solution.

4. Thin optical coating

It is well known [5, 6] that one can improve the properties of the glass by use of very thin surface coatings. For example, one can diminish the inflow of solar energy to 50% (during the summer), without changing the visible appearance with one type of coating. Another type can be transparent to solar radiation but decrease the out flow of heat (during the winter) to 50% of the magnitude in a normal uncoated glass [5, 6].

In large parts of the world the climate is "Warm" during the summer and "Cold" during the winter. It is clear that to improve the quality of livings, to minimize the energy needs in the livelihood and to efficiently utilize the energy consumption, scientists all over the globe are engaged in research on selective surface coating and energy efficiency. The key concept of spectral selectivity is that the glass coatings should have qualitatively different optical properties in different wavelength ranges [5, 6, 7]. A low emittance coating is of particular importance in a cold climate where the coating has unity transmittance for luminous & solar radiation in the wavelength range $0.3<\lambda<3$ μm and unity reflectance or zero emittance in the $3<\lambda<50$ μm wavelength range [8, 9, 10]. The solar control coating is useful in hot climate and the ideal coating should be transparent for visible radiation in the wavelength range $0.4<\lambda<0.7$μm and have unity reflectance at wavelengths $0.7<\lambda<3.0$ μm. With this concept in mind, our group at RU is engaged in research on thin optical coating of metal, semiconductor or even insulating films to make of their use in selective surfaces and devices.

4.1 Specialized experiments on thin optical coatings

Determination of thickness for thin coatings: The objective of this particular experiment is to deposit thin metal or semiconducting thin films and to determine of their thickness as well as of their transmission & reflection coefficients. For deposition of thin films, a vacuum coating unit (Edwards Vacuum Ltd. England) was procured and it has the options to produce the thin films by thermal evaporation as well as by e-beam evaporation technique [11]. To measure the optical properties of the thin coating, our department obtained a Perkin-Elmer, Lambda-19 spectrophotometer as a generous donation by International Science Programs (ISP), Uppsala University, Sweden.

Student in the 4th year Honor's level usually carry out their projects on thin optical coatings. The bench set-up for determination of the thickness of thin coatings is shown in Figure 4(a). The interference method for the determination of film thickness was done by a method developed by Tolansky [12] to a remarkable accuracy. When the interferometer is illuminated with a parallel beam of monochromatic light, a fringe system as shown in Figure 4(b) is produced. The displacement **I** of the fringes system across the film-substrate step is then measured to calculate the film thickness **t** using the relation

$$\mathbf{t} = \frac{\mathbf{I}}{\mathbf{h}} \times \frac{\lambda}{2} \quad (3)$$

where, **h** is the fringe height. In this method, the thickness measurement of 3 to 2000 nm can be done with an accuracy of ±1nm.

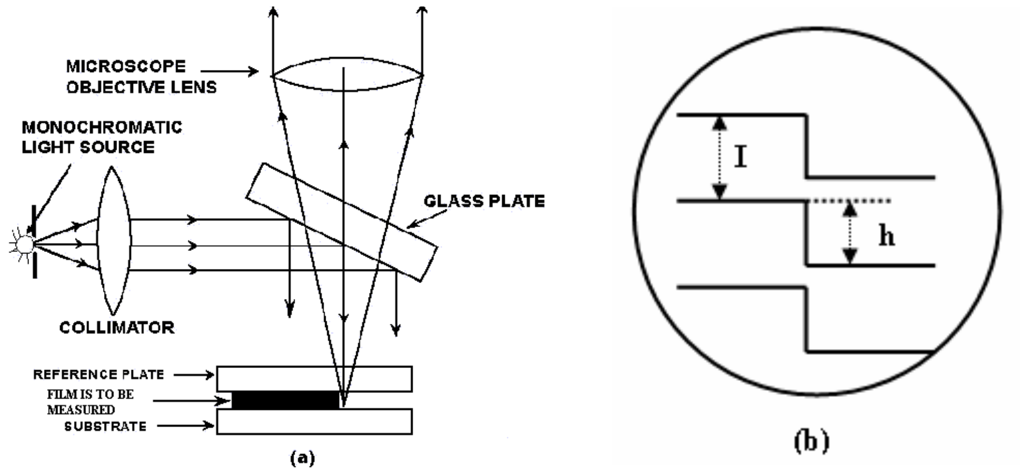

Fig. 4(a). Enlarge view of the interferometric arrangement for the measurement of film thickness; (b) The fringe pattern with step height ‘h’ and fringe spacing ‘I’.

Determination of optical band gap & refractive index: The objective of the experiment is to study the percentage of transmittance (T) and reflectance (R) of thin coatings obtained by its deposition of selected metal or semiconducting films in the selected wavelength range. From the obtained data of transmittance and reflectance spectra, the percentage of absorption (A) is to be calculated. Sample index of refraction is determined indirectly by measuring the transmittance as well as the thickness data by the conventional relation

$$\mathbf{n} = \frac{\mathbf{A}\mathbf{n_0}}{\mathbf{T}} \times \frac{1}{\mathbf{ln}\left(\frac{1}{\mathbf{T}}\right)} \qquad (4)$$

where, n_o refractive index of glass substrate (n_o = 1.5). From absorption data, the coefficient of absorption in the selected energy interval of the optical spectra helps to determine the optical band gap of the sample.

5. Conclusions

It is shown in our article that without using any sophisticated equipments, the optics education could be conducted in our laboratory and it helps to make understanding of the students the basic concept of optics The development of optics and photonics education requires a large number of well trained and motivated teachers and technicians who should discharge their experiences in teaching to the students efficiently. Most of the research and development in the area of photonics involves the use of optic fiber. We are now planning to revisit our experimental set-up by fiber optic based interferometer in addition of our conventional set-up. The science and teaching methods are truly international and this workshop provides a venue and opportunity for teaching and learning of the participants and has the capacity to bring people closer in both a professional and personal way.

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