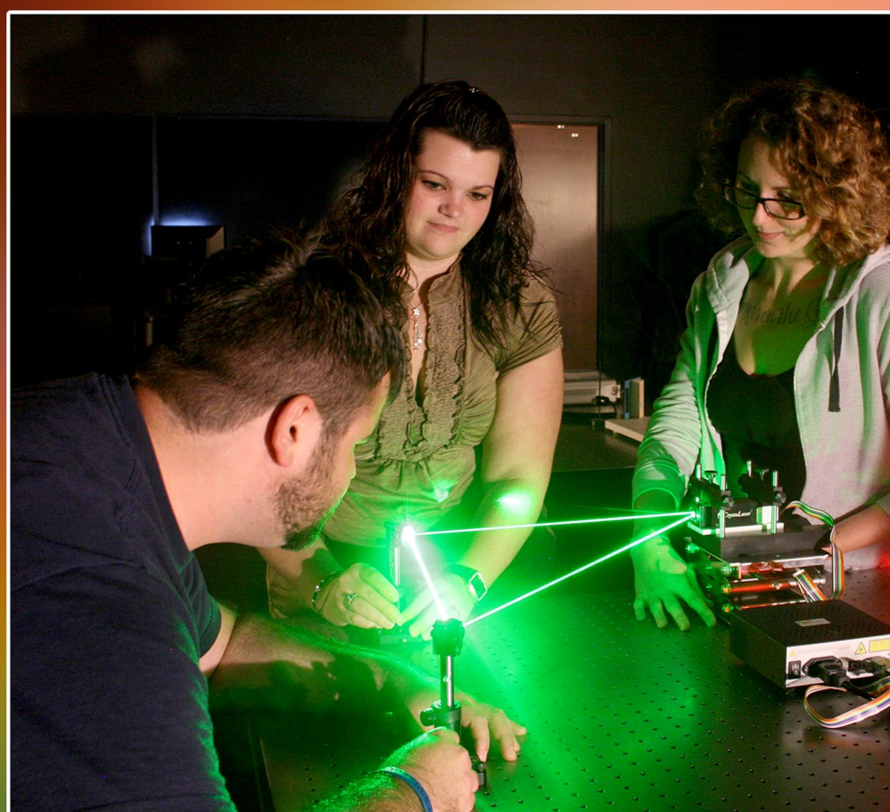
Optics and Photonics Series

Photonics Program Planning Guide for High Schools



Photonics Program Planning Guide for High Schools

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PREFACE

Photonics is a rapidly emerging technology that encompasses lasers, optoelectronics, micro-optics, fiber optics, digital imaging, spectroscopy and precision optics. Over 5000 U.S. companies are focused on applications of photonics, creating more than 10% of all U.S. public company revenues and 6% of public company jobs. Photonics devices are also vital to our nation's defense. Rewarding career opportunities in photonics for engineers and technicians are abundantly available throughout the U.S.

Many high school students are exploring their interests in STEM careers, as well as getting a "leg up" on college preparation, while earning valuable college credits, by enrolling in dual-credit (secondary/postsecondary) courses. *Fundamentals of Light and Lasers* is a popular, dual credit course for students interested in photonics technology.

The National Center for Optics and Photonics Education (OP-TEC) course, *Fundamentals of Light and Lasers* (FL&L), is the "foundation course" for photonics technology. This course provides the basic principles of light, lasers and laser safety that are needed to study specific types of laser systems, advanced geometric and physical optics, fiber optics and optical measurements. It also provides the foundation for studying the applications of lasers in telecommunications, electro-optical displays, biomedical equipment, manufacturing/materials processing, defense/homeland security, environmental monitoring, and nanotechnology.

FL&L is the first technical course taken in A.A.S. photonics programs offered by community and technical colleges throughout the U.S. The laboratories in this course are designed to demonstrate the technical principles of the course and to develop "hands-on skills" needed for further coursework and photonics technology practice.

This Planning Guide contains information about career opportunities in photonics as well as guidelines for high schools to plan and implement a dual-credit course in FL&L that will not only interest and prepare students for postsecondary education/training in photonics but will also earn postsecondary credit with partnering institutions.

The laboratory equipment used by colleges offering FL&L typically costs over $50,000 because it contains "industry-level" equipment and devices. However, alternate high school lab exercises can be performed using less expensive equipment. While this equipment may not be "industry-grade," it nevertheless supports the hands-on learning required for this course and develops useful hands-on skills. High school students who successfully complete FL&L, using this lab equipment, are completely qualified to advance to the next level of postsecondary photonics courses in their curriculum.

Because the experiments are performed using different equipment, OP-TEC has created a *Photon*ics *Lab Manual for High Schools* that describes the equipment, lists suppliers/costs and explains the unique lab layouts and procedures needed for this equipment. The *Photonics Lab Manual for High Schools* can be found at https://www.optecstore.org/products/photonics-lab-manual-for-high-schools/.

Daniel Hull, Principal Investigator June 2018
OP-TEC www.op-tec.org

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INTRODUCTION

This document is for high school administrators, counselors, and/or teachers who are looking for ways to provide their students with opportunities for a bright future in *photonics*—a fascinating, intellectually-challenging, and fast-growing technical field. Photonics includes lasers and fiber optics, as well as other technologies that use light to enhance the quality of life. In this Guide, you will learn about photonics, its applications, the educational and employment opportunities it offers your students, the requirements for teaching photonics in your school, and the assistance you can receive in implementing one or more photonics courses. This Guide will also describe the steps necessary to enhance your school's current STEM program, or to implement a new one.

What Is Photonics? How Is It Used?

Photonics is one of the fastest growing fields of modern technology. It is defined as:

> *the technology of generating and harnessing light and other forms of radiant energy whose quantum unit is the photon.*

In more general terms, photonics is the technology that generates and uses light to perform tasks that add to the quality of our lives. The main source for generating light in photonics is the laser. Most of us have heard about lasers and know from news reports, movies, books and medical procedures that they have many applications. Less is known about the extent to which lasers, fiber optics, and other photonics devices have increased the quality—and significantly lowered the costs—of many of the products we use every day. Bar code scanners, which use lasers and light sensors, have revolutionized the process of customer checkout and inventory management. Lasers have given us a level of healthcare that was unattainable as recently as a few years ago. Lasers and fiber optics are the foundation of our high-speed internet system. Every time we make a photocopy or print a document on a laser printer, photonics technology is being used. Applications of photonics technology have emerged and expanded rapidly since the first laser was produced in the 1960's; today, photonics technology has infused itself into many other technical fields. Because applications of light and lasers will continue to emerge, photonics has a secure future and will continue to be a part of most new technologies that emerge.

<u>Examples of Photonics Applications:</u>

Manufacturing—Lasers are as common on production assembly lines as welders and impact tools. Their high-power and tightly-defined beam profiles allow manufacturing and materials processing to be accomplished efficiently and effectively Lasers also allow the use of additive manufacturing of metals.

Lighting and displays—A primary use of energy in this country is lighting. Electric filament light bulbs are very inefficient and emit most of their energy as heat. Light emitting diodes (LEDs) are replacing filament and fluorescent lighting. Because most of their output is emitted as visible light, LEDs are very efficient. Photonics devices are also being used in video displays such as flat panel TVs, and are responsible for the bright, high-definition pictures they produce.

Environmental monitoring—Photonics systems, consisting of lasers, spectrometers and optical sensors, are being used to monitor atmospheric and liquid contaminants, as well as the effluence of industrial processes. The laser is an excellent probe for detecting harmful chemicals, and when coupled with optical detectors, can provide real-time monitoring of potentially dangerous environmental conditions.

Defense and homeland security—Laser-guided weapons and laser radar (LIDAR) enable military personnel to make high-precision strikes against terrorist targets, thereby reducing the number of missions U.S. airmen must fly and minimizing loss of civilian life. Very high-power fiber lasers are being used to destroy planes, missiles and land mines. Photonics systems detect trace amounts of deadly and explosive chemicals, enabling our nation's borders to be safer from the infiltration of explosives, as well as biological and chemical weapons.

Solar energy and nanotechnology—Solar power and nanotechnology are two rapidly-growing fields in the high-tech sector, and photonics technology is integral to both. Solar cells are being used to provide electric power for residential, industrial and community use. Nanotechnology deals with the manipulation of matter at very small scales, like atoms and molecules. Recently developed nanostructures are being used in medicine and commercially-produced materials with unusual strengths and other useful properties. Photonics provides the tools and techniques for altering and measuring the nanostructures of materials.

Internet—Modulated laser signals for fiber optic transmission has enabled enormous data rates for the Internet and reduced the size of telecommunications equipment.

Medical Equipment and Diagnostic Procedures—Lasers are being used for high-precision, selective surgical and ophthalmic procedures, as well as unique, precision medical diagnostics.

Photonics applications continue to expand in interesting and rewarding fields, and people who work in these fields have substantial opportunities to advance professionally and enjoy high-quality lives. High school administrators can be assured that photonics is a stable and growing technology, and students who pursue degrees related to it will have ample opportunity for challenging, rewarding, and stable careers. With this as a given, the next question is, "What are the possible careers available to photonics technicians?"

Career Opportunities in Photonics

Photonics is a rapidly emerging technology that encompasses lasers, optoelectronics, micro-optics, fiber optics, digital imaging, spectroscopy and precision optics. The need for photonics technicians in the U.S. is immense. Although over 800 new photonics technicians are needed each year, only 400 new photonics technicians currently complete their education and enter the job market. The disparity that exists between the demand and supply of qualified photonics technicians is critical.

Careers Paths in Photonics

There are three basic career paths in photonics: laser and optics research and development, precision optics, and photonics systems technicians. All three are described in this document to assure that high school administrators understand the full range of potential careers available in photonics, and to demonstrate that photonics is not a "one size fits all" career field.

Careers in photonics are accessible to students from across the broad spectrum of interests and aptitudes that are typically found in U.S. high schools. Although mathematics plays an important role in the study and application of photonics, a person does not have to take advanced placement mathematics courses to prepare effectively for some photonics careers. Students with average mathematics abilities and good hands-on skills—"contextual learners"— can be successful in photonics education and enjoy rewarding careers. In the past, contextual learners were often shut out of high-tech employment and had to accept less rewarding employment. Fortunately, that is changing. With the rapid expansion of photonics technology, career opportunities for all types of good accomplished students are on the rise.

The following provides a brief description of the three basic photonics career paths. A disproportionate amount of information has been provided for the photonics technician pathway.

Lasers and Optics R&D

This career pathway requires at least a bachelor's degree in physics or engineering and preferably an M.S. or a Ph.D. People working in this area are primarily involved in research of new photonics applications or development of equipment and processes that involve lasers and optics. Several major institutions in the U.S. conduct laser and/or electro-optics research, such as: The University of Arizona, College of Optical Sciences, the College of Optics and Photonics at the University of Central Florida (CREOL), the Center for Ultrafast Optical Science at the University of Michigan, and Lawrence Livermore National Laboratory (associated with the University of California). To gain an appreciation of the breadth of basic research being conducted in photonics, visit the websites of the centers and laboratories cited. Hundreds of companies are using lasers and incorporating them into equipment for various applications. To review some of the applications, search websites and images using the title "laser applications".

> ***Counseling Tip****—High school students who are proficient in advanced mathematics and science courses, are likely to have the aptitude and interest for pursuing baccalaureate education to pursue careers in laser R&D career pathways.*

Precision Optics Technicians

Precision optics technicians (POT) produce, test, and handle optical (infrared, visible, and ultraviolet) components that are used in lasers and sophisticated electro-optical systems for defense, homeland security, aerospace, biomedical equipment, digital displays, alternate energy production, and nanotechnology. POTs also integrate precision optical components into electro-optical systems and maintain them. POT skill standards and educational requirements can be found on the OP-TEC website at http://www.op-tec.org/precision-optics-skill-standards-2nd-edition.

Laser/Electro-Optics or Photonics Technicians

Photonics technicians build, test, install, operate, maintain, and repair laser and electro-optic devices and systems. They must understand and have hands-on experience in using and maintaining a wide variety of lasers, components, detectors, and related equipment in fields where photonics is an enabling technology. They work closely in teams with laser and optics researchers and engineers. Job description, skill standards and educational requirements for Photonics Systems Technicians can be found on the OP-TEC website at http://www.op-tec.org/skill-standards-photonics-systems-technicians. Annual starting salaries for photonics technicians range from $40,000 to $60,000.

> ***Counseling Tip****—Students who learn mathematics and science best in applied courses, where theories, phenomena, processes, skills, and techniques are taught from a contextual, hands-on perspective, are best suited to pursue A.A.S. degrees and the technician career pathway.*

The education of photonics technicians is based on both academic courses and hands-on experiences involving lasers, optics, electronics, high-voltage sources, and other equipment associated with photonics devices. These technicians do not need to take the higher levels of mathematics required by engineering career pathways. However, they should complete high school algebra, trigonometry and college algebra. The main emphasis of their education, in both high school and college, should be in hands-on applications where they have opportunities to learn mathematics, science, and photonics concepts; not from a theoretical basis, but rather within the context of how those concepts are used in the photonics industry.

A survey conducted by OP-TEC indicated that most employers prefer that their technicians have A.A.S. degrees, which means that the necessary credentials should be within reach for the majority of U.S. high school graduates. Tuition at two-year technical and community colleges that typically confer A.A.S. degrees is significantly lower than that at four-year colleges and universities. Most A.A.S. photonics programs can be completed in two years. Some A.A.S. graduates may elect to continue their education in pursuit of a Bachelor of Science in Engineering Technology (BSET) degree.

Photonics Education and Training in High Schools

Teaching photonics in high school leads students to higher academic achievement and gives them a better understanding of career opportunities in photonics and photonics-enabled technologies. Higher academic achievement results from the emphases in photonics courses on problem-solving and hands-on activities. Students who struggle with abstract, lecture-style mathematics and science courses are provided an approach to those disciplines that resonates with their learning styles. Thus, adding a photonics course in high school is a means to successfully reach the "middle 50%" of students and provide them an avenue for building a solid base in mathematics and science. This type of student success frequently leads to higher persistence and retention rates in high school, as well as increased enrollment in technical studies at postsecondary institutions.

High schools can integrate photonics into their curricula in several ways. The simplest way is to begin adding photonics concepts into courses that are already being taught. For instance, most high school physics courses include sections on light and optics. The typical high school physics approach to teaching those topics does not include "real world" applications. When photonics concepts are integrated into physics courses, students can learn the principles of light and optics in the context of how they are used in lasers, fiber optics, solar cells, and other applications. In effect, students gain the same knowledge they would gain in a more conventional science course, but from a photonics perspective. This means of adding photonics does not displace content from the curriculum; it simply allows the content to be taught in a different way. The strategy for adding photonics content to the curriculum can be extended to other science courses, for example, chemistry, health science and biology, where lasers are used as tools in analysis, diagnostics, and therapy. Photonics provides a real-world context for many mathematical concepts and thus could be effectively infused into mathematics courses.

A more effective option would be to add a photonics course to the curriculum. Typically, this is accomplished by adding the course to an existing CTE or STEM program. CTE programs are natural places for this course to reside. One purpose of CTE and STEM programs is to assist students in developing technical skills and gaining an awareness of technical career opportunities. Since photonics "enables" many technical fields, a CTE course in this technology would provide hands-on exposure to many career pathways.[1]

Adding photonics to a STEM program provides many of the advantages just described for CTE programs. Many STEM programs are housed in academies within the high school. Because they are based on technologies in which photonics plays at least some enabling role, STEM academies (like CTE programs) provide natural places to integrate photonics instruction. Every STEM academy has a primary focus, such as engineering technology, manufacturing technology, information technology, construction science, and environmental science. Providing courses in photonics expands academy students' understanding of their primary focus and provides further

[1] Dan Hull. (2012). *Career Pathways for STEM Technicians*.

context for mastering required science and mathematics concepts presented in state-mandated courses.

For both these single-course options, students can be given the opportunity to earn dual credit for postsecondary education. There are two good reasons to provide that opportunity. The first is obvious. Students earn credit for both high school and college courses, thus accelerating the completion of their postsecondary degrees. The second reason is that dual credit promotes the building of career pathways.

Career Pathways/Dual Credit

Career pathways are defined as:

> *coherent, articulated sequences of rigorous academic and technical courses, commencing in the ninth grade and leading to associate degrees, baccalaureate degrees and beyond, industry-recognized certificates, and/or licensure.*[1]

High schools provide the foundation of career pathways. As already stated, there are many benefits to offering photonics career pathways in high schools. But, for these programs to attract students there must be an articulated curriculum beyond high school. Students must see that their work in high school is not "an end unto itself", but "a means to an end". The definition provided above emphasizes that high school career pathways should lead to postsecondary degrees that qualify graduates for challenging and rewarding technician jobs in high-tech industries.

Both CTE programs and STEM academies provide excellent foundations for career pathways. However, the pathways are not complete unless they include the postsecondary components. OP-TEC strongly recommends that high school administrators, who are considering the addition of photonics courses, plan on building relationships with local community colleges that have programs in photonics, or technologies that are enabled by photonics. These institutions are interested in increasing their enrollments and are willing to partner with high schools in offering dual-credit courses that provide access to high-end laboratory equipment and help to acquire industry-sponsored support in the form of internships and worksite visits. Secondary/postsecondary partnerships with industry are mutually beneficial to the high schools and their partner colleges. High schools gain a postsecondary destination for their graduates that can lead to future employment, and colleges gain ready access to well-prepared students who can build enrollment in their programs and satisfy the employment demands.

Dual credit is a key element in building career pathways. It allows high school students to begin linking with colleges within a year or two before they graduate. This linking gives high school students an opportunity to ease into the college environment while retaining familiar family and social connections. It also gives them an opportunity to build confidence in their ability to succeed academically at the college level. Equally important, it provides high school students an opportunity, early in their academic careers, to test their interest in photonics and make decisions about whether to pursue postsecondary job preparation in this field.

Thus far, we have been talking about a single, dual-credit course in photonics. However, there is no reason that the dual-credit articulation cannot extend to multiple courses. For example, Indian Hills Community College (IHCC) in Iowa, offers an early college program that recruits high school students as they enter their junior year.[2] When these students graduate from high school, they have completed sufficient dual-credit and concurrent enrollment courses to earn thirty-nine college credits—enough to enter IHCC A.A.S. programs with the first year already completed.

Photonics Courses for High School Instruction

If the goal is to add only one course in photonics, high school administrators should look for broad coverage of photonics concepts that will provide students a base for more advanced study. At present, only a few courses with supporting instructional textbooks meet those specifications. A photonics course developed by OP-TEC is frequently used by high school students as a dual-credit course. The course and accompanying textbook are titled *Fundamentals of Light and Lasers, 2nd Edition.*[3]

Fundamentals of Light and Lasers (FL&L) is a basic study of light, the models and principles used to describe it, and how those principles are used in lasers. The text is formatted in six modules:

1. Nature and Properties of Light
2. Optical Handling and Positioning
3. Light Sources and Laser Safety
4. Basic Geometrical Optics
5. Basic Physical Optics
6. Principles of Lasers

Each module includes laboratories that enable students to learn optical and laser concepts from a hands-on perspective. Each module also provides a scenario that shows how the concepts presented are used in the photonics industry. The course's modular format also facilitates the integration of photonics concepts into existing science courses. The text is designed to enable teachers to use the entire course, or only selected modules.

The suggested prerequisites for FL&L are algebra 1, high school geometry and basic trigonometry. To help students who may need supplementary assistance in learning (or relearning) the relevant mathematics concepts, OP-TEC provides video tutorials of the eleven math concepts that are used in FL&L.[4] The FL&L course can be further supplemented with the career information provided on the OP-TEC website at www.op-tec.org/career-videos, which contain profiles of photonics professionals and descriptions of their job responsibilities.[5]

Tailoring a Photonics Course for High Schools

High schools rarely have the financial resources to install technology labs that require high-end, industrial-level equipment. To accommodate high school budgets, the lab component of the *Fundamentals of Light and Lasers* course has been developed in two versions.

The "college version" of the labs (i.e., the version that appears in the main text) provides hands-on experiences designed to help students master photonics-specific concepts using equipment

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[2] Indian Hills Community College, Laser & Optics Technology. (2018) Website available at http://www.indianhills.edu/academics/tech/laser.php

[3] Center for Occupational Research and Development (CORD). (2013). *Fundamentals of Light and Lasers, 2nd Edition*.

[4] Mathematics for Photonics Education Videos. OP-TEC. Website available at http://optecvideo.opteccrm.org/fundamentals-of-light-and-lasers/

[5] Photonics Career Videos. OP-TEC. Website available at http://www.op-tec.org/career-videos

that technicians in industry would use. This version is being used in colleges that have the necessary high-end equipment. Cost for a six-station lab using industry level equipment exceeds $50,000.

The other version of the labs (the "high school version") is described in a supplemental laboratory manual that requires less-expensive equipment, which is more affordable in high school science budgets. The high school version does not reduce the academic rigor of the course—only its cost. When taught using the high school version of the labs, the course is still sufficiently rigorous to qualify students for dual credit.

The supplemental laboratory manual, *Photonics Lab Manual for High Schools*, provides a much less expensive way to support the lab component of the course. Whereas the cost of the college version of the labs exceeds $8,000 per lab station, the high school version of the labs reduces the cost to about $2,500 per lab station.

OP-TEC recommends high schools to consider purchasing an equipment kit from the Midwest Photonics Education Center (MPEC, www.midwestphotonics.org[6]). For approximately $2,500, schools can purchase a boxed kit, complete with case, which contains all the necessary equipment for one lab stations to support the laboratory exercises in *Fundamentals of Light and Lasers*. This kit can be used with either version of the lab exercises.

Expanding Photonics Content in the Curriculum

Once a high school has added the *Fundamentals of Light and Lasers* course to its curriculum, completers are prepared for advanced photonics courses that are taught in community and technical colleges. To meet that need, OP-TEC has developed teaching materials that expand the information presented in FL&L. A second course titled *Laser Systems and Applications* (LS&A) covers more advanced concepts in photonics, as well as the operating principles, output characteristics, diagnostics, and applications for the six most widely used laser types. Important types of lasers are described and classified according to their active medium, output wavelength, and applications. The LS&A course is composed of ten modules, which are listed below with short descriptions:

Module 2-1: Laser Q-Switching, Mode Locking, and Frequency Doubling covers the basic principles and techniques of Q-Switching, the generation of ultrashort laser pulses through mode locking, and frequency doubling of laser output using nonlinear materials.

Module 2-2: Laser Output Characteristics covers laser beam characteristics, optical detectors, and important measurements.

Module 2-3: Laser Types and Their Applications covers laser materials, excitation techniques, and output characteristics; laser types and their operational dynamics; as well as present and future laser applications.

Module 2-4: Carbon Dioxide Lasers and Their Applications covers molecular energy levels, CO_2 laser composition and energy processes, continuous wave CO_2 lasers, intracavity devices for CO_2 lasers, applications of carbon dioxide lasers, safety considerations, and troubleshooting.

[6] Midwestern Photonics Education Center. Website available at http://www.midwestphotonics.org/

Module 2-5: Fiber Lasers and Their Applications covers basic structure and operation of fiber-lasers, from pump to output beam, master oscillator/power amplifier, pulsing methods, output characteristics of fiber lasers, fiber laser applications, safety considerations, and troubleshooting.

Module 2-6: Diode Lasers and Their Applications covers energy transfer in semiconductor lasers, basic semiconductor laser design, output characteristics of semiconductor lasers, materials used in semiconductor lasers, applications of semiconductor lasers, safety considerations, and troubleshooting.

Module 2-7: Argon-Ion Lasers and Their Applications covers energy transitions in ion lasers, ion laser plasma tube design, operating parameters of ion lasers, optical cavities of ion lasers, applications of argon-ion lasers, safety considerations, and troubleshooting.

Module 2-8: Nd:YAG Lasers and Their Applications covers CW Nd:YAG lasers, pulsed Nd:YAG lasers, applications of Nd:YAG lasers, safety considerations, and troubleshooting.

Module 2-9: Excimer Lasers and Their Applications covers excimer laser concepts, materials for excimer lasers, and applications of excimer lasers, safety considerations, and troubleshooting.

Module 2-10: Systems Integration in Photonics covers the basics of system integration, the role of the PST in systems integration, and steps in performing systems integration.

Typically, five modules are taught each semester. Modules 1, 2, and 3 should be taught first. Instructors can then choose two additional modules from Modules 4 through 9 to tailor the course to meet local needs and to make use of available resources. To extend the course into another semester or year, the remaining modules not used initially can be taught.

The LS&A course can give high school students a solid foundation for pursuing advanced postsecondary studies in photonics.

Photonics Labs and Equipment

A high school that is planning to adopt photonics should consider the facility allocation and equipment budget required to teach the laboratories associated with the course *Fundamentals of Light and Lasers*. This section will suggest a laboratory arrangement. It will also provide a list of the equipment in MPEC's equipment kit. In addition, information will be provided in this section regarding laser and electrical safety considerations that will affect the laboratory layout. It is strongly recommended that any high school that elects to add photonics course(s) appoint a laser safety officer and ensure that he or she understands and applies the safety principles presented in the ANSI Z136.5 *Standard for the Safe Use of Lasers in Educational Facilities.* Information on this document and training courses that support it can be found on the website of the Laser Institute of America (LIA; www.laserinstitute.org).

Laboratory Design

The laser laboratory design presented in this section will provide for up to eight work stations (MPEC equipment kits). Ideally, there should be two or three students per work station, although four per work station can be accommodated. For reasons of safety and control, we strongly recommend that the total number of students in the lab not exceed 24.

These work stations are designed to support the *Fundamentals of Light and Lasers* course. A suggested laboratory facility for this course would be a 24×32-foot room, without windows, and switches for dimming the lights. One possible arrangement for the laboratory is shown in Figure 1. If a high school chose to provide only six work stations, the configuration shown in Figure 1 could still be used, but in place of work stations 4 and 8, there would be additional storage areas.

Each lab station would require 30 watts of 120V AC electrical power. Walls should be erected between lab stations to provide an optical barrier to confine the laser beams within each station. Walls, or barriers, can be made of wood or drywall material but should have a textured surface and be coated with a flat (matte) paint. This lab would be classified as a "low-power laser" lab because it uses exclusively Class 2 lasers or 3a (3R), as defined in the Laser Safety Guide.

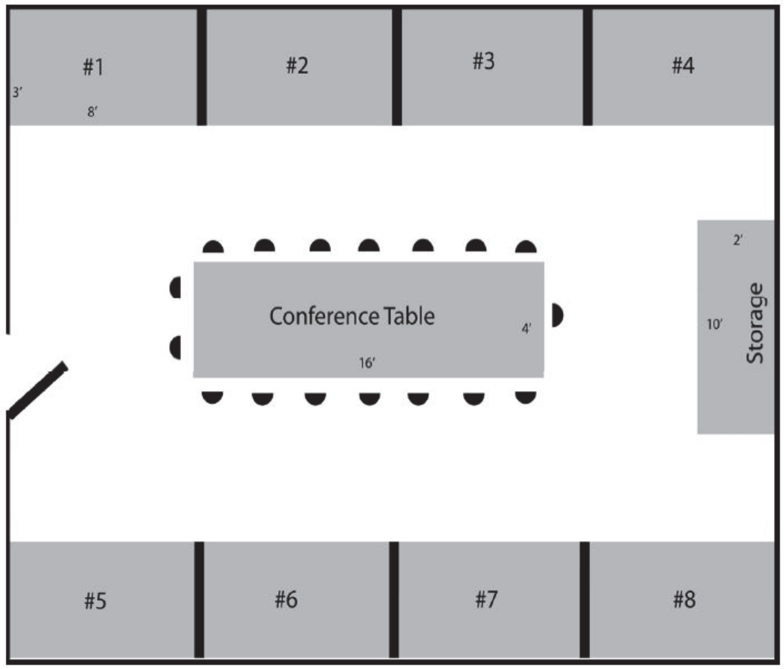

Figure 1. Lower Power Laser Laboratory

As mentioned in the previous section, high schools could expand their offerings of photonics topics through the addition of the modules in the *Laser Systems and Applications* course. However, due to the type of equipment used in LS&A course, safety factors require facilities that isolate lab groups in separate rooms. Again, because of the expense involved, high schools should partner with local postsecondary institutions to share lab facilities for LS&A.

Equipment List and Costs for a Basic Photonics Course

The following equipment list will support the high school lab version of *Fundamentals of Light and Lasers*. This will provide high school administrators a preview of the equipment costs that would be incurred in adding a basic photonics course.

MPEC Kit Equipment List				**$2,500**
Equip List Ref #	Quantity	P/N	Item	Vendor
1	1	PZ9 - (MPEC Case)	Case & Custom Foam	My Case Builder
2	2	23650013650	Plano Prolatch Stowaway Tackle Box	Plano
3	2	N/A	Pocket Stowaway Fixed Compartments	Academy
4	2	BA2	Base, Mounting, 2" × 3" × 3/8"	Thorlabs
5	1	RCB	Block, Acrylic, rectangular 75 × 50 × 15 mm	BME Lab & Science
6	1	01-307	Diffraction Grating, 1000 lines/mm	Edmund Optics
7	2	DH1	Filter Holder, dual	Thorlabs
8	1	IF FS1	Filter Set, Color (RGB)	Industrial Fiber Optics
9	2	CPS635R	Laser Diode Module	Thorlabs
10	2	LDS5	Laser Diode Power Supply, 5 VDC	Thorlabs
11	1	LC1258	Plano-Concave Lens, N-BK7, Ø25 mm, f = -75.0 mm, Uncoated	Thorlabs
12	1	LB1761	N-BK7 Bi-Convex Lens, Ø1" f = 25.4	Thorlabs
13	1	LE1202	Positive Meniscus Lens, N-BK7, Ø1", f = 200 mm, Uncoated	Thorlabs
14	1	LC1259	Plano-Concave Lens, N-BK7, Ø25 mm, f = -50.0 mm, Uncoated	Thorlabs
15	2	LMR1	Lens Mount, Fixed, Inside Diam = 25mm	Thorlabs
16	2	33-501	Mirror Mount, no mirror, 25mm × 25 mm	Edmund Optics
17	2	27-453	Mirror, 25.4 × 51 × 6 mm, First Surface Mirror, Grade 2	Edmund Optics
18	1	MB1218	Optical Breadboard, 12" × 18" ×.5"	Thorlabs
19	1	IF PM	Photometer, Digital, Low Power	Industrial Fiber Optics
20	1	73-961	Polarizer, glass, Diam=23mm	Edmund Optics
21	6	58-977	Post Holders 1.5" × 1.0"	Edmund Optics
22	7	58-961	Posts 1.5" × 5"	Edmund Optics
23	1	33-0220	Prism, Equilateral, 25mm × 75mm	Arbor Scientific
24	2	33-0225	Prism, Right Angle, 32mm × 50mm	Arbor Scientific
25	2	RA90	Right-Angle Clamp or Post Holder .5"	Thorlabs
26	1	RSP1	Rotation Mount, Ø1" Optics, 8-32 Tap	Thorlabs
27	1	RP01	Rotation Stage, 2.5" × 2.5"	Thorlabs
28	1	S100R	Single Slit, (3), Double Slit (1), on one slide, 50 × 50 mm	Thorlabs
29	1	P2-7061	Spectroscope	Arbor Scientific
30	1	PT1	Translation, Stage, single axis	Thorlabs
31	1	VC3	V-Clamp, Cylindrical Laser Mount, 2.5" (2 - piece)	Thorlabs

32	1	WPMQ05M-633	Wave Plate, Multi-Order Quartz, ¼ Wave, φ=12.7mm, w/mount 25mm+B91	Thorlabs
33	1	G19 LED	LED Inspection Flashlight	Coast
34	1	07-251	Microscope Slide (72 pcs/pack)	Arbor Scientific
35	2	P2-9405	Polarizer, slide mounted (50 pcs/pack)	Arbor Scientific
36	1	Scraper Blades	Razor blades, single edge	Stanley
37	1	18" Stainless Steel	Stainless Steel Ruler with Non Slip Cork Base, English and Metric, 18", Westcott	Amazon
38	7	69207	Hex Key Set	Amazon
39	6	SH25S075	Socket Cap Screws, ¼"-20 × ¾"	Thorlabs
40	6	SS25S075	Socket Set Screw, ¼"-20 × ¾"	Thorlabs
41	5		3" × 5", white index cards	
42	1		Protractor	
43	1		1" × 1" Double-sided tape	
44	1	62-534	Optical Cleaning Kit	Edmund Optics

(One work station, *Fundamentals of Light and Lasers* course using high school lab manual)

Teacher Requirements and Training for Teaching Photonics Courses

Selection of an appropriate teacher for the high school FL&L course is critical. Two alternatives must be considered before this decision can be made.

Dual credit—If the course is to be taught for dual credit, the teacher must meet the requirements specified by the college's accreditation agency. The college and high school will have formalized a partnership by signing a memorandum of understanding (MOU). The MOU outlines the responsibilities of each partner and covers issues related to the development, implementation, and sustainability of the dual credit program. Some dual credit MOUs are revised on an annual basis, while others extend for several years. In some dual credit offerings, the college will provide a qualified instructor.

However, if a high school teacher meets the requirements specified by the college's accreditation agency, the college may designate this teacher as an adjunct for the specific purpose of teaching the dual credit course. In the dual credit situation, the college that is offering the credit will sometimes assume responsibility for finding a qualified teacher. If the candidate lacks experience in high school teaching, the partnering high school will assume the responsibility of providing professional development on the educational practices and policies of the high school as specified by its school district. In some cases, students enroll in existing classes on the college campus. Regardless of the type of offering, the level of success in establishing and sustaining dual credit programs requires strong high school-college partnerships.

High school credit only—The second alternative is when a high school elects to add a photonics course that earns *only* high school credit. In this situation, the high school assumes the responsibility of finding and preparing a qualified teacher.

The remainder of this section provides guidance on what qualification the FL&L teacher should have and how a teacher can become qualified to teach this course.

What science and technology background will photonics teachers need?

High schools teachers with experience in teaching physics or engineering technology have the best foundations for the FL&L course.

Selected high school teachers should become thoroughly familiar with the entire course content, labs, aids and teaching strategies for the FL&L course. This preparation is described in the next section.

In addition to the technical content, teachers should have a thorough understanding of laser safety. One teacher, or knowledgeable administrator, should be designated as the *laser safety officer* for the photonics program and/or for the photonics laboratory. The authoritative guide in laser safety is the American National Standards Institute (ANSI) Z136.5 *Safe Use of Lasers in Educational Institutions,* which can be obtained from the website of the Laser Institute of America (LIA) www.lia.org . Information about training for laser safety officers can also be obtained from the LIA.

Recommended training and experience for photonics teachers

OP-TEC offers training for high school teachers who plan to teach optics and photonics. The training consists of three components:

1. Twelve-week online courses (one for each course) covering the content of *Fundamentals of Light and Lasers* and *Laser Systems and Applications,* along with strategies for teaching them. These are offered without cost by OP-TEC.
2. A three-day "hands-on" workshop hosted by MPEC at Indian Hills Community College (IHCC). During the workshop, visiting faculty conduct the experiments described in the course texts and become familiar with lab equipment and vendors. Morning and/or afternoon meetings are held with IHCC faculty to discuss the labs and equipment and other aspects of planning and organizing photonics courses and programs. Costs to participating teachers and/or high schools will be limited to the teacher's time and travel expenses.

Next Steps

The previous sections of this guide have outlined the details of training, curriculum planning, and laboratory setups necessary to implement photonics education at the high school level. Please contact OP-TEC if you have questions for implementing photonics instruction at your high school. If you recognize the opportunities photonics will provide your students and are now interested in taking the next steps toward this implementation, OP-TEC and your local college will lead you through these next steps. Four frequently asked questions are addressed in the following section.

Who is OP-TEC?

Headquartered in Waco, Texas, The National Center for Optics and Photonics Education, OP-TEC (www.op-tec.org) is a consortium of two-year colleges, high schools, universities, national laboratories, industry partners, and professional societies funded by the National Science Foundation's Advanced Technological Education (ATE) program. The participating entities have joined forces to create a secondary-to-postsecondary "pipeline" of highly qualified and strongly motivated students and to empower high schools and community colleges to meet the urgent need for technicians in optics and photonics.

OP-TEC also serves secondary STEM programs and postsecondary A.A.S. programs devoted to lasers, optics, and photonics technology, or technologies enabled by optics and photonics. In addition, OP-TEC provides support through curriculum, instructional materials, assessment, faculty development, recruiting, and support for institutional reform. OP-TEC serves as a national clearinghouse for teaching materials; encourages more schools and colleges to offer programs, courses, and career information; and helps high school teachers, as well as community and technical college faculty members to develop programs and labs to teach technical content. Visit OP-TEC web site www.op-tec.org .

What is the key step in implementing photonics instruction at your high school?

Implementing photonics instruction at your high school involves several steps, described in this document. However, the key step is finding a postsecondary partner with whom to develop an articulated high school postsecondary curriculum sequence. Some of the qualifications the postsecondary partner should have are:

- An established photonics program that has produced graduates who work in industry.
- Laboratory facilities that provide experience in working with laser and optical equipment found in photonics industrial sites.
- An advisory council composed of photonics employers.
- Experience (or at least interest) in building relationships with high schools in your area

Names and contact information on colleges with these capabilities/resources are available through the OP-TEC website. See "OPCN network" (http://www.op-tec.org/opcn). Most of these colleges have experience in helping high schools implement photonics instruction and one will either serve as your partner or find a partner for you. In all cases, OP-TEC will monitor your partnership progress and provide you assistance as needed. You are also encouraged to contact us with questions.

How should my high school begin implementing photonics instruction?

OP-TEC recommends that a high school begin implementation by offering the *Fundamentals of Light and Lasers* course using the *Photonics Lab Manual for High Schools.* This course provides the necessary technical basics, is rigorous enough to earn dual credit, and gives students insights into photonics careers. Another reason to start with this course is that the laboratory component can be performed in most high school science labs, using equipment that can be purchased for about $2,500 for one lab station ($15,000 total, assuming the lab provides for six work stations with 3-4 students per stations, or 18-24 students total). If the lab for a class of 24 students can be divided into two sections, which meet at different times, the students can be accommodated into two, 12-student sections. Assigning 3 students per lab station would require only four sets of equipment, costing $10,000 total.

Are there safety issues that must be considered?

Whenever lasers are used, safety standards must be followed. These standards are outlined in the American National Standards Institute (ANSI) Z136.5 *Safe Use of Lasers in Educational Institutions,* which can be obtained from the website of Laser Institute of America (LIA; www.lia.org). OP-TEC highly recommends that a high school's district office enroll a qualified person in an LIA Laser Safety Officer training course to ensure that the ANSI standards are properly applied.