AC 2011-2203: INTEGRATING CURRICULUM, INSTRUCTION, AND ASSESSMENT IN A LASER SYSTEMS COURSE

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Integrating Curriculum, Instruction, and Assessment in a Laser Systems Course

Three inter-dependent elements undergird effective teaching and learning in STEM educational settings: curriculum (content), instructional practices (pedagogy), and assessment[1]. These elements should be explicitly linked as educators design courses and educational materials. Norfolk State University established Bachelor and Master of Science programs in Optical Engineering in fall 2003. Optical Engineering is an emerging discipline that bridges Physics and Electrical Engineering principles, and currently only five ABET accredited Optical Engineering programs exist in the U.S. As a newly developing area, the curricular structure of U.S. Optical Engineering programs are somewhat fluid, including a clear understanding of the challenges students face as they move through the optical engineering curriculum.

Faculty researchers at Norfolk State University have launched a project to better understand common misconceptions of students as they matriculate through the undergraduate optical engineering program. The effort has begun with a third-year course on laser systems. The NSU lasers course represents the first opportunity for students to learn and understand how a practical optoelectronic system operates, and the course also features an emphasis on design. Many students experience difficulty in the course based on factors such as unfamiliar jargon, and the course is a re-visitation of several principals that have first been introduced in their freshman year Physics course, but may not been strongly reinforced during the second year curriculum. Others struggle with the overall complexity of the course, which discusses multiple physical processes that occur simultaneously. Interdependent and dynamic processes related to the interaction of optical energy with a gain medium and situated within the confines of an optical resonator (i.e. the laser cavity) are discussed. Understanding how the laser cavity and gain media interact to produce a definable optical output signal that is dynamic and readily subject to multiple environmental conditions is arguably among the most difficult challenges that the students may have encountered as they enter the third year of the curriculum. Add to this the challenge of performing while using an unfamiliar vocabulary laced with terms such as population inversion, mode space, absorption band, gain profile, and homogeneous and heterogeneous broadening, and there is no surprise that many struggle during the first several weeks of the course.

This paper introduces a set of factors that have emerged as challenge areas based on a two-year study of student performance and on the four year experiences of the author. The results are preliminary and should be interpreted as proposed areas for which students may experience difficulty. An on-going review by a faculty team will provide a broader perspective and is expected to introduce additional areas, as well as to refine, improve, or repudiate the current inventory. Detailed results of the faculty surveys should be available in summer 2011.

Student Profile

The students that have participated in this study are third year students in the Norfolk State University optical engineering program. The lasers course is offered in the fall semester of the third year curriculum. The pre-requisites for the lasers course include a two-semester sequence in Physics, a two-semester sequence in geometric and physical optics, and four semesters of math (three semesters of calculus and differential equations). It should be noted that the students are not scheduled to take an Electromagnetics course until the spring semester of the third year. Although not an official pre-requisite, the students typically have completed a semester in chemistry, a two-semester sequence in electronics and circuit theory, and a course in materials science before they begin the third year of the Optical Engineering program.

The discussion presented here is based on interview and survey data taken across two academic years, and the student sample size is 17. The surveys and interviews were done after the course was completed, and soon to be analyzed results of a pilot concept inventory will be published in an upcoming paper.

Language Barriers to Learning About Lasers

The term language is here used to describe words and symbols. It is interesting to note that a National Academy of Engineering panel cited English proficiency as a core challenge for many students wishing to learn science and math principles[2]. This citation acknowledges that as students process the technical information, they learn best (or at least better) using words (language) with which they have familiarity. A short survey of the introductory sections of several laser theory textbooks reveals two levels of interpretation that students are asked to navigate: unfamiliar terminology, and to a lesser degree, unfamiliar notation. Specifically, students are asked to learn several new terms, and they are asked to expand the range of contexts that apply to specific terms. Expanding on this idea, this effort has also considered the expanded use of symbols that occurs in the lasers course, and a few observations related to the application of new or unfamiliar symbols is discussed.

Before a discussion of challenges is presented, the research team notes a few things that optical engineering students agreed were helpful about their previous coursework. Optical engineering is a hybrid between electrical engineering and applied physics. The NSU optical engineering students complete a two-semester sequence in optics and a semester of materials science before they reach the lasers course. Based on these courses, there are a few terms that were not considered new or confusing by the students surveyed for this paper. These include reflection coefficient, reflectance and reflectivity, crystalline structure, conduction and valence bands, photon, and optical transformation matrix.

Two general types of language challenges are discussed. The first is the case of using a new symbols to represent a familiar parameter. Consider the case where a person may have previously been asked to represent the parameter, frequency, using the letter f or ω. In most cases, laser textbooks use ν as the symbol for frequency. It is not considered difficult to begin using ν, rather than f, as the symbol for frequency. However, it does mean that a familiar cognitive pathway is now being interrupted, and a different symbol is now being added to the list of symbols that represent frequency. By observation, it may be as long as three or more weeks before students change their notation in homework samples to reflect the new convention. On occasion, some students maintain their original preference throughout the semester. It is striking that this occurs in some, and not others. And this effectively raised the question of how this impacts the learning experience. Results from student interviews did support the suggestion that students experience an internal process when they make the transition from f to ν, but no effort has been made to further quantify or describe this or similar experiences. It also has been noted that students in their second year courses run into this same scenario. However, the total number of language challenges experienced in second year courses is not considered to be as significant as those experienced in the lasers course.

A second wrinkle that may exist for optics students is the recognition that the letter, f, may frequently be thought of as a symbol to represent the focal length of an optical component. Given the fact that NSU optical engineering students complete a full year of courses in geometric and physical optics just prior to their matriculation in the lasers course, their experience may be more complex than would be the case for a traditional electrical engineering or applied physics student.

Another type of language challenge is the large number of new terms that students must utilize in the lasers course. Learning new terms is core in a learning experience. It does however introduce a modicum of work and is therefore a factor to be accounted. Table 1 below lists the terms that more than 70% of surveyed students felt were confusing or unfamiliar.

Table 1. Language Related Challenges That Students Agree Upon

Challenges Cited by Students
Use ν, rather than f or ω, to represent frequency
E is used to represent both energy and field amplitude.
ψ is used to represent the wave expression rather than an angle, and what exactly is the wave expression
Bandwidth, linewidth, and FWHM are used interchangeably, but they can represent very different things
Confusing or Unfamiliar Terms Cited by Students
Linewidth vs Bandwidth vs FWHM
Free Spectral Range
Gain Profile, Gain Saturation, and Gain Cross-Section
Longitudinal and Transverse Modes
Homogeneous and Heterogeneous Broadening
Rayleigh Range
Spontaneous and Stimulated emission or absorption
Blackbody Radiation and Spontaneous/Stimulated Radiation
Spectral, Spatial, and Temporal Coherence
Finesse and Q-factor
Etalon
Population inversion
Constant phase surface

The final language related challenge noted in this work is the use of a similar symbol to represent a parameter in multiple contexts. For example, the term linewidth is in laser theory applied to the gain profile of the laser media, the detailed transmission spectra of a resonant mode for the laser cavity, and the actual spectra of the laser signal. In the case of an optically excited (optically pumped) laser, the term may also be used to describe the spectral range over which the input energy for the laser system exists. Moreover, the term linewidth may be replaced interchangeably by the terms FWHM (full-width-half-max) or, less frequently, bandwidth. Here again, the student may a priori have already established a term that they associate with this parameter. Adding new terminologies further adds to the puzzle of words, ideas, principles, and hard and fast rules that students interpret and apply.

Cumulatively, all of the above factors form a context that students often describe as confusing, frustrating, or overwhelming. These experiences are real for the student, and even if the instructor is unfazed by this student-centered challenge, the motivation to understand how to best function within this context has been an important driver for this effort.

Common Misconceptions about Laser Theory

The research team has drafted a list of misconceptions that appear to be a challenge to a rigorous understanding of laser theory. The misconceptions are being reviewed by a broader team through the use of a Delphi survey instrument and available results will be presented at the meeting. The common misconceptions may exist as the students enter the lasers course and may therefore influence their interpretation of how processes occur in physical systems[3, 4]. As is the case with any misconception, the instructor may need to complete specific activities to expose and appropriately challenge the misconception as early as is reasonable.

1. Students may believe that emission of a photon (by stimulated or spontaneous emission) will only occur when an excited electron carrier is destroyed.
2. Students may believe that by defining a specific resonant spatial mode (e.g. TEM_{00} or TEM_{01}), you have also defined a specific spectral mode (wavelength)
3. Students may believe that by defining a specific spectral mode (wavelength), you have also defined a specific spatial mode (e.g. $TEM_{m,n}$)
4. Students may not recognize that a constant phase surface may or may not be co-incident with the physical surface (or screen) that reflects a beam.
5. Students may believe that a constant phase surface must also have a constant intensity.

A pilot concept inventory instrument has been developed using approaches developed in previous inventory efforts[5]. The tool is being used to measure the impact of the course on student understanding in the areas outlined above. Additionally, a teaching module relating the familiar concepts of conservation of energy and mass laws to light and matter interaction processes has been implemented in the NSU lasers course. This is being done to help clarify students' understanding of what happens to electron carriers during spontaneous and stimulated emission events. Finally, an open-cavity laser experiment has been implemented as a core activity in the companion lasers laboratory course. The activity is being done to clarify links between laser spectra and spatial mode characteristics. Available results of the focus group interviews and a Delphi survey will be presented at the meeting.

Conclusion

This paper describes preliminary results of an effort that links curricular structure, instruction and pedagogy, and assessment. The overall goal is to achieve enhanced understanding of principles in laser theory. Along the way, the author hopes to identify key challenges to achieving the desired learning outcomes, and a set of strategies to attack the identified challenges. The results to date include a recognition of language barriers, and the identification of a few specific principles in laser resonance theory. Specific instructional strategies are proposed and active pedagogical approaches in a laboratory setting are on-going. A tailored assessment instrument is also in a pilot phase.

References

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