OP-TEC Program Planning Guide for High Schools

Dan Hull and John Souders

APRIL 2010

OP-TEC
National Center for Optics and Photonics Education

This material is based on work supported by the National Science Foundation under Grant No. NSF/DUE 0603275. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

If you have questions or require additional information, refer to the OP-TEC website www.op-tec.org or contact us. We are available and eager to assist you in planning and enhancing educational opportunities for photonics technicians.

Dan Hull
PI, Director, OP-TEC
P.O. Box 21689
Waco, TX 76702-1689
(245) 741-8338
(254) 399-6581 fax
hull@cord.org

Dr. John Souders
Director of Curriculum, OP-TEC
P.O. Box 21689
Waco, TX 76702-1689
(254) 772-8756 ext 393
(254) 772-8972 fax
souders@cord.org

OP-TEC Program Planning Guide for High Schools

Dan Hull and John Souders

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 area. Photonics includes lasers and fiber optics, as well as all other technologies that use light to enhance the quality of life. Through this document, you will learn in less than 30 minutes what photonics is, the opportunities it offers your students, the requirements for offering this technology in your school, and the assistance you can receive in implementing photonics instruction. As a bonus, the document will describe the steps necessary to enhance your school's current STEM program or implement a new one.

What Is Photonics? How Is It Used?

Photonics is one of the fastest growing technology areas in the world. 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. All of us have heard about lasers and know from science fiction movies like *Star Wars* that they have many capabilities. 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. We listen to digitally recorded music on inexpensive CD players whose main component is a laser. Lasers have given us a level of healthcare that was unattainable as recently as a few years ago. Laser light carries millions and millions of phone calls along fiber optic lines, providing clear, undistorted voice signals. Every time we make a photocopy or print a document on a laser printer, photonics technology is being used. Applications of photonics technology have grown nearly exponentially since the first laser was produced in the early sixties, and today photonics technology has infused itself into virtually every other technical area. Because light will always be at the center of technology expansion, photonics has a secure future and will continue to be a part of any new technologies that spring forward.

Here are few more general applications of photonics.

Manufacturing—The laser is as common on production assembly lines as torque wrenches and impact tools. Their high power and tightly defined beam profiles allow manufacturing processes to be accomplished efficiently and effectively. Through robotic arms, lasers weld, grind, position, and measure—all to high precision and with no complaints of fatigue.

Lighting and displays—One of the main uses of energy in this country is lighting. The standard electric light bulb is very inefficient and emits most of its energy as heat. A photonics device called a light emitting diode (LED) is now available and is beginning to compete effectively in the lighting market. Because most of their output is emitted as visible light, LEDs are very efficient. Likewise photonics devices have found their way into displays such as flat panels and are integral to the bright, high-definition pictures they produce.

Environmental monitoring—Photonics is on the cutting edge of the green movement. Photonics systems consisting of lasers and optical sensors are being used to monitor 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—Photonics is one of the most critical technologies in maintaining our security. Laser-guided weapons 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. With the ability of photonics systems to detect trace amounts of certain chemicals, our borders are now safer from the infiltration of biological and chemical weapons.

Solar energy and nanotechnology—Solar power and nanotechnology are two of the fastest-growing fields in the high-tech sector, and photonics technology is integral to both. Photonics provides an excellent means for converting light into electricity, thus increasing the efficiency of solar cells and making them more cost-effective. As its name suggests, nanotechnology deals with very small scales that approach the size of atoms. Recently developed nanostructures such as buckyballs and nanotubes have great potential to become commercially produced materials with strengths and other useful properties that exceed anything else in existence today. Photonics provides the only viable means for measuring the nanostructures of these materials and ensuring that they meet design specifications. As the applications of these two devices expand, so will the value of photonics.

Internet—We already mentioned how photonics enables the transmission of an enormous number of phone calls. But this application of photonics is just the tip of the iceberg in processing and transmitting information. The Internet could not operate at the speed and volume it does without diode lasers and fiber optics.

The future of photonics is very secure, and people who participate in it will have substantial opportunities to advance professionally and enjoy high-quality lives. High school administrators can be assured that photonics is here to stay and that students who pursue degrees related to it will have ample opportunity for challenging, rewarding, and stable careers. With this a given, the next question is, "What kind of careers can photonics workers have?"

Career Opportunities in Photonics

One of the main concerns for high school administrators as they consider implementing new technology programs is the ability of the chosen programs to provide educational opportunities at the postsecondary level that can lead to challenging, rewarding, and stable careers. The field of photonics unquestionably provides those opportunities and more. With the rapid growth of the photonics industry and the large worldwide demand for its products, the future of people with the education and skills necessary to work in this industry is very bright. The following quotation from the National Research Council publication titled *Harnessing Light: Optical Science and Engineering for the 21st Century* shows how extensive this growth is:

> *Optics is rapidly becoming an important focus for new businesses in the global economy. In the United States, both large and small businesses are significant players in emerging optics business activity. Optics-related companies number more than 5000, and their net financial impact amounts to more than $50 billion annually.*

Careers Paths in Photonics

There are three basic careers paths in photonics: laser and optics research and development, optical engineering, and laser/electro-optics technicians. All three are covered in this document to ensure 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. Though 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 photonics careers. Students with average mathematics abilities and good hands-on skills—"contextual learners"—can also find rewarding careers. In times 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 students are on the rise.

The following provides a brief description of the three basic photonics career paths. We have purposely provided a disproportionate amount of information for the technician pathway, since the other two are more commonly known.

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 basic research designed to increase understanding of fundamental principles. Often the results of this research lead to new applications that extend the technology base. Several major institutions in the U.S. conduct this type of research, institutions such as the University of Arizona Optical Science Center, the Center for Research and Education in Optics and Lasers at the University of Central Florida, the Center for Ultrafast Optical Science at the University of Michigan, and Lawrence Livermore National Laboratory (associated with the University of California). For a complete list of facilities that conduct photonics research, visit *http://www.photonics.com/directory/socuni/uniusa.asp*. To gain an appreciation of the breadth of basic research being conducted in photonics, visit the websites of the centers and laboratories listed.

Optical Engineering

People in this career path focus on applications of photonics. In other words, they take the results of basic photonics research and, by applying it, generate new laser systems, monitoring equipment, sensors, and other devices and applications. These professionals also find new ways to use photonics devices and design systems in implementing these innovations. Typically these people have engineering degrees (baccalaureate and graduate) from the institutions listed at the URL presented above.

> ***Counseling Tip****—The student who does well and enjoys standard abstract mathematics and science courses, where no attempt is made to apply the concepts to real-world situations, probably has the aptitude/interest for pursuing the laser R&D and optical engineering career pathways.*

Laser/Electro-Optics or Photonics Technicians

These photonics professionals 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. Starting salaries range from $38,000 to $50,000.

> ***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 probably best suited to pursue AAS degrees and the technician career pathway.*

The education of photonics technicians is based on both academic courses and hands-on training involving lasers, 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 the other two career pathways. However, they should complete high school algebra and trigonometry and college algebra. The main emphasis of their education, in both high school and college, should be on hands-on applications in which they have the opportunity to learn mathematics, science, and photonics concepts not from a theoretical basis, but rather within the contexts of how those concepts are used in the photonics industry.

A recent survey[1] conducted by OP-TEC indicated that employers want the majority of their technicians to have AAS degrees, which means that the necessary credentials should be within reach for the majority of U.S. high school graduates. Tuition at the two-year technical and community colleges that typically confer AAS degrees is significantly lower than that at four-year colleges and universities, and AAS students typically do not incur expenses for room and board since they can live at home. Most AAS photonics programs can be completed in two years. Some AAS graduates elect to pursue Bachelor of Science in Engineering Technology (BSET) degrees. Many institutions that offer this degree will apply AAS photonics credits toward graduation.

The OP-TEC survey also focused on the availability of photonics positions in industry, both now and five years from now. The survey indicated that over 19,000 photonics technicians are currently employed in the U.S., that over 2100 additional photonics technicians will be needed next year, and that approximately 5900 will be needed in five years (2014).

Photonics Education and Training in High Schools

Teaching photonics in high school leads to higher academic achievement and gives students a better understanding of career opportunities in photonics and photonics-enabled technologies. Higher academic achievement results from the photonics courses' emphasis on problem-solving and hands-on activities. Students who struggle with conventional lecture-style mathematics and science courses are given a way to approach those disciplines that better resonates with their learning styles. Thus, adding a photonics course in high school is a means to 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 leads to higher persistence and retention rates in high school and 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 approach to teaching those topics is devoid of "real world" applications. When photonics concepts are integrated into those 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

[1] Hull, Ruggiere, and Illich, Photonics Technician Employment in the United States: An Industry Survey of Current and Future Demand in 2009 for Education and Training Programs, OP-TEC Monograph, May 2009

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. This strategy for adding photonics content to the curriculum can be extended to other science courses, for example, chemistry 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 aggressive option would to add a full-fledged photonics course to the curriculum. Typically this is done by adding the course to an existing CTE or STEM program. CTE programs are natural places for this course to reside. Their purpose 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 area would provide hands-on exposure to many career pathways.

Adding photonics to a STEM program provides many of the advantages just described for CTE programs. Many STEM programs are housed in academies. 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, emerging technologies, information technology, construction science, and environmental science. Providing courses in photonics expands academy students' understanding of their main focus and provides further context for mastering 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. 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.*

High schools are an essential part of career pathways. As already stated, there are many benefits to offering photonics in high schools. But for these programs to attract students there must be something beyond high school. Students must see that their work in high school is not an end, but a means to an end. As the definition provided above makes clear, the ends toward which career pathways lead are postsecondary degrees that qualify graduates for challenging and lucrative 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 always interested in increasing their enrollments and are generally willing to partner with high schools in offering dual-credit courses, providing access to high-end laboratory equipment, and helping acquire industry-sponsored support in the form of internships and worksite visits. These partnerships 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 students who can build enrollment in their programs and satisfy the employment demands of their advisory councils.

Dual credit is a key element in building career pathways. It allows high school students to beginning linking with colleges a year or two before they graduate. This linking gives high school students an opportunity to ease into the college environment while retaining familiar parental 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 courses in it.

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

So, if you add a course in photonics to your high offerings, what course should it be?

Photonics Courses for High School Instruction

If their goal is to add only one course in photonics, high school administrators should look for broad coverage of basic 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. To give an example, we will use a course developed by OP-TEC that has been used by high school students in a dual-credit course. The course and accompanying textbook is titled *Fundamentals of Light and Lasers.*

As the name indicates, the *Fundamentals of Light and Lasers* course is a basic study of light, the models and principles used to describe it, and how those principles are used in lasers. The models and principles are presented in six modules:

1. Nature and Properties of Light
2. Optical Handling and Positioning
3. Light Sources and Laser Safety
4. Basic Geometric 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 therein are used in the photonics industry. The course's modular format 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 course's mathematics prerequisites are algebra 1 and high school geometry. To help students who may need supplementary assistance in learning (or relearning) the relevant mathematics concepts, OP-TEC provides a companion text titled *Mathematics for Photonics Education*. This supplemental text includes an assessment to help teachers identify the mathematics concepts that their students are least prepared to use. *Fundamentals of Light and Lasers* can be further supplemented with the career information provided on OP-TEC DVDs, which contain profiles of photonics professionals and descriptions of their job responsibilities.

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. Because of this reality, the lab component of the *Fundamentals of Light and Lasers* course comes 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 that technicians in industry would use. This version would be used in colleges that have the necessary high-end equipment. A dual-credit offering of the course would probably also use this version, since instruction would be provided at the college. The other version of the labs (the "high school version") is contained in a supplemental laboratory manual that calls for less-expensive equipment that is more in keeping with 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—titled *High School Photonics Lab Manual for the OP-TEC Course "Fundamentals of Light and Lasers*"—provides a much less expensive way to support the lab component of the course. The college version of the labs costs about $8,000 per lab station, while the high school version reduces the cost to about $1300 per lab station. An equipment list (which includes part numbers, vendors, and pricing) for the high school version is presented in the "Photonics Labs and Equipment" section of this guide.

Expanding Photonics Content in the Curriculum

Once a high school has added the *Fundamentals of Light and Lasers* course to its curriculum, the need for additional photonics content may arise. To meet that need, OP-TEC has developed materials that expand the information presented in *Fundamental of Lights and Lasers*. These materials consist of three modules (of six) from an OP-TEC course titled *Elements of Photonics*:

1. Operational Characteristics of Lasers
2. Specific Laser Types
3. Optical Detectors and Human Vision

The laboratories used in these modules require equipment similar to that required for the college version of *Fundamentals of Light and Lasers*. High schools that would like to offer these modules should consider partnering with postsecondary institutions or local employers that have the necessary equipment.

If a high school wants to add even more photonics content to its curriculum, it can use the remaining three modules in OP-TEC's *Elements of Photonics*:

4. Principles of Fiber Optics Communications
5. Photonics Devices for Imaging, Storage, and Display
6. Basic Principles and Applications of Holography

These modules provide a means for teachers to broaden students' understanding of how photonics is applied in industry. Before taking these modules, students should take the *Fundamentals of Light and Lasers* course and the first three modules in *Elements of Photonics*.

Like *Fundamentals of Light Lasers,* the six modules of *Elements of Photonics* are academically rigorous enough to qualify for dual credit. The two courses can give high school students a solid foundation for pursuing postsecondary study 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 instructional modules described in the preceding section. This section will suggest a laboratory arrangement. It will also provide a list of the equipment called for in the high school lab manual described in the previous section. 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 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 here will provide for eight work stations. Ideally, there should be two students per work station, although three per work station can be accommodated. For reasons of safety and control, we strongly recommend that the total number of students not exceed 24.

These work stations are designed to support the *Fundamentals of Light and Lasers* course. A suggested laboratory 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 the 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 and 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.

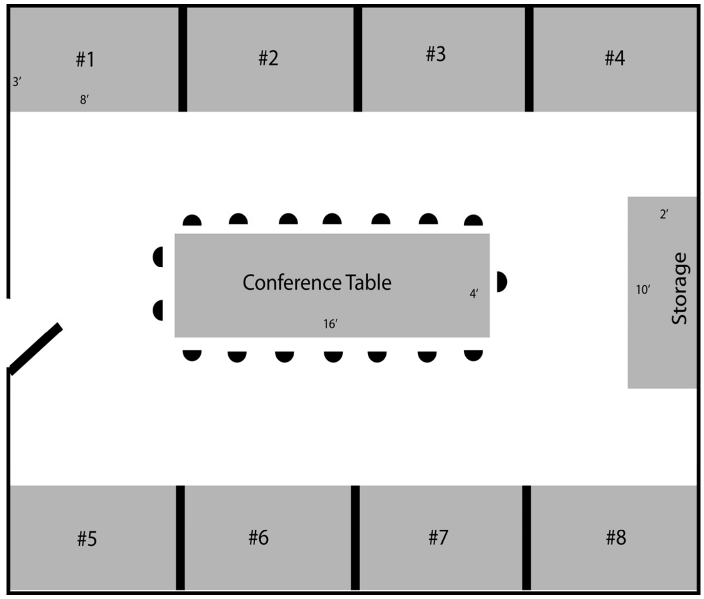

Figure 1. Lower Power Laser Laboratory

As mentioned in the previous section, high schools could expand their offerings of photonics topics through the addition of the modules in the *Elements of Photonics* course. However, due to the type of equipment used in this course, facilities that isolate lab groups in separate rooms are often required. Again, because of the expense involved, high schools should partner with local postsecondary institutions or industries that have these facilities.

Equipment List and Costs for a Basic Photonics Course

The following equipment list will support the high school version of *Fundamentals of Light and Lasers*. This is presented to give high school administrators a sense of the equipment costs that would be incurred in adding a basic photonics course.

Equip List Ref #	Quantity	P/N	Item	Vendor	Price	Total
1	1	MB1218	Base Plate	Thorlabs	$208.66	$208.66
2	2	17474 TL	Laser Pointer/LED Light	Marlin P. Jones & Associates	$4.95	$9.90
3	2	VC-3	V-Clamp Mount for Laser	Thorlabs	$42.30	$84.60
4	2	m33-501	1" Mounted First Surface Mirrors	Edmund Optics	$35.00	$70.00
5	5	m58-961	1.5" Post	Edmund Optics	$9.00	$45.00
6	5	M58-977	1.5" Post Holder	Edmund Optics	$10.00	$50.00
7	1	M54-038	Industrial Fiber Optics Digital Photometer	Edmund Optics	$199.00	$199.00
8	1	W96212	1" Diam Negative Meniscus Lens, -55mm f	Anchor Optics	$3.15	$3.15
9	1	W20919	1" Diam Plano Concave Lens, -93mm f	Anchor Optics	$4.55	$4.55
10	1	W74570	1" Diam Plano Convex Lens, 24mm f	Anchor Optics	$7.70	$7.70
11	1	W74259	1" Diam Positive Meniscus Lens, 201mm f	Anchor Optics	$4.55	$4.55

Equip List Ref #	Quantity	P/N	Item	Vendor	Price	Total
12	3	LMR1	1" Fixed Lens Mount	Thorlabs	$15.68	$47.04
13	3	BA2	Mounting Base	Thorlabs	$7.27	$21.81
14	2	AX73961	1" Round Glass Polarizer	Anchor Optics	$8.00	$16.00
15	2	DH1	Dual Filter Holder	Thorlabs	$13.20	$26.40
16	1	33-0175	Primary/Secondary Color Sheets	Arbor Scientific	$2.50	$2.50
17	1	01_3900	Metric Ruler	Arbor Scientific	$10.00	$10.00
18		P2-7009	Smoked Acrylic Block Lens Set	Arbor Scientific	$99.00	$99.00
19	1	33-0980	Diffraction Grating	Arbor Scientific	$3.00	$3.00
20	2	Jul-51	Microscope Slide	Arbor Scientific	$1.00	$2.00
21	2	W27453	1" Square Mirror	Anchor Optics	$4.55	$9.10
22	1	3120406	Spectroscope, pkg. of 6	Edmund Scientifics	$9.95	$9.95
23	2	16V0446	Lens and Prism Acrylic Set	Ward's Natural Science	$32.25	$64.50
24	1	16578-01	Target Set	Newport	$112.49	$112.49
25	1	RP01	Rotational Platform	Thorlabs	$91.00	$91.00
26	2	KM100	Kinematic Mirror Mount	Thorlabs	$39.90	$79.80
27	2	ME1-G01	25.4 mm Round Protected Aluminum Mirror	Thorlabs	$11.20	$22.40
28	1	3081453	Lens Cleaning Kit	Edmund Scientifics	$5.95	$5.95
29	1	14V0515	Plastic Forceps	Ward's Natural Science	$4.95	$4.95
				Total		**$1315.00**
Supplies or Incidental Equipment List						
30	1	N/A	8.5" × 14" White Paper	N/A		
31	1	N/A	Roll of Masking Tape	N/A		
32	1	N/A	Protractor	N/A		
33	1	N/A	Pencil	N/A		
34	1	N/A	Set of Colored Pencils	N/A		
35		N/A	Books	N/A		
36	1	N/A	Silly Putty	N/A		
37	1	N/A	Index Cards	N/A		

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

Teacher Requirements and Training for Teaching Photonics Courses

An important decision high school administrators must make in implementing a photonics course is the selection of a teacher. Two situations must be addressed before this decision can be made.

1. *Dual credit*—If the course is being taught for dual credit, the teacher must meet the requirements specified by the college's accreditation agency. In most 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 hire 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 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.

2. *High school credit only*—The second situation occurs 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 a qualified teacher.

The remainder of this section provides guidance on what qualification this 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 this course. However, teachers who have expertise in the following topics would also make good candidates.

1. Mathematics through pre-calculus
2. Geometric optics
3. Wave optics
4. Modern physics or basic atomic physics
5. Experience in organizing and working in clean, safe laboratories

At a minimum, teachers should be thoroughly familiar with all of the content in the *Fundamentals of Light and Lasers* course described in the next section. A broader, more in-depth understanding of this content can be obtained from the Laser/Electro-Optics Technology (LEOT) series produced by CORD for use in two-year photonics technician programs.

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.laserinstitute.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 *Elements of Photonics* along with strategies for teaching them.
2. A three-day "hands-on" workshop hosted at OP-TEC in Waco, Texas, or at a partner college. 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 OP-TEC staff and/or partner college faculty to discuss the labs and equipment and other aspects of planning and organizing photonics courses and programs.

3. Teacher externships (optional) with companies that produce or use photonics equipment in manufacturing environments

The cost for providing the training will be borne by OP-TEC. Costs to participating teachers and/or high schools will be limited to the participants' 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. You now have had a complete overview of what is involved in implementing photonics instruction at your high school. We hope at this point that you recognize the opportunities photonics will provide your students and are now interested in taking the next steps toward this implementation. As a way of leading you to these next steps, we conclude this document with answers to four frequently asked questions.

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 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 and community and technical college faculty members develop programs and labs to teach technical content.

OP-TEC's partner colleges are:

Camden County College, Camden, New Jersey

Central Carolina Community College, Lillington, North Carolina

Indian Hills Community College, Ottumwa, Iowa

Indian River State College, Fort Pierce, Florida

Indiana University of Pennsylvania, Freeport, Pennsylvania

Advanced Technology and Education Park of the South Orange County Community College District

Texas State Technical College, Waco, Texas

Tri-County Technical College, Pendleton, South Carolina

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

As you have learned from this document, implementing photonics instruction at your high school involves several steps. However, the key step is finding a postsecondary partner who will help keep you from reinventing the wheel and wasting resources. Here are some of the qualifications this partner should have:

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

OP-TEC recommends that you seek a partner from one of its partner colleges. Contact information for each of these colleges is available through the OP-TEC website (*www.op-tec.org*). All OP-TEC partner colleges have experience in helping high schools implement photonics instruction and will either serve as your partner or find a partner for you. In all cases, OP-TEC will monitor your partnership's progress and provide assistance as needed. You are also encouraged to contact us with questions. We want you to succeed in this implementation and will gladly provide our expertise.

How should my high school begin implementing photonics instruction?

OP-TEC recommends that a high school start by offering the *Fundamentals of Light and Lasers* course using the *High School Lab Manual for OP-TEC Course "Fundamentals of Light and Lasers."* 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 its laboratory component can be performed in a standard high school science lab using equipment that can be purchased for about $7800 (assuming that the lab provides six work stations with three students per station; 18 students 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.laserinstitute.org*). OP-TEC highly recommends that a high school's district office send a qualified person to an LIA laser safety officer training course to ensure that these standards are properly applied.