Education Programs of the Institute for Optical Sciences at the University of Toronto

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ABSTRACT

The Institute for Optical Sciences at the University of Toronto is an association of faculty members from various departments with research interests in optics. The institute has an extensive program of academic activities, for graduate and undergraduate students, as well as public outreach.

For undergraduate students, we have a course on holography. We provide opportunities for students to gain optics experience through research by providing access to summer research positions and by enrolling them in the Research Skills Program, a summer course teaching the basic skills needed in research.

For graduate students, we offer the Distinguished Visiting Scientists program, where world-renowned researchers come for a week, giving a series of 3 lectures and interacting closely with students and professors. The extended stay allows the program to run like a mini-course.

We launched a Collaborative Master's Program in Optics, where students earn a degree from their home department, along with a certification of participation in the collaborative program. Physics, Chemistry and Engineering students attending together are exposed to the various points of view on optics, ranging from the pure to the applied sciences.

For the general public, we offer the Stoicheff Lecture, a yearly public lecture on optics, organized with the Royal Canadian Institute. Our institute also initiated Science Rendezvous, a yearly public celebration of science across the Greater Toronto Area, with lab tours, demonstrations, and other opportunities to learn about science and those who are actively advancing it. This year, this event attracted over 20,000 attendees.

KEYWORDS

Undergraduate education, graduate education, experimental methods, research skills, public outreach.

1. INTRODUCTION

The study of optics is a multi-disciplinary endeavour, requiring concepts of Physics and Engineering. Production of optical materials and devices also requires expertise in Chemistry and Materials Science. At the University of Toronto, the Institute for Optical Sciences (IOS) provides a common home for approximately 27 faculty members with an interest in optics from the Departments of Physics, Electrical and Computer Engineering, Chemistry and Materials Science and Engineering.

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Besides the research of its individual members, the IOS is active in the following three areas: contract research services for other academic and industrial users; promoting entrepreneurship and transfer of technology, acting as a bridge between university research and the industry; as well as an extensive academic program, which is described in detail below. Over the past 4 years, the IOS has helped launch 8 start up companies and numerous others indirectly through the *Entrepreneurship 101* course we developed that is now independent from the IOS.

The main goal of the academic program at the IOS is to make student education more complete and more efficient by complementing the resources available to students in their home departments. In addition we are active in public outreach, demonstrating the importance of optics and science as a whole to the general public.

2. PROGRAMS FOR UNDERGRADUATE STUDENTS

At the undergraduate student level we focus on accessible methods to teach optics, stimulating the students' creativity at the same time, and facilitating the students' access to the research labs.

We have recently introduced a holography course *Holography for 3D Visualization*, as a very visual method to introduce students to the science of optics, and as a bridge between the art and science communities. The course emphasizes both the art and science of display holography, enrolling both art and science students, with collaborating instructors for these components. Besides learning the course material, the two very different groups of students learn to communicate and work with each other on common projects. Recording their own holograms gives students an excellent motivation to study the optics of interference and diffraction, making optics accessible to students who would not normally study it. More details about the course are presented elsewhere[1].

At a large research university, the academic community divides its time mainly between teaching and research. Undergraduate students are very well acquainted with the teaching aspect, through their courses, but most of them are quite unfamiliar with the research activities. This is in spite of the fact that most professors do work with some undergraduate students in their research projects during the summer. Many students, however, do not know about these opportunities, since they are almost never well announced. At the same time, professors are reluctant to admit a large number of undergraduate students, due to the necessary time investment to make them productive in the labs. We facilitate undergraduate student access to the research labs by responding to both issues raised above.

To reduce the necessary time required, on the part of each professor or senior graduate student, in order to train new students for work in the research lab, we are running a yearly summer course called the *Research Skills Program*[2]. This is a non-credit series of seminars that summer students are encouraged to attend, running from May to mid-August. The goal is to cover the topics that are general enough to be needed by all, regardless of the exact research topic. We start off with a description of the scientific literature, and give examples of how to search it effectively. Then we continue with instructions on how to keep a lab book, the design of experiments, small signal and noise analysis, basic techniques in the optics lab, data analysis and interpretation, and patents. Emphasis in this course is also placed on effective technical communications, both written and oral. We consider the elements necessary to write a scientific paper and to produce a poster. Finally we give students the opportunity to practice formal and informal technical presentations. At the beginning of each class, two students are asked to give an informal 5-minute description of their work. In the second half of the course, students then give two formal presentations, in the style of a conference paper.

We normally get around 25 students attending the course each summer. In the absence of such a course, individual professors or graduate students would have to perform this training in much smaller groups (usually 1 or 2 students). Training in a larger class provides significant economies of scale. More importantly, however, the training is done in a more rigorous fashion, as opposed to the more ad-hoc instructions and explanations that undergraduate students receive from their supervisors. A further advantage is that we form a community among undergraduate students working on research. They are usually the most junior students in each research group, and may feel overwhelmed and intimidated by the expertise of more senior researchers around them. This weekly course gives them the opportunity to exchange information with other students who are in a similar situation.

In order to facilitate access to the university research for those students who would not normally consider such an activity during the summer, we actively collect and promote research project descriptions. Staring in January and February, we collect from professors project descriptions that are suitable for undergraduate students. The availability of the projects is then announced on-line, and through email to most relevant undergraduate programs. We also collect the student applications and do a first round of screening before distributing them to the individual professors.

In many ways, learning through research, compared to learning in courses, requires a different attitude and skill set. Problems are no longer guaranteed to have solutions. If they do, they may have multiple answers, with no clear choice between competing advantages. Projects can take several years to complete. Our Research Skills Program and related activities are helping students with this change.

3. PROGRAMS FOR GRAUDATE STUDENTS

The Institute for Optical Sciences has over 100 graduate students working on a variety of optics-related research topics in the labs of the professors associated with the institute. They are registered in either Master's or PhD programs in one of the four departments mentioned above. The institute is helping these students by encouraging them to take a more inter-disciplinary approach to their education and allowing them to take credit for doing so; helping them make connections in the global scientific community; helping them take better advantage of the available research equipment; and forming a community among optics students.

In the fall of 2008, the institute has introduced a collaborative Master's Program in Optics. At the University of Toronto, collaborative graduate programs are offered jointly by several departments. They study topics where no single department has the full expertise. This fits well with the way optics is covered at the university, where the Physics and Chemistry departments focus on the fundamental science of optics, while the departments of Electrical and Computer Engineering, and Materials Science and Engineering study the applications of optics in technology. These are the four departments that offer the collaborative program.

In this program, students first apply and register in their home departments and then additionally register in the collaborative program. Therefore, they must satisfy all requirements of the home program. The requirements of the collaborative program are that the thesis topic must be in optics, and that students take the seminar course *Selected Topics in Optics Research.* Upon completion, students receive the degree from their home department, with an additional notice on their transcript certifying the completion of the collaborative program.

The course required for the collaborative program consists of a series of seminars and student presentations. The seminars introduce brief practical topics that are useful for work in optics. Examples include best practices in the optics lab; numerical simulation tools for optics and electromagnetism; lens design and optical aberrations; signals and noise analysis. The remaining time in the course is devoted to student seminars. We invite senior graduate students to present their research topics. Given the diverse background of the students in the collaborative program, we keep the presentations to only 10 minutes. During each meeting we have 4 such presentations.

One of the many goals of the collaborative program is to create a community among the optics students at the University of Toronto. Coming from four different departments and two different faculties, these students do not have many opportunities to interact with each other. The collaborative program provides a setting where this can be done effectively. Students taking advantage of the resources available at the Institute for Optical Sciences will be exposed to multiple points of view on optics, and will acquire a more multi-disciplinary education. The certification of completion of the collaborative program gives them credit for this.

To connect the students in the global scientific community, we run a Distinguished Visiting Scientists program. We invite a number of world-renowned scientists to spend a week at the University of Toronto, giving a series of three lectures and interacting with the students and faculty. The extended stay allows the visitors to organize their lectures in the style of a mini-course, providing more in-depth technical detail than can be covered in a simple seminar. During the remaining time, the visitors will have open office hours where students can drop in with questions, and other meetings with graduate students and faculty.

Spending a full week in Toronto makes it possible for students to meet such world-class scientists personally, and to build their connections in the global optics community. Students regularly go to lunch or dinner with the visitors. This is in contrast to the standard 1-hour seminars, where speakers usually do not have time for more than a few meetings, mostly with other professors, and do not have much time to devote to graduate students individually.

One of the biggest challenges awaiting junior graduate students is the large number of instruments and experimental techniques that they must master in order to complete their work successfully. While some of the most common instruments and techniques are covered in undergraduate courses, most are never taught formally. Expertise is acquired slowly, from discussions with more senior students, and is often incomplete. Most standard graduate courses do not usually cover experimental techniques either, instead focusing on in-depth theoretical studies. This lack of familiarity with sufficient experimental methodologies increases the time to graduate and can often mean the difference between solving a problem or not. To help students acquire the necessary experimental skills of a successful optics researcher more quickly, the Institute for Optical Sciences together with the Department of Chemistry have launched a laboratory course, *Advanced Experimental Methods: Optics to Electronics*. The course is divided into three modules.

The first module consists of lectures complemented by simple experiments and measurements. Students learn how to use the standard data collection instruments, such as lock-in amplifiers and boxcar integrators, as well as an introduction to signal and noise analysis. They then perform various measurements of thermal and shot noise, and collect weak signals from a noisy environment. In the lectures on optics we cover topics on light sources and detectors, optical beam propagation and collection systems, along with standard techniques in spectroscopy, etc. Students practice by setting up spatial filters and interferometers, collecting fluorescence signals, and others.

In the second module, students are assigned projects that they must complete using the parts provided. Examples include assembling an ellipsometer from standard optical components, assembling a confocal Raman spectrometer, and setting up dynamic light scattering measurements. Here we encourage students to find the best solution by themselves with minimal guidance. As opposed to standard undergraduate laboratories, students must determine themselves the detailed procedure to follow. Some of the experiments are open-ended, with students encouraged to explore as many options as possible.

The remaining portion of the course is devoted to entirely open projects, where students propose an experiment and carry it through. The goal, again, is an independent exploration of various experimental techniques. Some students attempt to duplicate a complex setup from the recent literature. Others attempt new variations on existing techniques. During the last week of the course, students give presentations on their results. Examples of student projects are: building an optical parametric amplifier, measuring thermally-excited capillary waves, stabilizing an interferometer using a feedback loop and a piezo-electric transducer, or building an organic light-emitting diode.

4. ACTIVITIES FOR THE PUBLIC

In addition to the programs organized for our students, we organize two yearly events for the scientific literacy of the general public.

We organize the *Stoicheff Lecture*, named in the honour of Professor Boris P. Stoicheff, a preeminent spectroscopist. This is a one-hour public lecture on a particular topic in optics, delivered for the general public by one of the experts in the field. The event is organized every December, in collaboration with the Royal Canadian Institute, the oldest scientific organization in Canada, and attracts an attendance of approximately 400.

The Institute for Optical Sciences also initiated *Science Rendezvous*, a yearly public celebration of sciences in Toronto. Its main goal is to help the public see the importance of science, and to serve as a culture transformation from a science averse society to one that actively embraces the sciences. The event now has the support and participation of most universities and research institutions in the Greater Toronto Area. Each institution organizes public demonstrations and hands-on activities, lab tours, and others. To gain some appreciation of the potential and impact of this event, see www.sciencerendezvous.ca.

At the University of Toronto, a number of science and engineering departments participate actively. Some of the optics-related exhibits and demonstrations are as follows: a show of holograms, ray and lens optics, spectroscopy of various light sources, laser shows, polarization and birefringence, index of refraction and index matching, gelatin optics and total internal reflection, optical communications, liquid crystals. Additionally, a number of optics-related challenges and puzzles were set up for the public. Among them were a laser beam security and alarm system and a hologram containing hidden information, as part of a competition set to emulate saving the planet – of course through the proper use of science.

In May of 2009, the event attracted 10,000 attendees at the University of Toronto, and 20,000 in the Greater Toronto Area. Beside the direct benefit of allowing the public to see and learn what goes on at their local universities, the event gave several hundreds of student volunteers the opportunity to showcase their work and to demonstrate their enthusiasm and excitement for science to a very wide audience.

5. SUMMARY

The Institute for Optical Sciences at the University of Toronto organizes a number of programs and activities designed to complement the courses and research performed in the departments of Physics, Electrical and Computer Engineering, Chemistry, and Materials Science and Engineering. Various programs are targeted at University students at all levels, ranging from introductory optics courses at the undergraduate level, to advanced experimental techniques at the graduate level, along with means to connect the students in both their local and global community. Additional programs aim to improve scientific literacy among the general public. Together, these programs improve the student experience at the University, and make students more efficient in their work, both now and in the future.

REFERENCES

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