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Abstract

Optical engineering has existed as a specialty within electrical engineering, physics, material science, and other academic departments and as a significant industry focus for over 70 years. For most of that period only a few degree-granting programs existed in the United States, with the first at the University of Rochester in 1929 and the second at the University of Arizona in 1964. In the last thirty years, however, eight additional degree-granting programs in optical engineering or optics and photonics have been established. Documenting the development of these educational programs in optics has not been completed, yet such an endeavor would yield valuable insight on the emergence of this interdisciplinary field. This paper will review the degree-granting optics programs in the U.S. by tracking the history of their development and comparing curricula.

Data for this synthesis of information about American optics programs has been collected through web search, literature review, and information available from the Optical Society of America and SPIE’s optics education website as well as interviews with program leaders. To limit the scope, only departments and programs that offer degrees specifically in optics and photonics or optical engineering are reviewed. Similarities are revealed in course offerings and research specialties within these departments. Through this initial review of program development in the field of optics, we identify patterns of how this interdisciplinary field has grown with inputs and outcomes in physics, engineering, and the sciences.

I. Introduction

Some of the world’s best optics and optical engineering programs have been established and grown in scope significantly in the past twenty to thirty years, but little research has been completed on how they developed. Some of the programs have a track record of producing papers about their departments along with curriculum and education-based information about their programs while others have little or no widely available work about their program. Also, there are not any current overviews about all of these departments. As many of the grand challenges for engineering are highly related to optics and optical engineering, this critical body of knowledge will remain instrumental through the 21st century. Even the Popular Science listing of the 100 innovations of 2010 includes many technologies made possible through optics. The only question remaining is how are people learning these critical technologies; in other words, what pedagogies are being used to train the innovators who will answer many of the engineering questions facing the next generation?

While optics and optical engineering studies and research are often housed in physics and electrical engineering departments, our web study has found eleven degree granting programs in optics and photonics or optical engineering. Understanding these programs’ development, goals, and curriculum provides insight on this group of scientists and engineers who have become
increasingly valuable in the modern world. In addition to offering an uncommon degree option, the faculty who make up these departments are uncommonly interdisciplinary in their own backgrounds. Through examination of eleven programs, we (a) explore the establishment timelines, similarities and motivations for the departments, (b) diffusion of optics education (c) examine the faculty backgrounds and (d) describe curricular approaches. This framework describes optics education as an alignment of multidisciplinary perspectives for developing an interdisciplinary field. Interviews were conducted with seven department chairs or other representatives of the programs to add additional depth and perspective about the programs’ establishment as well as understanding the current status of the departments.

II. History of Optics Programs

The first optics education program was established in the United States at the University of Rochester through a corporate grant from Eastman Kodak and Bausch and Lomb with two primary objectives. First, the program supports “the training of students in the theory of optics and optical instruments so that there may be an adequate supply of men versed in theory and skilled in the design of optical instruments” and preparing optometrists and ophthalmologists 7, 8. With these two initial objectives of the first school of optics, the frequent question asked of modern optical scientists and engineers related to eye health is not too far off. The first objective pertained mostly to optical instruments that included camera lenses, microscopes and telescopes in the late 20s and early 30s. As the field became increasingly advanced, especially with the invention of the laser in the 1960s, the field of optics completely changed and would revolutionize the rest of the twentieth and twenty-first century in radical ways.

_A Jewel in the Crown_ 7 documents literally the first forty years of optics education in the United States, but the decades that would follow are equally interesting. Rochester’s first competitor did not come on the scene until the 60s at the University of Arizona, then ten additional departments or degree granting programs would follow. Figure 1 shows a graphical timeline of the emergence of departments, with the greatest spike in the 1980s. The programs in the 1980s included the first associates degree program, as well as one of the first bachelor degree programs. In interviews, several department chairs stated that many of the programs rarely recruit graduate students whose academic background is in optics, but most often from physics and electrical engineering. As the bachelor level programs have emerged, more graduate students are staying in the discipline for graduate school, yet many also switch over to physics and electrical engineering. Figure 2 shows a graphical representation of associate, bachelor, master, and Ph.D. degree granting programs. Of the eleven institutions reviewed, nine offer more than one level of degree in optics, with the most overlap in master’s degree offerings. Only three of the programs offer all degrees (bachelor, master, and Ph.D. degrees), and only two offer both bachelor and master level degrees.
In interviews conducted with many of the department chairs common motivating factors for the establishment of their respective departments were discussed. Industry influence, or in the case of one department, military needs, were the primary motivation for degree programs in optics. External impetus, funding opportunities, and excellent industry relationships, were similar founding factors which most departments took full advantage of. Labs are often funded solely by industry; students gain professional experience by working on industry projects and internships at companies closely related to their academic departments. Faculty also collaborate with industry peers on a regular basis in optics departments. Due to the close relationship between optics technology companies and the academic programs, funding is rarely a limiting factor, which also has a significant influence on research focus. Many of the department chairs
identified a greater need in their programs to seek funding or engineering research centers from the National Science Foundation. Many also have research relationships with the Department of Defense.

III. Diffusion of Optics Education

With so many opportunities within optics many wonder why there are not more degree granting optics programs in the US. Interviews with the department chairs allude to overall comfort with the size of the discipline. As even the “famous” departments must work to actively recruit students. Changes are also made to the curriculum to produce competitive students, especially those who may not continue to the Ph.D. level. Diffusion of Innovations\textsuperscript{10} provides some perspective as to why this may be. In the first chapter Rogers describes four steps for a new idea, to become widespread and accepted. The four main elements are the innovation itself, communication, time, and a social system.

If formal, degree granting, optics education is considered an innovation, then needs such as advantage, compatibility with current values, complexity, trialability, and observability come into play. For optics education, advantage over physics or electrical engineering and the compatibility of values for faculty and students in those departments is important. Complexity or factor of unfamiliarity is one that optics has struggled with for decades. Those who identify themselves as optical scientists or optical engineers often find themselves explaining what it is that they actually do. As mentioned before, it took thirty-five years for a second optics program to open in the US, and still eighty years later there are only 11 degree granting programs which indicated some challenges with trialability that Rogers mentions. Experimentation with the output of graduates of optics programs has been done for the entire duration, but with good results. A quick keyword search on Monster.com\textsuperscript{11} using “optics” yields over 1,000 job results, along with hundreds of job postings from optics related professional organizations and companies. Additionally there are many jobs that may not be labeled optics that optics graduates are qualified for. While demand exists for those with optics knowledge remains, hesitation for universities to establish more of these programs exists. Interviews also describe the tension within academia for establishing new departments, and the challenges placed on some of the degree granting programs that are forced to work between two departments or even colleges. Program chairs experiencing these challenges expressed need for separate departments to provide priority for optics work, and allow for the necessary depth for students being trained in the discipline. Similar limitations include physical space, financial and human resources, curriculum offerings, and autonomy within the college.

Communication of optics programs likely is influenced by homophily “the degree to which two or more individuals who interact are similar in certain attributes\textsuperscript{9}.” Interviews uncovered a qualitative consistency among faculty and students in optics: many of them shuffle professional time or earn degrees from the same few departments. Even advisory boards of departments represent the same institutions. Rogers says “the nature of diffusion demands that at least some degree of heterophily be present between the two participants in the communication process\textsuperscript{9}.”
As many of the graduates and faculty circulate between the same schools, there is limited opportunity to expand outside of the discipline. This could be a major limiting factor for the overall diffusion of optics education. Communication of optics and optics education greatly inhibits the enrollment of students at the lower levels. Of the associate and bachelor level programs interviewed, recruitment including outreach events and involvement in first year courses are critical to enrolling students, yet most programs are still relatively small compared to the physical sciences and traditional engineering departments. In interviews it was suggested by department chairs that optics is a discipline that undergraduate students are more likely to switch into due to the interdisciplinary nature of the field.

Students must “switch in” to the discipline due to the relatively low number of undergraduate programs and graduates in optics and the larger number of graduate level programs and enrollment. While optics is a relatively larger field, the same argument can be made for engineering education. Like optics, engineering education relies on content and foundation in different disciplines. With limited degree granting programs in engineering education, like optics, individuals who are a part of the field “switch in” and utilize content knowledge from their home disciplines in a new area.

IV. Curriculum Comparison

Similar to other science and engineering disciplines, optics programs require a solid background in the physical sciences and mathematics. All of the graduate programs reviewed require an undergraduate major in science or engineering and the structure of the undergraduate optics programs are similar to science and engineering programs. In interviews, one reason consistently offered for the limited number of bachelor level programs in optics is that a very large amount of coursework would be required to prepare students to enter the optics workforce. There are five undergraduate ABET accredited optical engineering programs in the U.S., with the first achieving accreditation in 1998, and the remaining between 2002 and 2006\textsuperscript{11}. The only ABET accredited optical engineering technology program was accredited in 1995, although it had been in existence for nearly 20 years before. Due to the relatively unfamiliar territory of optics education, SPIE, one of the optics and photonics societies, joined ABET to add professional perspective on accrediting these departments\textsuperscript{12}.

When looking at the whole group of optics education programs in the U.S., there are some definite areas of competence both in curriculum and research. A web search of department program offerings and interviews are the primary data sources for determining the areas of specialty. There are three “powerhouse” departments that teach and do research in all areas of optics, which also are the largest departments. Of the eight remaining departments, optical science, optical communication, and optoelectronics are core parts of the curriculum. Although we do not suggest that any of the other departments do not have some offerings, only two of the remaining departments show consistent coursework and research in biophotonics and imaging. Within these areas of specialty there is definitely a range between science and engineering, and
links to other disciplines, which we hypothesize acts as the magnetic link that attracts people to optics.

Optical sciences, which is mostly related to physics study, is more concerned with electromagnetic, geometric optics, and quantum optics. Optical sciences are more concerned with understanding and utilizing the natural behavior of light. On the other end of the spectrum is optical engineering, which is focused on system design using optics knowledge toward applications. On this end, fiber optic communication, optoelectronic devices, lasers, and imaging are found. Many participants in this type of work are often electrical engineers, or engineers representing other disciplines that may use these technologies in their work. Very often environmental, mechanical, and materials engineers and with researchers seeking medical applications of the technology work in these areas. Biophotonics, spectroscopy, and nanooptics tend to lie in the middle of optical science and engineering, and reach to other disciplines especially biology, chemistry, and materials science. These bridges between optics and other disciplines demonstrate the interdisciplinary nature of the discipline. Students earning degrees with focus on the middle range of optics research also take courses in the relating disciplines to create a more solid foundation for their research.

V. Faculty Background

Another interdisciplinary feature of optics is the academic background of the faculty in optics departments. With limited options for earning a Ph.D. in optics, individuals trained in related disciplines are generally the faculty making up optics departments. The most frequently occurring doctorate degree among optics faculty is electrical engineering, followed closely by physics. Final reviews of the over 225 faculty in optics departments will provide exact percentage of disciplinary representation in optics education.

In interviews with department chairs, it was found that recruiting of faculty was also a question that brought similar answers among institutions. Many of the traditional methods of recruiting faculty used in other disciplines, such as conference postings and advertisements are utilized in optics conferences and publications. One consistent topic was also the need for post graduation experience before hiring a faculty member in optics departments. Most of the departments expect and require industry, postdoctoral or other research experience for a candidate to be considered qualified. This external experience is considered highly valuable in order to be a productive researcher in the department. Additionally, these industry relationships are utilized by new faculty to start up their research in academia through former employers. One particular department chair also emphasized the diversity challenges in optics hiring. Departments tend to struggle to find candidates female candidates and diverse candidates. Challenges in recruiting diverse faculty is also reflected in recruiting graduate students. Another common occurrence among departments interviewed is joint appointments within optics and some other related field.

VI. Future work
This paper represents some of the preliminary steps in a longer study to include an evaluation of students in optics, bibliometric review of optics pedagogy, international perspectives on optics education, and comparison study between optics and engineering education. The guiding hypothesis of the overall work is that optics is an interdisciplinary discipline and has a similar growth and development pattern to other interdisciplinary disciplines. The next phase of research will survey and interview students and faculty at the eleven departments of optics, and those who may identify with optics. The goal is to understand the trajectories and disciplines that brought them into optics as well as position their academic and research interests in the major areas of optics. In the undertaking of this study it was apparent that there are very few publications in optics education or engineering education about optics. Most of the existing works are conference papers. This portion of the study will categorize optics education pedagogy and research, and evaluate the influence of engineering education on optics. As many of the departments are newer, we suspect that there will be evidence of scholarly teaching and engineering education related themes integrated into department cultures. A section will also be dedicated to the international optics education community. As with many of the sciences and engineering there is a large international presence in this field, and interviews with department chairs have suggested that there are key differences in cultural views of optics that influence education and research in their departments. Engineering education is widely accepted as an interdisciplinary field, so comparing the histories and trajectories of these two disciplines and any overlap will also be included in the larger study.

VII. Conclusion

This study showed optics on a surface level to be an interdisciplinary field. Although recognized within optics, this documentation is an important step. The interdisciplinary development of the programs was largely motivated by interdisciplinary technological needs, and the multiple disciplines and training perspectives of the faculty that comprise these departments is unlike most other fields. In understanding the culture of optics, it is important to recognize that industry relationships are vital in establishing, maintaining, and training optical scientists and engineers. Industry provides external sustainability, which also differs from many other engineering and science disciplines. These characteristics together paint optics as a much more interdisciplinary field, which also relies heavily on and provides technology to a wide variety of fields such as chemistry, materials science and engineering, nano-science, physics, electrical engineering, and medical areas.


