Creation of a technician education program in laser and precision optical technology at Pasadena City College

Brian Monacelli *[a]
[a] Pasadena City College, 1570 E Colorado Blvd, Pasadena, CA 91106

ABSTRACT

An Associate of Science Degree is essential for technical students who seek applied, hands-on employment in the technical workforce after education at a community college. Pasadena City College administration has stepped up to work with experienced faculty to create a program in Laser Technology that is based on tested, industrial skill-driven curricula. This paper will discuss the foundation of this Laser Tech Program and its guidance by its many industrial advisors.

Keywords: technician education, applied education, hands-on skills, associate of science degree

1. INTRODUCTION

In order to create any technical components, build any cutting-edge systems, or develop any commercial products, companies need employees with applied skills who are good with their hands and able to read and enact intricate technical procedures. In order to motivate new students to seek such employment in technical fields, competitive compensation for challenging tasks is essential. Students require respectable salaries after working hard to hone their technical skills, and their compensation should begin with an Associate of Science (AS) Degree.

Based on a laser and electro-optics technology program that has been developed over the past few decades at Irvine Valley College, Pasadena City College (PCC) administration now employs experienced faculty to grant students an AS Degree in Laser Technology, now approved by the State of California. This program is based on tested curricula in lasers, photonics, and precision optics that were developed in partnership with the National Science Foundation (NSF) and industrial advisors, teaching techniques derived from industry skill standards. Laser Tech faculty is partnering with many industrial advisors to help establish and guide this Laser Tech Program at PCC so the next generation of the optics workforce is ready to assemble and align novel optical systems.

This paper covers the rich history and development of this program at IVC, ongoing partnerships with industry, ongoing funding via the NSF, and the transfer of this program's curricula and industry-grade equipment to PCC.

2. CREATING AN EDUCATIONAL FRAMEWORK FOR LASER TECHNICIANS

2.1 Initial work in Laser and Electro-Optics Technology Education at Irvine Valley College

In 1989, professors at Irvine Valley College (IVC) began to teach hands-on courses covering optical technologies, including the use and maintenance of lasers, the polishing of optical components, and the measurement of optical system performance. The initial for-credit Laser and Electro-Optics Technology (LET) courses included an *Introduction to Optics* course, followed by courses in *Geometric Optics*, *Lasers*, and *Advanced Topics*, the latter of which is a course to be modified based on modern technologies. All courses used industry-quality hardware in their academic labs, and course structures were motivated by apprenticeships and on-the-job training techniques that were often used in Germany and other technically advanced nations, but not often seen outside of vocational schools in the United States. Laboratory exercises were conducted by Standard Operating Procedures, just like those an employee would use on the job. Under this teaching modality, students arrived at class to interact with the same tools and processes they would be using on the job.

The LET program had advisory board members from Newport Corporation (now MKS), Melles Griot, Ford Aeroneutronics, McDonald-Douglas, and Rockwell International, among others. Corporations supplied some funding, and often lent hardware and support staff to help teach courses. Although the full-time faculty had substantial industrial

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*BMonacelli@Pasadena.edu

experience, employed technicians were hired to adjunct faculty roles, so that specific skills could be taught by the masters of the craft. That is, optics polishing was taught by a master optician—it is an understatement to say that this precious skill, in particular, cannot be learned from a textbook. Academia also participated in this educational effort as staff from University of California, Irvine and California State University, Fullerton offered teaching support.

Hardware included basic lasers and optics, as well as a 1-kW carbon dioxide laser-welding system, a 1-W Argon-ion laser, a computerized imaging MTF-measurement system, optical polishers, and four laser-safe rooms. To bolster this hardware-intensive curriculum, assets were shared among astronomy and physics courses at IVC, and enrollments were as high as 25 students per class.

However, no lab technician was hired to support this academic hardware, and there was no significant advertising or marketing budget, so the program declined in enrollment when the laser-safe rooms were converted to lecture halls.

2.2 Light work in education under the Center for Applied Competitive Technologies (CACT) grant

Corporations departed Orange County during the 1990s, and for-credit LET courses were cut due to enrollment quotas imposed by the college. Technical courses survived by moving to a fee-based model, offering courses to specific industry partners on a contract basis.

The early 2000s brought Center for Applied Competitive Technologies (CACT) grants, under which *a la carte* contract-based courses were taught directly industrial partners including Raytheon, Massimo, Newport Corporation, Oakley, and others. Instruction was held at the Advanced Technology and Education Park (ATEP) campus of IVC. Courses were taught in laser systems, optical interferometry, optical fibers, Zemax, SolidWorks, LabView (with applications in optoelectronics), and even holography (based on student demand after learning about a professor's experience in captivating undergraduate holography workshops at Rose-Hulman Institute of Technology).

These courses were targeted and practical; they used the same industrial hardware that had been used during the earlier days of the LET program, as they helped raise public awareness of the applied education happening at IVC. Additional hardware was donated by industrial partners and procured via the grants, including a general-purpose phase-shifting Zygo interferometer with a radial slide accessory, which is still a critical instructional tool in this curriculum.

2.3 Earning the attention of the National Science Foundation (NSF)

In 2011, representatives of the NSF's National Center for Photonics and Optics Education (OP-TEC) and Schott Glass approached the remaining Laser Tech faculty member for multiple purposes. Foremost, they conveyed that technician workforce in optics was declining, as many would be retiring soon, and few schools were training younger generations. They encouraged the reestablishment of for-credit courses, certificates, and an Associate of Science degree in laser and optical technology. Faculty worked with the IVC curriculum committee to adapt the OP-TEC materials into two fundamental courses in optics: *Introduction to Light and Lasers* and *Fundamentals of Photonics* (later renamed *Optical Devices*). Both of these courses, as well as the other courses in this curriculum, are detailed in a later section.

The NSF OP-TEC representatives also encouraged IVC to apply for a small college Advanced Technological Education (ATE) grant. This led to the *Irvine Valley College Photonics Initiative* [1] (NSF award #1304102), which was written efficiently, submitted to the NSF, and awarded in early 2013. Under this grant, IVC combined OP-TEC's proven fundamental optics and photonics teaching materials with an established electronics technology core curriculum to create a hands-on, two-year Photonics Technology certificate program. IVC faculty increased awareness of careers in photonics through coursework, experiential learning, and internships that lead directly to employment. However, attempts to create a California State-approved Associate of Science degree did not progress beyond IVC.

An overt goal of the Photonics Initiative was to establish IVC as the West Coast leader among OP-TEC's network of Partner Colleges at which optics curricula were taught. The Initiative supported regional optics and photonics companies by educating current employees to acquire "competitive technical skills that allow them to improve job performance and increase career opportunities." This responsive, photonics-based collaboration created a pipeline between IVC and regional high schools, local industries, and even four-year universities. IVC's Photonics Initiative prepared graduates with STEM knowledge and skills that cross multiple industries, led to innovative applications in advanced technologies, and contributed to a vibrant local economy.

2.4 Authoring Precision Optics Technology curricula for the NSF

OP-TEC also recruited IVC Laser Tech faculty to author curricula aimed at technician-level education in precision optics fabrication, inspection, and metrology. As it had with its established technician-level texts, OP-TEC surveyed an industrial board to amass *industrial skill standards* for precision optics technicians. Based on these standards, texts were written by IVC faculty in partnership with leaders in the precision optics and optical metrology community, including technical staff at Precision Optical, Reynard Corporation, Nu-Tek Precision Optics, Mahr, 4D Technologies (now Nanometrics), and Zygo (now Ametek). Two texts were written to teach these important topics in optics, and both of these texts were converted into for-credit course to establish four courses in the Laser Technology program (which was then called the Photonics Technology program).

The *Quality Assurance of Precision Optics* [2] text covers succinctly the fabrication and inspection of precision optical elements, whether they are transmissive, or reflective; made of glass, metal, ceramic, or polymers. The International Organization for Standardization (ISO) standard that controls the manufacturing of optical elements, ISO 10110 *Preparation of drawings for optical elements and systems*, is covered in detail. Admittedly, an update of this text from its initial 2015 form is required to capture the ISO 10110 revisions implemented in 2017 through 2019. A benefit of a dynamic technical curriculum is that updates are immediately included in the teaching material used to instruct the course of the same name (discussed below). These updates should appear in future revisions of this text. In addition, a glossary accompanies this text to help students navigate the alphabet soup of acronyms and specific terminology introduced in most technical courses.

The *Metrology of Optical Systems* [3] text covers material that few undergraduate optics students learn, as this course highlights the assessment of an optical system's quality. The optical metrics covered include point spread function, modulation transfer function, and wavefront error, along with examples of techniques used to measure these metrics in the industrial laboratory. A well-equipped optics laboratory is required to perform these measurements well, such as the phase-shifting interferometer, detectors, lasers, alignment scopes, and beam-profiling cameras. Some equipment was donated by industrial partners, and some was purchased via grant funding.

2.5 Center planning grant from the NSF

After successfully completing the three-year small college grant, the next step was to plan to become the Western Center in Optics Education for the NSF. This required a short-term Center Planning grant, which was awarded in 2016 as *Western US Center Planning Grant for Lasers + Photonics Education* [4] (NSF award #1601295). This allowed IVC to extend its reach to partner with other academic and industrial partners across the western US, which included schools and industries in California, Oregon, Washington, Arizona, Nevada, Idaho, Montana, Utah, and Colorado.

2.6 Full-time faculty in Laser Technology at IVC

In 2016, given the success of happily employed Laser Tech graduates and the NSF proposals, Dr. Desiré Whitmore joined IVC as the first full-time Laser Technology faculty member—all efforts to teach Laser Tech since the early 2000s had been taught by adjunct faculty, so it was a boon to hire a team member who could participate fully in the college's academic and administrative processes. Enrollment in Laser Tech courses measurably increased under Dr. Whitmore's leadership, as it was finally possible to offer two sections of each course annually. This enabled particularly ambitious students to finish all four courses required for the Laser Tech certificate within two semesters.

The success of the program also brought new equipment donations from industry, notably a large donation of cameras and optomechanical components by ThorLabs and beam-profiling camera from Ophir, as well as the purchase of an Agilent Cary 7000 spectroradiometer, which immediately became a critical instructional tool. Outreach events, technology demonstrations, and shop-floor tours were conducted in partnership with Alcon, Precision Optical, Newport Corporation, 4D Technology, TRIOPTICS, and Lawrence Livermore National Laboratory (depicted in Figure 1).

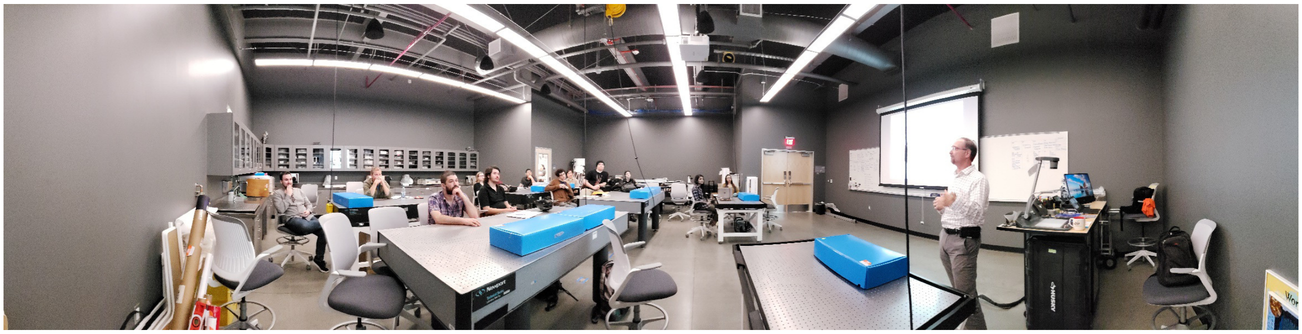

Figure 1. The IVC Laser Lab, shown here during a presentation by Brian Olejniczak of Lawrence Livermore National Laboratory, is equipped with industrial-grade optical hardware.

2.7 NSF curriculum-development grant proposed in lieu of NSF Center grant

However, when it finally came time to apply for the NSF Western-regional center grant, the NSF was no longer funding regional centers. IVC Laser Tech faculty had to change course, even after a strong year preparing to become an NSF Center, during which solid network of over 50 supportive industrial partners were made aware of the Laser Tech program and would consider hiring its graduates. A network of partner colleges had been amassed around the western US; these colleges were considering our curricula as they developed their own to meet their regional industrial needs. Still acting as a leader among Western US college teaching technician-level optics and laser technology, IVC shared with these partner colleges teaching materials including presentation slides, laboratory exercises, and quizzes.

Because curricula were being distributed and online education has been growing in popularity, even for courses that are essentially hands-on, it was desirable to create lecture material that may be easily distributed via a learning management system (LMS). Canvas was chosen as this LMS, and a third NSF grant was proposed and awarded, the *Optics, Photonics, and Lasers Technical Education Curriculum Development* (*OPAL-TEC*) grant [5] (NSF award #1801019). This was a slightly prophetic grant, albeit its output is not quite ready for distribution and online education during the current pandemic.

The ongoing goal of this grant is to create a repository of teaching materials that will be available to share as open educational resources (OER). The Principal Investigator of this grant is partnered with Stephanie Bostwick, co-PI and faculty at Lake Washington Institute of Technology in the Seattle, Washington area, to create the OER. Permission to use the OP-TEC teaching materials has been obtained from the current NSF center in charge of these resources, LASER-TEC (located at Indian River State College, in Fort Pierce, Florida). Under Creative Commons licensing via OPAL-TEC grant funding, these proven, industry-reviewed teaching materials are being converted to OER in Canvas, and digital badges are also being developed.

2.8 Discontinuance at IVC to enable transfer to PCC

Dr. Whitmore departed IVC in 2018 and industrial partners of the IVC Laser Technology program recognized that an AS degree had not been created at IVC after many years of effort, so they encouraged Laser Tech faculty to seek additional administrative and academic support elsewhere.

In the Spring of 2019, multiple college around the Southern California region were considered, and Pasadena City College (PCC) showed the most interest and enthusiasm to host the Laser Technology program. The location of PCC near NASA's Jet Propulsion Laboratory and among many technical industries in the Los Angeles area, is appropriate for increased industrial participation. This move was supported by the industrial advisory board of the IVC Laser Tech program, a meeting of which was held at SPIE's Photonics West conference in February 2020.

In late July 2020, the IVC Laser Technology Program was formally discontinued, and the academic laboratory equipment began the process of transfer to PCC so that instruction may begin during the Fall 2020 academic semester.

2.9 Establishing a Laser Technology program at PCC

Working efficiently (for academia), administration and faculty of the PCC curriculum committee had adopted by early 2020 the four Laser Technology courses created and proven at IVC. The administration moved quickly to hire the IVC Laser Tech faculty member to an adjunct professor role, and the PCC curriculum committee also established two certificates and an Associate of Science degree in Laser Technology. Without having offered a Laser Technology course, PCC now has the framework to offer the AS degree that so many IVC Laser Tech students worked hard to deserve, but were not awarded by IVC.

Marketing support is established at PCC, as demonstrated by the creation of the Laser Tech Program logos shown in Figure 2, and a website and marketing materials are currently being created.

Figure 2. Two versions of PCC Laser Technology Program logos are already created by the PCC marketing team.

2.10 Educational outreach efforts

Throughout the years of teaching Laser Technology, it became quite apparent that it is essential to augment public awareness about the prevalence of technology, particularly optical technology, in modern society. Most people just don't recognize the splendor of science they hold in their hands and take for granted every day. Optical devices are ubiquitous, and the public should be compelled to understand how their lives benefit from this science's many fascinating applications. Educational outreach was conducted in multiple platforms to support this attitude and with it, the burgeoning Laser Technology program.

At least monthly in the 1990s, and again from 2011 to 2018, professors involved in teaching Laser Tech courses taught technology in middle and high school science classes around Orange County. Science teachers in chemistry, physics, and earth science classrooms could take a break for a period or two to learn with their students about the applications of light in modern technical systems. Enrollment in Laser Tech courses has proven that these types of educational outreach activities motivate young students to continue technical education even if they lack the financial resources or academic competency to progress from high school to a four-year university [6]. Technically adept students learn that they can still pursue their dreams of working in a technical field even if they do not earn perfect grades, or cannot afford the higher education or endure the required, complex (often math) courses of an engineering degree.

Many times each year from 2007 through 2015, IVC Laser Tech professors would participate in outreach events organized by the Optical Society of Southern California (OSSC.org) at the Discovery Science Center in Santa Ana, California to conduct demonstrations in the science of light. Initial presentations were conducted during the days of Harry Potter's initial popularity, so the science was presented as a form of magic as in the popular stories by J.K. Rowling. However, as educators became more involved with these demonstrations, it was clear that the science needed to be conveyed in a practical manner, not as wizardry. The message that "you can understand this!" needed to be clear to the audience, so the presenters shed their wizard robes to convey more accessible examples to the public audiences.

Annually, since 2014, students enrolled in Laser Tech courses would earn course credit to demonstrate what they learned in class by conducting their own educational outreach at the Vital Link's *Imaginology* STEAM event at the Orange County Fairgrounds. Not only could this "platform to discover careers in agriculture, technology, science, and the arts" be a useful recruiting venue, but it was a means by which to raise public awareness of optical technology. However, the primary benefit of student participation in these events was subtle: a frequent complaint of industrial management is that the interpersonal communication skills of technician-level employees is undeveloped. This public forum allows students to communicate with and demonstrate optical phenomenology to the general public, and if their demonstrations were presented clearly, it was evident that they understood the science. Hardware-based demonstrations included, for example, unique presentations about the role of polarizers and color mixing in optical displays, the use of mirrors and prisms when comparing binoculars with telescopes, and the use of fiber optics in data communication and lighting.

As indicated here, public outreach efforts began in the 1990s at the Laser Tech program's inception, and they will continue at PCC to propagate public appreciation of the technologies enabled by light. Optics is an inherently engaging science, that creates a visceral appreciation even for a non-technical audience.

3. LASER TECHNOLOGY COURSE, CERTIFICATE, AND DEGREE STRUCTURES

Though many different topics in optics may be useful for technicians, it is essential to first lay down the basics. Advanced courses can then be altered to the needs of the local industry. In Southern California, prominent industrial partners include the aerospace, medical device, and entertainment industries. To contrast, in the optics hub of Rochester, New York, optical component manufacturing is a critical discipline. In Bozeman, Montana, laser companies are pervasive and essential. Granted, there are prominent optical component manufacturing and laser-based industries in Southern California, but the diversity of the region requires a breadth of topics to be covered. Therefore, this coursework combines a broad range of useful, applied topics that have worked well for the graduates of *this* Laser Tech Program.

Student success is measurable. Of the over 150 students who have taken Laser Tech courses at IVC, Laser Tech faculty is remains in direct email contact with over 85% (128) of them. Of these corresponding students, 94% are employed in a technical field related to optics or still enrolled in courses to earn a technical degree. Roughly 30% of these students came from industry seeking to improve their applied skills, 20% came through the program intending to continue to an engineering degree (well aware that hands-on experience is seldom seen in university engineering programs), and about 50% are terminal two-year degree students who want to graduate efficiently and earn jobs as technicians. This larger fraction is why it was critical to establish the AS degree in Laser Technology, which the following courses comprise.

3.1 Course 1: *Fundamentals of Light and Lasers*

This course introduces the fundamental properties of light, including its interaction with and generation from materials. Optical hardware is used in lecture demonstrations and laboratory experiments to show how light can be controlled. Essential components of optical systems are studied, including lenses, mirrors, prisms, windows, sources, detectors, optoelectronics, polarizers, fibers, and gratings. Students will gain hands-on experience with industrial hardware and tools as they construct basic optical component test setups and systems in the laboratory.

This is a three-unit course, which typically includes an hour-long lecture followed by 2 to 4 hours spent with students conducting laboratory activities during each week's class. These hands-on laboratory exercises are the heart of the Laser Tech program. This course is taught via the OP-TEC text [7] of the same name, which is currently in its third revision, based, in part, on the feedback about the text provided by IVC Laser Tech students to the publisher annually since 2013.

Transfer of this course to universities in the California State University (CSU) and University of California (UC) system while at IVC, although this transfer plan has not yet been established at PCC.

3.2 Course 2: *Optical Devices* (formerly known as *Fundamentals of Photonics*)

This course details the most important tools that are used when working with light, from lasers and other light sources to cameras and sensors. Optical devices are used in lecture demonstrations and laboratory experiments to show how light can be generated, manipulated, and captured. Hardware is broken down to its constituent components—lasers are reduced to gain media, pump sources, and mirror cavities; cameras are reduced to the lenses, detectors and processors. Students will gain hands-on experience with industrial hardware and tools in the laboratory. This course follows the generation of photons in the optical source through beam manipulating optics to the generation of electrons in the detector. This end-to-end photon accounting makes the student well aware of all light-matter interactions and loss mechanisms in an optical system.

Though *Fundamentals of Light and Lasers* is recommended preparation for this course, none of the Laser Tech courses have prerequisites. so technical staff already employed in industry can join any class at any time. Experienced technical workers add a unique element to the laboratory classroom, so excluding their enrollment in higher-level courses due to course sequencing is not beneficial to any involved.

This is also a three-unit course, which follows a similar laboratory-intensive format to *Fundamentals of Light and Lasers*. This course may also be established for transfer to universities in the CSU and UC system, but this has not yet been established at PCC.

3.3 Course 3: *Quality Assurance of Precision Optics*

This course addresses the basics of specification, manufacturing, and assessment of precision optics. It presents an introduction to quality assurance (QA) practices required to identify, inspect, and measure optical components. Materials and tools found in an industrial optics fabrication and inspection shop are used in lecture demonstrations and laboratory experiments. Students gain hands-on experience with these industrial materials and QA tools in the laboratory.

Though *Fundamentals of Light and Lasers* and *Optical Devices* are recommended preparation for this course, again, none of the Laser Tech courses have prerequisites for the reasons mentioned earlier.

Due to more extensive laboratory time, this is a four-unit course, which follows a similar laboratory-intensive format to the other Laser Tech courses. The NSF/OP-TEC text of the same name is used to teach this course. This course is offered for co-credit through the UCI Division of Continuing Education (CE), per an arrangement to offer more hands-on learning opportunities to students of the UCI CE Optical Instrument Design Program.

This course has not only the dubious distinction of being among the most difficult offered at IVC [8], but it is a course that includes extensive interaction with industry, through a strong partnership with Precision Optical [9, 10, 11], a precision optics vendor located in Costa Mesa, California. Working engineers and technicians lead shop floor tours of their facility, as shown in Figure 3, demonstrating each step of the delicate sequence required to manufacture precision optical elements. The final of three courses at their facility includes the inspection of prisms to the ISO10110 standard drawing that was used to generate the parts. Students leave this course able to read and create these drawings.

Figure 3. IVC Laser Tech students learn how to cut raw glass (left) and inspect the surface quality of precision optics during a shop-floor tours at Precision Optical. Working technicians lead instruction during these unique, interactive demonstrations.

3.4 Course 4: *Metrology of Optical Systems*

This course is a hands-on laboratory course that details the measurement techniques required to ensure that a fabricated optical assembly or system meets its performance specifications. It covers the design and application of optical metrology instrumentation such as interferometers and modulation transfer function measurement systems. Emphasis is on field test applications that are required in quality assurance for optical engineering and manufacturing. Students gain hands-on experience in the laboratory with industrial hardware and tools.

This is a three-unit course, which follows a similar laboratory-intensive format to the other Laser Tech courses. The NSF/OP-TEC text of the same name is used to teach this course. This course is also offered for co-credit through the UCI Division of CE.

Industrial partners that manufacture metrology systems, such as 4D Technologies, Zygo, TRIOPTICS, Imagine Optic, and Mahr, have all conducted interactive hardware demonstrations for students during this course. These interactions present opportunities for students to learn about hardware that is not (yet) available for their use during academic laboratory activities.

3.5 Bonus independent work-study course: *Cooperative Work Experience in Optics*

This course provides students an opportunity for supervised work experience. Students extend their classroom-based occupational learning by working at a job related to their major and to their occupational goal. Student, instructor, and employer will cooperatively develop a minimum of three learning objectives. One unit of credit is awarded for each 75 hours of paid or 60 hours of volunteer employment for successful completion of learning objectives, and for attendance at scheduled seminar sessions. A maximum of four units may be applied toward major requirements or a certificate.

This course may also be established for transfer to universities in the CSU system, as it was at IVC, but this has not yet been established at PCC.

Under this independent-study course at IVC, students were able to expand their classroom interests into their real-world explorations. In 2015, one student was able to outfit a weather balloon with a variety of optical sensors [12], such as spectrometer and a polarimeter, based only on the preliminary introduction to the operation of these instruments that had been outlined in class. This allows undergraduate *community college* students the opportunity to publish, as this student did, manifesting quite a unique experience for students at this level.

3.6 Certificates of Proficiency in Laser Technology

Some students just enroll for a few courses to advance their education, some enroll for a certificate to advance in their job, some enroll for a full degree to advance their career. Therefore, it is essential to remain flexible to the students' whims when awarding a symbol of completion. This certificate requires completion of only the four Laser Tech courses: *Fundamentals of Light and Lasers, Optical Devices, Quality Assurance of Precision Optics,* and *Metrology of Optical Systems.*

This Certificate of Proficiency is intended for industry professionals who are seeking hands-on training with equipment used in laser and optical technology and the skills necessary to thrive in corporate labs that use or manufacture optical systems. These students do not seek an AS degree, nor do they need coursework in electronics.

3.7 Associate of Science degree in Laser Technology

The Laser Technology Associate of Science degree will teach students the hands-on skills necessary to thrive in corporate labs that use or manufacture optical systems. This certificate requires completion of the same four Laser Tech courses as the Certificate, in addition to general electives, the PCC *Electronics* course, and either the PCC course *Analog Devices and Circuits* or *Microcontrollers and Embedded Design*. All of these courses have a strong emphasis on laboratory work and industrial-grade hardware demonstrations and applications. Students gain the applied skills required to succeed as a precision optics fabrication technician, a laser technician, in four-year engineering programs, or in graduate school. Relevant industries include aerospace, medicine, remote sensing and environmental monitoring, energy, manufacturing, defense and homeland security, telecommunications, and entertainment.

Students are assessed on their ability to

1. Recognize and describe the purposes of different optical components and systems, including lenses, mirrors, prisms, windows, diffraction gratings, polarizers, waveplates, optical fibers, lasers, LEDs, detectors, cameras, and optoelectronics.
2. Demonstrate effective application of optical devices to generate, manipulate, and/or detect light.
3. Operate safely high-energy, high-voltage laser systems to comply with ANSI and OSHA standards required in industrial laboratory environments.
4. Apply the quality assurance (QA) practices required to inspect optical components to ISO 10110 drawing standards and/or military specifications (MIL SPECS), and measure their performance using the industrial tools of an optics fabrication shop.
5. Perform the technical tasks required to characterize of a precision optical system, such as the measurement of a system's transmitted wavefront error or its performance in the creation of high-resolution images.

4. THE FUTURE OF TECHNICIAN-LEVEL EDUCATION IN OPTICS AND LASERS

Increasing awareness of the need for laser technicians starts with industrial participation in academia and extends into our government to the technical leaders of the NSF. Through these efforts, the public is becoming well aware of the need for employees trained in applications of the science of light. Professional optical societies, the SPIE and the OSA, are doing their part to promote technician roles as valid careers. By including technician jobs on websites that feature careers in optics [13, 14], this challenging work is validated as a viable, lucrative career option (because it truly is)!

Similar Optical and Laser Technology programs are located around the nation, coordinated by the NSF's current Center of Laser and Fiber Optics education, LASER-TEC, at IRSC. Excellent leadership exists there and at programs that have been established for decades like the optical technician programs at Monroe Community College [15, 16, 17] in Rochester, New York, and at Springfield Technical Community College in Springfield, Massachusetts. Laser Tech programs are being established with strong industrial partnerships in Bozeman, Montana and Boulder, Colorado, and new optics courses are emerging at colleges in smaller markets. It is also significant that these courses have been accepted at the University of California, Irvine's Division of Continuing Education as electives. This highlights the understanding that typical university-level courses do not include this level of applied interaction with hardware.

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