Session 2632

Design and Collaborative-learning in Lasers and Photonics Courses

Alexander N. Cartwright
Department of Electrical Engineering
State University of New York at Buffalo

Abstract

The growth of photonics technology (light emission and detection technology) continues at a terrific rate and is expected to be as high as 20% this year. At the same time, this increase in market demand for photonics equipment leads to a demand for skilled workers with hands-on experience. However, traditionally, Lasers and Opto-electronics have been taught as theoretical courses with very little applied work included. Here, recent efforts in converting the Photonics courses (Introduction to Lasers and Consumer Optoelectronics) at the State University of New York at Buffalo to include high design content will be presented. Specifically, a cost effective (only changes teaching style) collaborative active-learning environment, similar to a research environment, to stimulate student interest was implemented. This learning environment incorporates cooperative learning, experience-based hands-on learning, and the application of information technologies. In the first semester Introduction to Lasers course, students are required to design a laser system given a gain medium. The second semester course, Consumer Optoelectronics, offered in the spring, requires the design and implementation of an optical system that can replace current electronic systems. Moreover, these courses were designed to train engineers for entry into industry by emphasizing group efforts, active learning, and gender and race friendly learning styles. From the first two offerings of these courses using this style, it is clear that the students learned the material, enjoyed the course, and were enthusiastic about future optical design courses. Here, the qualitative assessment of, and some example design projects from, Introduction to Lasers and Consumer Optoelectronics, will be presented. Furthermore, a quantitative assessment of the methodology will be presented.

I. Introduction

The photonics industry is growing at a rate of approximately twenty percent per year and, more importantly, this growth is expected to continue for at least the next five years. Photonics, as opposed to electronics, is focused on the design of systems that can manipulate photons, instead of electrons, for signal and information processing. These photonic systems can be as simple as a single element imaging system to as complicated as a multi-element fiber optic communications system. Moreover, photonic systems are prevalent in today's information processing technology that includes such systems as fiber optic communications systems, CD-ROM's, optical scanners, displays, and laser printers. Unfortunately, with all the growth of this industry, most academic institutions have not embraced the education of a work-force for this growing industry. To date, the majority of the training in lasers and photonics is conducted at the graduate level. With the continued advances in photonics, the need for earlier training becomes essential. Specifically, little attention has been focused on the development of a cohesive program that teaches students the design issues necessary for undergraduate students to contribute in entry-level positions in this exciting market. This lack of educating students in photonics is quite perplexing since, for the most part, design principles taught throughout Electrical Engineering can be directly applied to the design of photonic systems.

Concurrently, student interest in physics related courses in Electrical Engineering, like photonics, materials, and fabrication, continues to decline. The author feels that this decline is partially due to the inability to engage the students in physics related courses in an exciting manner. That is, traditionally, physics related courses are taught as theory based lecture style courses. These courses are viewed as boring by the majority of students. In contrast, students in computer engineering (an area with growing student enrollment) can be successful and actively participating in their education from the very beginning, e.g., when learning to program they write a program and immediately see the results of their work.

It has been proposed (and implemented to some degree) that these physics related courses can be improved by including multimedia technologies, including some Web based materials, that enhance the student learning environment by providing virtual laboratories and lectures. Although these technologies can potentially provide an enhanced learning environment, they are expensive to establish and maintain, and, therefore, are not readily available. In addition, as pointed out by Wallace and Mutooni[1], merely presenting the material using WEB based learning does not guarantee students will use it effectively. Therefore, it is imperative that we not only modify the content of these physics related courses but we must modify the learning environment to make the courses both challenging and enjoyable.

Provided that it is possible to modify the course content and learning environment of physics related courses to actively engage students in their own learning, there is still an additional barrier to providing a cohesive undergraduate program in photonics. That is, the undergraduate curriculum in most Electrical Engineering programs leaves little room for students to investigate photonics. Fortunately, there is becoming more of a desire for schools to follow the example of Carnegie Mellon University and allow students to choose their senior level courses with little specific requirements from their Electrical Engineering program. At the State University of New York at Buffalo (SUNYAB) the author is active in modifying the undergraduate curriculum to allow students to learn in a highly diversified curriculum.

II. Modification of Learning Environment

It is with the above background that the author decided to change the archaic manner in which two of the existing photonics courses were being offered at SUNYAB. These courses were inherited by the author when he joined the faculty in the Fall of 1995. The two photonics courses, Lasers Electronics I and Laser Electronics II, were both taught using a traditional lecture style. Specifically, in both of these courses the theory was presented in the classroom and the students were assigned homework problems designed to teach the concepts of interest. It is well established that this teaching style is largely ineffective in motivating students and stimulating student interest because it does not provide the essential experience that one gains with experience-based (hands-on) cooperative learning [2,3]. Moreover, this teaching style tends to make students work in a more competitive or individualist environment that does not promote learning. Students focus more on how to get a good grade, rather than understanding, and helping each other to understand the material. It was clear that these courses needed to have the learning environment changed to allow these courses to have students excel in photonics.

However, any changes in the photonics curricula should be based on the general trends throughout the country. As mentioned earlier, the photonics industry is now providing turnkey laser sources that make it possible to make state-of-the-art technologies available at the undergraduate level. Therefore, students at the undergraduate level can and should contribute to the photonic industry as photonic engineers. Moreover, we have arrived at a point that the understanding of lasers and photonics can be taught without enormous amounts of math and physics because qualitative understanding can *precede* quantitative understanding. In addition, many companies are converting to a team-oriented work environment. Consequently, any teaching environment should teach interpersonal skills through classroom discussions and group projects.

Therefore, the two courses, traditionally taught as lectures, have been converted to design courses that incorporate pedagogical techniques that have resulted from engineering and science curriculum reform: cooperative learning, experience-based hands-on learning, and application of information technologies. These three techniques were central to the report from the Presidential Young Investigator Colloquium on "America's Academic Future" [4]. Even so, with a few exceptions [5,6,7], engineering courses have not embraced these techniques. However, two experience-based techniques have been used successfully in math and computer courses at the University of Wisconsin Eau Claire, RAQ (reading to answer questions) [8,9] and LAB (Launch, Activity, Build understanding) [10]. The curricula of these had to be reformed in to fully exploit these teaching techniques. Moreover, the curricula were updated and the courses renamed to Introduction to Lasers and Consumer Optoelectronics to fulfill student demand in these areas. Both of these courses will be discussed in some detail in later sections of this paper. As such, the photonics courses have been changed to design courses: the laser course requires the design of a laser; the consumer optoelectronics course requires the design of an optical device that replaces an electronic device (groups decide what to design). Combined with the incorporation of information technologies, these changes provide an excellent discovery-oriented environment to enhance student learning. Moreover, this active-learning environment, prepares students for industry by emphasizing working in teams, speaking and writing skills, and solving ill-defined problems [11].

Furthermore, the photonics courses have home pages on the WWW, encourage the use of email, and require the use of technical professional software. Taken together, these changes provide an excellent discovery-oriented environment to enhance student learning. More importantly, these undergraduate laboratory courses with high design content stimulate interest in materials, lasers, and physics (areas with declining student populations and student interest).

This learning environment has a number of advantages over using traditional lecture style teaching for teaching photonics. Specifically, with experience-based learning (active vs. passive learning) we are teaching students the basics and relying on laboratory/computer experience to stimulate an interest in theory. In this way, it instills the theoretical ideas more concretely by allowing students to design actual systems using the theory learned in class. In addition, the use of formal cooperative learning groups teaches the students the importance of group interactions and decision making strategies. This team-work prepares students for jobs in industry that rely on the cooperative interaction of many people within a group. Moreover, by requiring written and oral communication of design concepts and procedures we improve the student's soft skills. More importantly, this learning environment is designed to use the design projects and laboratory experiments to show the multidisciplinary aspects of lasers and photonics, i.e., some knowledge of computers, optics, controls, physics, chemistry and mathematics are essential in todays industry. Finally, we emphasize the use of information technologies (software, WWW) to enhance the learning process. Taken together, these advantages help to prepare the undergraduate students for either industry or advanced graduate work by teaching both independence and interdependence in a supportive collaborative environment.

Discussion Sessions

In addition to changing the fundamental operational mode of the learning environment for these two courses. We have modified the style of the lecture period within the classroom. Instead of the typical lecture that manages, mostly, to put students to sleep. The author has changed this to mostly discussion sessions. A typical discussion session course requires the students to actively participate in the lecture. It is important to emphasize that the students must participate in these discussions. The professor's role is to make sure that the class stays on track to achieve their design goal. In addition, the professor serves as a starting point for finding the necessary information/reading to answer the questions that arise in class. The cycle of an ideal discussion is as follows:

a) The professor launches the discussion, e.g. design a laser.
b) The class discusses the launch, in cooperative learning groups, and the professor suggest reading.
c) Laboratory experiments consisting of real experiments (in a laser lab) or virtual experiments on a computer are assigned to improve understanding. Upon completion of these experiments, we discuss the topics again to see if the experiments spurred more questions.
d) If the questions are related to previous readings, we return to those topics. If not, postpone the discussions and incorporate recently acquired knowledge into the design.
e) Once a discussion topic is included in the design process, we need to see if more information is necessary. If so, go back to (a).

Notice that in a design course, the discussion is re-launched each time a topic is changed. These launches consist simply of discussions of what is necessary to proceed with the design.

Goals of this learning environment

The major change in the teaching technique of these courses is to shift the emphasis from the teacher providing all information and hoping that students magically absorb the material to teaching students how to learn what is necessary. As such, the major goals of this teaching/learning environment are:

1. To teach students how to learn.

2. To teach students to work in team-oriented environments.

3. To emphasize and improve the students soft-skills (report writing and presentations) for reporting of progress on projects.

4. To teach the specific concepts for the course, i.e., a student should have some technical knowledge of lasers after completing the Introduction to Lasers course.

5. To teach students how to use technology to improve learning.

In summary, this learning environment focuses on shifting the burden of the learning effort to the student. The student feels that they are part of the process and, therefore, feel some obligation to prepare for the course. This sense of obligation is imposed by both their fellow group members and by themselves (peer pressure).

III. Specific Implementation: Introductions to Lasers

In this course the students design a laser resonator based on a given gain medium's specifications. Formal working groups of three to four students are established at the beginning of the semester. These groups work together on homework, projects, laboratories, and reports. In addition, in-class discussions use formal cooperative learning groups to address various aspects of the design process. Moreover, students are responsible for researching the literature, monthly reports (ten-minute oral along with slides), and a final thirty-minute oral and a final report. In conjunction with the design of the laser and in-class discussions, students performed experiments in the Laboratory for Advanced Spectroscopic Evaluation (LASE) at SUNYAB. These experiments are designed to investigate various laser phenomena. Significant use of computer resources, such as Matlab, Maple, or Mathematica, was required. Moreover, Java™ Applets are being developed to be used as some of the activities and laboratories. These applets are interactive, readily accessible on the WWW, and serve to prepare the students for laboratory experiments and to introduce and enforce theoretical concepts. To this end, we have developed a few educational applets that cover topics of interest: Photon Lifetime, Fabry-Perot Resonators, Cavity Stability, and Polarization of Light are available at http://www.ee.buffalo.edu/~anc/javaprog.html. These applets enhance the educational experience but are rather laborious to develop. Taken together, these experiments, computer simulations and discussions provided the necessary experience and tools to design the laser. Additionally, students learned to make tradeoffs and to justify their decisions.

In addition to the discussions, formal lectures were provided to keep the course on track. Therefore, a formal class syllabus with specific dates for homework assignments, computer simulations, and exams was provided. The exams were almost completely individual. However, one question from the midterm was a group question that was finished during the exam period. In this way, students still had to keep-up in the course to be able to perform well on individual exams and quizzes. Finally, to keep group members honest, students were allowed to evaluate and assign a grade to their fellow group members. The exact details of the evaluation of the students are provided below.

Projects

Student are required to design a laser systems based on a given gain medium. The group is allowed to decide the level of emphasis that is placed on the application of the laser, i.e., designing a laser for a very specific application. To date, the projects have included the design of Ti:Sapphire lasers, HeNe lasers, Argon Ion lasers, and Nd:YAG lasers. In addition, applications have focused on Barcode scanners, laser drilling, laser marking, and submarine detection. More importantly, students are required to complete the complete design, including computer simulation of laser modes, specifications for the mirrors, lens, and gain material. In addition they must provide a price estimate by obtaining pricing information for the purchase of the specified components from an optical company. In the past two semesters, the designs have been very professional. In the last offering of this course, students were required to submit the group final report as a web page. Examples of these reports can be seen at http://www.ee.buffalo.edu/~anc/ee492 and will be discussed in more detail during the presentation.

Student Evaluation

As shown in Table 1, student evaluation is based both on individual performance and group efforts. Notice that the total percentage exceeds 100% when we include the bonus group evaluations. Therefore, if your evaluations by your fellow group members are exceptional you significantly improve your grade. To date, the evaluations by the peers have been extremely consistent with the overall grade the student received in the course. Typically, the students are very capable of fairly evaluating their peers, even if they are very good friends.

Table 1: Percentages used for student evaluation for various components of the Introduction to Lasers course.

Quizzes (based on reading)	10 %	Individual and Group
Midterm Exam	15 %	Individual and 1 Group Question
Final Exam	20 %	Individual
Homework	10 %	Individual and Group
Computer Simulations	10 %	Individual and Group
Laboratories	10 %	Individual and Group
Group Design Projects	15 %	Group
Group Presentations	10 %	Group
Group Evaluations	Bonus 10 %	Group

IV. Implementation: Consumer Optoelectronics

This course is a more open-ended photonic design course. The students, working in groups, design new products using photonic devices as building blocks. The lectures consist of presentations by the students on various optical systems, e.g., CD-ROMs, Laser Drilling, Display Technology, Optical Non-destructive Testing. The learning environment is the same as the

Introduction to Lasers course. This course has been significantly changed since its initial offering and this spring semester will be the first semester that contains enough students for a fair assessment (16 students).

V. Observations

In the past two offerings of Introduction to Lasers, there have been fourteen and thirteen students. This number of students makes any statistical assessment method unreliable. However, the author did notice some excellent results of the change in teaching style. The students find the course more appealing and the class attendance is generally excellent (in general less than two students will miss a lecture, most frequently all students were present). In addition, the lecture/discussion periods, based on student feedback, were fun for both the teacher and students. In both semesters reviews, a number of students pointed to the, to quote some of the reviews, "free and open discussions during lectures", "flexibility in course material", "a good atmosphere in class". In addition, the students felt some sense of duty to the course, as evidenced by one student: "I didn't have the time to fully devote myself and explore more deeply."

At the beginning of the course, students are typically reluctant to talk and participate in the discussions. As the semester continues, the students become more comfortable with this style. The biggest challenge for the professor is to act as a facilitator and try to steer any discussions toward the topic of interest. Of course, these discussion sessions do not proceed in the same manner as the ideal class session discussed above. The author had to resort to formal lectures in order to cover some specific details. However, in those cases the author tried to limit the amount of time of sustained lecturing. Students were encouraged to answer questions, state the necessary steps or give an expected answer to the questions based on previous experience. This allowed the lecture to be broken into shorter time periods. Furthermore, students were allowed to deliver some of the lecture material.

It is interesting, that before the beginning of the semester, the author had decided to sacrifice the amount of material studied in the course for a better understanding of less material. In addition, for the second semester of teaching Introduction to Lasers, a new textbook that was designed for a senior level course was used. Two surprising things happened. Firstly, in both semesters we covered about the same amount of material as in previous lecture style courses. Secondly, students were extremely critical of the textbooks. I think that this criticism is partially due to the fact that most textbooks are written for lecture style courses and, therefore, do not allow for a free flowing idea exchange.

In my opinion, the students not only had a good grasp of the concepts. As should be expected with any group-oriented course, no one fell too far behind in the course to become completely lost. In general, the students performed extremely well.

Finally, the author must admit to making a big mistake by allowing the students to choose their own groups in the first offering of this type of course. This resulted in one group containing the best students in the course (based on GPA). However, in the next semester, the author used the techniques for choosing effective groups discussed by Hunkeller and Sharp[12]. In particular, students were assigned to groups in such a way as to make the groups as heterogeneous as possible.

VI. Assessment

The complete assessment of this technique is very difficult because of the small class enrollment. In addition, this style of course requires that the professor be completely prepared for lecture. In fact, the professor is opening himself/herself up for questions that they are not prepared to discuss. It is planned to conduct a complete assessment of the next offering of both courses following some of the procedures presented by Demetry and Groccia[13].

VII. Summary and Conclusions

In this work, we present a change in the pedagogy used in classrooms for more physics oriented courses in electrical engineering. This new learning environment emphasizes hands-on learning, collaborative learning, the use of information technologies and design issues. Based on the experience in the past three semesters, the technique is successful at stimulating student interest in photonics and materials. In particular, the second semester course has seen a doubling of enrollment (eight students in Spring 1998 and sixteen in Spring 1999). This increase is partially attributable to the new learning environment as well as the students becoming more aware of the multitude of consumer products that use photonics.

At the end of the courses, the students are capable of answering conceptual questions of lasers and photonics. However, this course was too small to base any significance to the perceived differences in the learning and understanding of the concepts. In addition, the author may have been biased by his desire for the technique to be successful. Finally, based on the enjoyable experience of using this technique for three semesters, the author hopes that others will try to employ this learning environment in their course.

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ALEXANDER N. CARTWRIGHT: Alexander N. Cartwright received his Ph.D. from the University of Iowa in 1995 and has been an Assistant Professor at the State University of New York at Buffalo since August 1995. In 1998, he was fortunate enough to receive a NSF CAREER Award that supports his research and educational activities. He is active in curriculum reform and devoted to the education of students through research activities. These research activities include the study of GaN based optoelectronic devices and optical non-destructive testing.