Ref ETOP059

Optical Engineering education with curriculum mapping for ABET accreditation.

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Abstract

The Physics and Optical Engineering department at Rose-Hulman Institute of Technology offers three degrees at the undergraduate level; physics, optical engineering, and engineering physics. The department recently transitioned a science-based applied optics degree into a B.S (Optical Engineering) degree. With this transition we began the process of seeking accreditation for the optical engineering program through the Accreditation Board of Engineering and Technology (ABET). This paper describes several assessment components of the accreditation process which includes a detailed curriculum mapping exercise to meet engineering standards. We discuss the overall outcome based optical engineering education.

Summary

1. Background

Rose-Hulman Institute of Technology is an undergraduate science and engineering institution although we have an active master's level graduate program in many areas. The Department of Physics and Optical Engineering offers a B. S. degree in Optical Engineering, B. S. degree in Engineering Physics, B. S. degree in Physics, and a M. S. degree in Optical Engineering. The optics program at Rose-Hulman was initiated in 1983, and realizing the importance of optical measurement and testing, courses such as Optical Instrumentation as well as testing and Fiber Optics and Application were incorporated. These courses address some aspects of measurement and testing. However, to enrich the Applied Optics curriculum, many new courses have been introduced such as: Applied Optics Projects Lab I, Applied Optics Projects Lab II, Optical Metrology, Semiconductor Materials, and Micro-sensors. Further, certificates in semiconductor materials and devices as well as image processing enables the student to expand their background by studying these diverse topics.

The multidisciplinary field of optics in the undergraduate curriculum is facing revolutionary changes, as optical techniques become the standard tools for industrial inspection and as optical components become standard items in consumer products. As educators, we are faced with a task of designing a curriculum to meet the growing needs of the market trend. This requires the need to improve the curriculum from the traditional science course sequence and match the need for more applied and engineering nature of the courses. With this transition we initiated the process of seeking accreditation for this optical engineering program through the Accreditation Board of Engineering and Technology (ABET). Presently the University of Alabama and University of Arizona are the only two schools that have ABET accredited programs in optical engineering. The intent of the optical engineering program at Rose-Hulman is to prepare students for the practice of engineering at a professional level. This program is not intended as a supporting role in optical engineering but provides the basic practices of optical engineering supported by a strong group of faculty expertise in the area.

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This paper describes one assessment component of the accreditation process called curriculum mapping. This mapping is used to determine how well the contents of our courses match the overall educational and learning outcome of our program.

2. Educational outcomes and objectives

Optics education in the undergraduate curriculum is multidisciplinary and involves a strong engineering aspect. Curriculum changes should focus, among others, on the overall outcome, which force educators to charter the delivery of the subject information at the appropriate time in the course sequence. We are faced with the task of designing a curriculum to meet not only the growing needs of market trend but also to make the students learn the essentials. Students need to gain knowledge in a broad range of fields from pure physics to almost every discipline of engineering but appropriately staggered by designing courses that have specific outcomes. This should not essentially be focused on the methodology of teaching but on a broader level of evenly distributed but reinforced learning styles for the students. This task is significantly difficult in the optics curriculum because optics courses are usually a blend of new technology, engineering and physics. At Rose-Hulman, this concept has geared us to evaluate the traditional course sequence in courses with laboratory in terms of information content and student outcomes. Overall, laboratory experiments are designed to reinforce concepts for understanding the basic scientific ideas of a particular course along with the necessary experimental skills. RHIT's optics program has evolved gradually to mix the two worlds with the introduction of project-based courses that awaken the scientific curiosity as well as the engineering creativity. There has also been a focus to enable the students to employ their optics and scientific knowledge to build products as well. We have been in a process of constantly restructuring the program to meet the challenges of tomorrow by carefully assessing the needs of the students, the engineering community and the market place.

The OE program educational subcategorized goals/outcomes are:

Goal A: Knowledge of the Fundamentals: An understanding of the fundamentals of science and engineering

Outcome A.1: Demonstrate competency in calculus, basic physics and general chemistry.

Outcome A.2: Demonstrate competency in basic engineering science topics with common themes among engineering disciplines.

Outcome A.3: Demonstrate competency in optical engineering topics, i.e.,

- A.3.1. In the sciences, fundamentals of optics
- A.3.2. Optical material, devices, sources, and systems
- A.3.3. Advanced topics in optics leading to the application with basic principles
- A.3.4. Systems level understanding of optics
- A.3.5. Modeling of light propagations through systems
- A.3.6. Physical principles of light and how they interact with matter
- A.3.7. Application of optics to measurement
- A.3.8. Optics as enabling technology
- A.3.9. Optical technologies leading to experiments in optics
- A.3.10. Appropriate modern experimental and computing techniques in optics

Goal B1: Interpreting Data: Ability to interpret graphical, numerical, and textual data.

Outcome B1.1: Be able to recognize the necessity to use graphical and numerical analysis
Outcome B1.2: Select appropriate, self-explanatory graph formats for data.
Outcome B1.3: Summarize the graphical, numerical, and textual information in memos and reports.
Outcome B1.4: Use appropriate statistical and analytical procedures to interpret the results.
Outcome B1.5: Extract trends and demonstrate their importance from numerical data, graphs, and text.

Goal B2: System Level Modeling: Ability to model components and system optical engineering problems.

Outcome B2.1: Define the system and variables involved.
Outcome B2.2: Develop the appropriate boundaries and equations.
Outcome B2.3: Set up the system of equations and find a reasonable solution.
Outcome B2.4: Do a parametric study where appropriate, tabulate and plot the results.
Outcome B2.5: Be able to recognize the limitations of the system
Outcome B2.6: Demonstrate the ability to use appropriate software tools for modeling. (eg. Code V, Zemax, Matlab)

Goal B3: Experimentation: Ability to design and conduct experiments to understand the relationships between variables in a problem which may or may not have been mathematically modeled before.

Outcome B3.1: Identify the problem.
Outcome B3.2: Develop a hypothesis.
Outcome B3.3: Determine what data needs to be collected.
Outcome B3.4: Select appropriate measurement techniques to collect the data.
Outcome B3.5: Demonstrate the ability to use the tools for measurement.
Outcome B3.6: Determine and/or estimate experimental uncertainties.
Outcome B3.7: Collect and document the data.
Outcome B3.8: Analyze the data.
Outcome B3.9: Draw conclusions.

Goal C: Design: Ability to design a product or process to satisfy client's needs subject to constraints

Outcome C.1: Elicit the customer needs and constraints. Recognize that several viable processes and procedures are almost always possible.
Outcome C.2: Break down the system or process to its fundamental elements and components.
Outcome C.3: Carry out an initial study of the process structure and economics using appropriate tools.
Outcome C.4: Carry out a conceptual process design using appropriate tools. Use computational tools to perform studies of the design developed.

Outcome C.5: Demonstrate an ability to incorporate economic analysis and cost issues in design.

Outcome C.6: Demonstrate an awareness of the final steps in the completion of a design project.

Outcome C.7: Document the project work and give an oral and formal written report.

Goal D: Team work and Deliverables: Ability to work in multi-disciplinary teams and to understand the effective team dynamics and be able to deliver a product.

Outcome D.1: Share responsibilities and duties in the team

Outcome D.2: Understand the importance of different areas of expertise

Outcome D.3: Understand the importance of the various components of the project

Outcome D.4: Setting milestones for the project

Outcome D.5: Take on different roles when applicable.

Outcome D.6: Analyze ideas objectively.

Outcome D.7: Discern feasible solutions.

Outcome D.8: Develop a strategy for action.

Outcome D.9: Be able to meet outcome on schedule

Outcome D.10: Be able to document work.

Outcome D.11: Build consensus.

Goal E: Problem Solving: Ability to apply relevant scientific and engineering principles to solve real world optical engineering problems.

Outcome E.1: Identify, inspect and define the problem.

Outcome E.2: Understand the basic principles and fundamental concepts for solving the problem

Outcome E.3: Research and gather information.

Outcome E.4: Use correct data and choose appropriate tools to prepare solutions that reflect problem complexity with requested and required detail.

Outcome E.5: Make appropriate assumptions and use judgment to understand their effects on the solution.

Outcome E.6: Determine the magnitude and significance of the errors involved.

Outcome E.7: Design experiments to learn the concept.

Outcome E.8: Demonstrate an awareness of the open-ended nature of real world problems and the multiplicity of solutions.

Outcome E.9: Develop criteria for evaluation of the proposed solutions and process of refinement.

Goal F: Professional Practice and Ethics: A sound understanding of what an optics professional is and have an awareness and understanding of professional ethics.

Outcome F.1: Demonstrate knowledge of the (Optical) Engineering Code of Ethics.

Outcome F.2: Evaluate the ethical dimensions of professional practice.

Outcome F.3: Practice responsible decision making.

Outcome F.4: Be prepared for professional practice after graduation.

Goal G: Communication: Ability to communicate effectively in oral, written, and visual forms.

Outcome G.1: Identify the technical knowledge and information needs of the audience.
Outcome G.2: Use appropriate technologies, organize and present information that meets audience needs.
Outcome G.3: Provide technical content that is factually correct, supported with evidence, explained with sufficient detail, and properly documented.
Outcome G.4: Determine how well ideas have been relayed.
Outcome G.5: When preparing reports and papers, submit work that is free of errors in spelling, punctuation, grammar, and usage.

Goals H, J: Contemporary issues, non-technical issues, global awareness: An awareness of contemporary and non-technical issues in the engineering profession and the role of professionals in an interdependent global society.

Outcome H.1: Study humanities and social sciences topics to gain a broad enough knowledge to form reasoned opinions on non-technical issues.
Outcome H.2: Be knowledgeable of contemporary issues related to engineering practice.
Outcome H.3: Show an awareness of the impact of technology on culture and the environment and vice versa.
Outcome H.4: Show an awareness of diverse cultural and humanistic traditions as they relate to engineering practice.

Goal I: Independent Learning: A facility for independent learning and continued professional development.

Outcome I.1: Demonstrate an awareness that the solutions to open-ended problems in nature have multiple solutions that require independent thinking and learning.
Outcome I.2: Recognize that a successful analysis of data in laboratory and design projects requires creative and independent thinking.
Outcome I.3: Demonstrate an understanding that learning is a life long experience and they need to find some of the answers through their own thinking and research.

The first educational outcome, the knowledge of fundamentals, relies on several important aspects of optics where the students should have basic knowledge to be able to suit them as optical engineers. For example, Goal A is categorized into three major outcomes on basic science, mathematics, engineering, and foundation of optical engineering. In the foundations of optical engineering we have 10 major divisions than students need to fulfill to succeed as optical engineers. Each of the goals from A to I have gone through several review with the advice of several constituencies and were tied to the RHIT and ABET learning outcomes [1,2]. Table 1 shows how the OE program outcomes are consistent with the requirements of ABET.

Table 1: Correlation between OE Outcome to ABET ‘a’ through ‘k’ criteria

OE/ABET	a. Funda mentals	b. Experi ment	c. Design	d. Teams	e. Prob-lems	f. Ethics	g. Comm unicate	h. Global	i. Life long	j. Contem . Issues	k. Tools
A: Knowledge of fundamentals											
B1: Interpreting Data											
B2: System Level Modeling											
B3: Experimentation											
C: Design											
D: Team Work											
E: Problem Solving											
F: Ethics											
G: Communications											
H,J: Contemporary Issues											
I: Life Long Learning											

3. Curriculum mapping as assessment tool

In order to evaluate and assess the OE program as how well it is targeted to the outcomes set by the department faculty, advisory board, external industrial client a departmental committee was created and surveys completed. The main task of this committee is also to review the criteria for optical engineering education every year. This committee looks at the assessment results from several sources using concept inventory, RHIT e-portfolio, and curriculum mapping to make recommendation for faculty to modify and alter subject material content and delivery. Additionally, student end-of-the-quarter evaluations give several indications on the subject content and delivery as well. The laboratory reports are surveyed each year by a group of faculty to assess the overall performance of the students. There questionnaires are filled out by faculty every year by looking at the laboratory report of students. All the OE classes have laboratory activities associated with them and several faculty use a standard rubrics for laboratory grading providing a consistent approach to the students.

The optical engineering curriculum is shown in Appendix A. The student needs to have a total of 194 credits to graduate with the optical engineering degree. The courses that are bolded are optical engineering classes where faculty members fill a departmental curriculum mapping every quarter at the end of the class. Faculty members also write a short summary of the improvements and difficulties in the class.

Figure 1 shows the flow chart of the review process used in the overall assessment and refinement process for the OE program. Every quarter before the beginning of the quarter faculty members review the comments made by faculty in the curriculum mapping, the concept inventory test from the class that is administered during the fist week and the ABET files from the previous year. The curriculum committee reviews, on a bi-weekly basis, the developments in the curriculum mapping of the department. At the end of the quarter the committee reviews the improvements made and chooses certain goals to be assessed in order to observe if the educational outcomes are being met. Every year in the department advisory board meeting which consists of industrial and educational leaders make recommendations based on the report submitted to them on the curriculum assessment. They also make recommendations on the goals and outcomes of the OE program. During the annual departmental conclave the recommendation of the board, the curriculum assessment data, and the faculty quarterly reports on courses are collected and certain goals and outcomes are chosen for the following year to be assessed. On a yearly basis, the data from concept inventory, lab assessment matrix, alumni survey, student survey, and the course reviews are looked at to make appropriate changes for the measurement rubrics and to make appropriate curriculum changes. On a three year cycle the department reviews the goals and Outcome of the OE program with the trends in technology, trends in teaching tools, and all surveys for making appropriate changes. This process ensures that several aspects of the curriculum are in place and being assessed and improved in a consistent and regular basis.

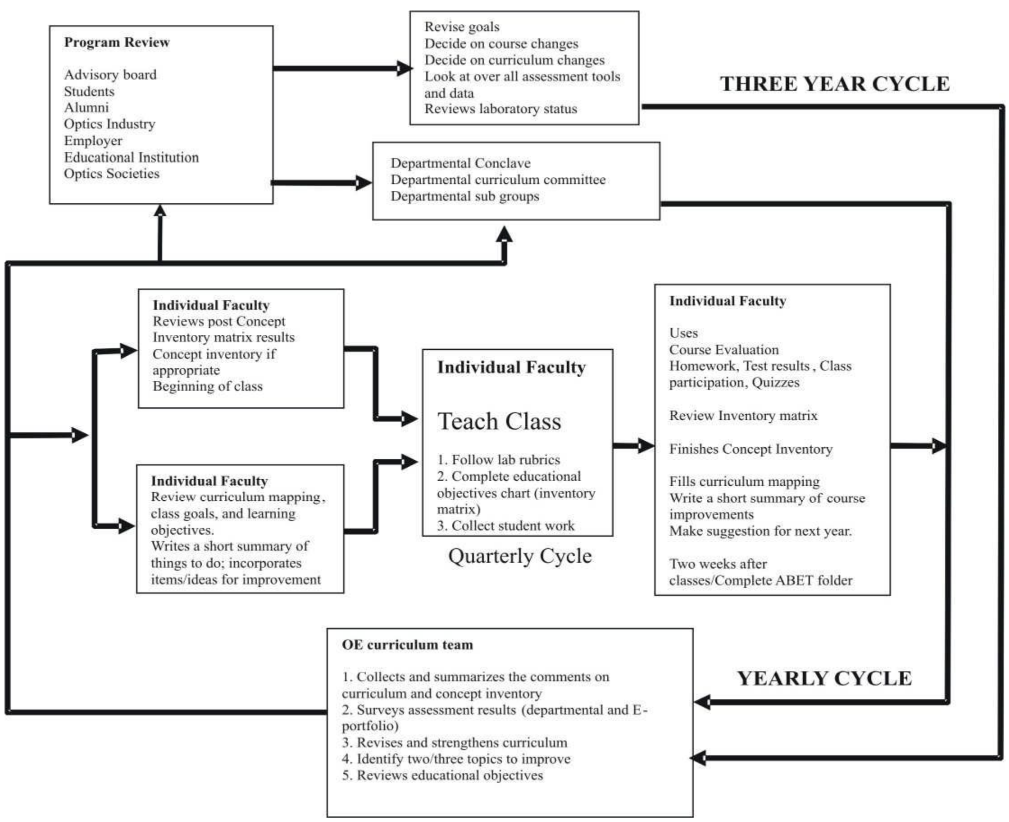

Figure 1. Optical Engineering Curriculum Review and Assessment

In the process of setting up the assessment and evaluation of the OE program the first steps taken in the department was to set-up a method of mapping all the course goals and Outcome to the overall program goals and Outcome. To accomplish this task an Excel spread sheet was developed where each course had a listing of all the educational Outcome of the program and as faculty at the end of the quarter determine what outcomes were met in a particular course they have taught. In a column to the right of the outcomes, faculty marks an ‘x’ meaning that that particular outcome was covered in class. Further, this is also cross checked with the course example materials submitted. Table 2 shows part of the spread sheet used for mapping the goals of Optical Systems OE295.

In the first trial run it was found that the OE curriculum was very strong in delivering the fundamentals but received a poor rating on ethics and communication. Additionally, it was also reflected from the initial trial run of the curriculum mapping a course on optical systems needed to be included at the end of the sophomore year to capture the ever growing demand on the systems approach. For example in the column for OE 495 on the knowledge of fundamentals only 10 out of the 12 outcomes were met can be seen in table 3. Additionally in communication one can see that only one out of the possible five outcomes was being met in almost all the classes. Upon serious review, faculty emphasis on communication in their classes has lead to getting a better distribution of four out of the five outcomes as is evident from table 4.

Outcome A: Knowledge of the Fundamentals **An understanding of the fundamentals of science and engineering**			**OE 495**	Comments and Refinement **Please use the shaded box only**
a		Demonstrate competency in calculus, basic physics and general chemistry.	X	
b		Demonstrate competency in basic engineering science topics with common themes among engineering disciplines.		
c		Demonstrate competency in optical engineering topics, i.e.,	X	
	i	in the sciences, fundamentals of optics	X	
	ii	optical material, devices, sources, and systems	X	
	iii	Advanced topics in optics leading to the application with basic principles	X	
	iv	Systems level understanding of optics	X	
	v	Modeling of light propagations through systems		
	vi	Physical principles of light and how they interact with matter	X	
	vii	Application of optics to measurement	X	
	viii	Optics as enabling technology	X	
	ix	Optical technologies leading to experiments in optics		
	x	appropriate modern experimental and computing techniques in optics	X	
		Aggregate	10	
				Observations/Comments

Table 2. Example of the curriculum mapping for OE495 *Optical Metrology* filled in by the faculty

Additionally, in the process of redesigning the curriculum, it was realized that the students were lacking of learning about numerical and statistical analysis. In the initial design of the curriculum it was decided by the faculty that statistical methods would be covered in the laboratory section of every OE class. As such almost all the courses that are OE courses are laboratory intensive. Assuming that during the process of collecting data, that is random in nature, faculty will teach the technique of applying appropriate statistical tools to address the randomness of the data. Both the senior survey along with curriculum mapping showed the lack of competency gained in this area. Consequently, the department added the course MA225 *Statistical and Numerical Methods* as a required course. Furthermore, the curriculum mapping is used as a cross checking method that ABET committee reviews every year to get a better picture of the overall performance of students in the OE program.

Student Learning Outcomes	OE 495	OE 485	OE 480	OE 450	OE 415	OE 416	OE 393	OE 295	OE 280	OE 172	OE 171	PH 292	PH 405	PH 406
A: Knowledge of Fundamentals	10	9	8	12	7	7	12	12	9	5	5	12	2	4
B1: Interpreting Data	5	5	4	5		5	5	5	5			5	5	5
B2: System Level Modeling	3	3	6	5	6	6	6	5	5			6		6
B3: Experimentation	7	7	7	7	9	9	9	7	7			7	7	7
C: Design	2		2	2	6	7	3	2	2					2
D: Team Work and Deliverables					8	8								
E: Problem Solving	6	5	3	8	9	7	5	4	3	1	1	8	8	8
F: Professional Ethics														
G: Communication	1	1	1	1	5	5	1	1	1	2	2	1	1	1
H,J Contemporary issues														
I: Independent Learning					3	3								

Table 3: Aggregate data for the OE program in 2002-03

Student Learning Outcomes	OE 495	OE 485	OE 480	OE 450	OE 415	OE 416	OE 393	OE 295	OE 280	OE 172	OE 171	PH 292	PH 255	PH 405	PH 406
A: Knowledge of Fundamentals	10	12		10	7	7	13	11	9	6	3	9	6	9	5
B1: Interpreting Data	3	5		5	5	5	5	5	3	1		5	5	5	4
B2: System Level Modeling		6		4	6	6	6	5	5	1			1	6	
B3: Experimentation	8	9		9	9	9	9	9	9			9	9	9	7
C: Design		3		1	7	7	4								
D: Team Work and Deliverables		5		2	9	9						1	2	7	3
E: Problem Solving	2	9		9	6	9	9	7	2	4	1	7	7	9	2
F: Professional Ethics					1	1									1
G: Communication	2	4		4	4	5	5	5	2	5		4		2	2
H,J Contemporary issues		2		2			2			4					
I: Independent Learning		3		3	3	3	3			3		2		3	

Table 4: Aggregate data of how many times a certain outcome in the OE program was met in 2003-04

The curriculum mapping tracks the individual goals and outcomes of courses to the overall goals and outcomes of the OE program. In the continual improvement and evolution of the program courses were gradually introduced and modified. An example of that is the implementation of the three quarter capstone design classes in 2004-05. Several laboratory changes are being made to strengthen the experimentation and design aspects of the learning of the students. A grading rubric has evolved from the early days of the Optics program and is now used as a standard method of grading in several of the OE classes. Additionally the problem solving ability of the student is rigorously being tested in all the classes. Upon graduation optical engineering students must be able to know the fundamentals concepts of optics and be able to determine its appropriate use and apply them in the area of design and testing. Additionally, faculty improvements made during a course of a class is also captured in the curriculum mapping. Table 5 shows mapping comments for OE415, OE393, and OE295. The following are the list of assessment tools used in evaluating the program: faculty input, curriculum mapping, e-portfolio, senior and junior survey, concept inventory, departmental rating, OE departmental committee, yearly review, advisory board, alumni survey, industrial client survey, and dashboard indicators.

Student Learning Outcomes	OE 415	OE 393	OE 295
A: Knowledge of Fundamentals	0	Topics include propagation of light in fibers, fiber structures wave fluids, fabrication, signal degradation, coupling, transmitters, receivers, measurements, sensors	Topics include MTF, radiometry, photometry, system ray matrix and laser beam propagation
B1: Interpreting Data	0	lab component	lab component to the course
B2: System Level Modeling	0	communication systems	0
B3: Experimentation	0	lab component and mini-project	Lab component to the course
C: Design	0	mini-project	0
D: Team Work and Deliverables	0	0	0
E: Problem Solving	0	homework, lab experiments and mini-project	0
F: Professional Ethics	At this time, we plan to teach them ethics in the modified Design sequence.	0	0
G: Communication	0	lab reports and mini-project poster and oral report	lab reports
H,J Contemporary issues	0	fiber communications impact on others	0
I: Independent Learning	0	lab experiments and mini-project	0

Table 5: Example of comments made in the curriculum mapping 2003-04

4. Conclusion

The optical engineering program will pursue ABET accreditation in 2006-07 academic year. This year is the third cycle for doing curriculum mapping for the optical engineering program. The overall benefit of the curriculum mapping has been to determine the overall educational outcome on a snap shot for the whole program. The snap shot profile has helped identify deficiencies and weakness of the program. For example, after the first cycle, the snap shot profile revealed that students were not being exposed enough to Team Work and Professional Ethics as it could not be covered in a one quarter project course. The one quarter project course starts with a statement of work where students have to deliver a prototype in three months. Consequently because of the stringent requirement on the deliverables, there was no time available to teach explicitly ethics and team work even though the students were practicing it in their work. Therefore, we decided to expand the design course to a full year sequence of three courses where the students were explicitly exposed to analyzing the code of ethics for optical engineers, doing a case study, and developing teaming skills. The next cycle of curriculum mapping showed a dramatic change in these two categories strengthening the program in these areas. Secondly, statistical analysis of data was being taught in the labs but did not show explicitly in the curriculum mapping. So upon reviewing the second cycle of the curriculum mapping it was decided to introduce a new course on statistics as a requirement for graduation. Additionally curriculum mapping also provides a continual refinement of courses as an instructor teaches it from year to year and also provides continuity from one instructor to another.

References

[1] Rose-Hulman Institute of Technology, Institutional Research, Planning & Assessment. http://www.rose-hulman.edu/irpa/index.html

[2] Accreditation Board of Engineering and Technology, http://www.abet.org/forms.shtml

APPENDIX A. OPTICAL ENGINEERING CURRICULUM

FRESHMAN

Fall

MA111	Calc I	5
PH111	Physics I	4
CLSK100	College Life	1
RH131	Rhetoric &Com	4
EM104	Graph. Comm.	2
OE171	Holog & Photo	2
	Total	16 or 18*

Winter

PH 112	Physics II	4
MA 112	Calculus II	5
CM 201	Eng. Chem. I	4
CS 120	Fund. of Comp.	4
	Total	17

Spring

PH 113	Physics III	4
MA 113	Calculus III	5
CM 202	Eng. Chem. II	4
OE 172	Optics in Tech	2
EM103	Eng. Design	2
	Total	15 or 17*

SOPHOMORE

Fall

MA223	Eng. Statistics or	4
Or SL151	Prin. of Econ	
PH 235	Many-Part Phys.	4
MA 221	Diff. Eq. I	4
PH292	***Physical Optics***	***4***
	Total	16

Winter

ES203	Electrical Systems	4
PH 255	Fnd. of Mod Phys	4
MA 222	Diff. Eq II	4
OE280	***Paraxial optics***	***4***
	Total	16

Spring

	Elective	4
OE295	***Optical systems***	***4***
SL 151	Prin. of Econ or	4
MA223	Eng. Statistics	
Or ECE200	Circ. & Systems	4
	Total	16

JUNIOR

Fall

PH 316	Elec & Mag Fields	4
HSS	Elective	4
PH 405	***S C Mat & Dev I***	***4***
ECE300	Sig. & Systems	4
	Total	16

Winter

OE 393	***Fiber Opt & App***	***4***
	Elective	4
HSS	Elective or	4
RH330	Technical Comm.	
PH 406	***SC Mat & Dev II***	***4***
	Total	16

Spring

	Elective	4
HSS	Elective	4
RH 330	Technical Comm.	4
or HSS	Elective	
OE450	***Laser Systems***	***4***
	Total	16

SENIOR

Fall

OE 480	***Lens Des&Abb***	***4***
OE 495	***Opt Metrology***	***4***
HSS	Elective	4
OE415	***Opt Eng Des I***	***4***
	Total	16

Winter

OE485	***Electro-Opt. & app.***	***4***
HSS	Elective	4
	Eng. Elective	4
OE416	***Opt Eng Des II***	***4***
	Total	16

Spring

	Eng. Elective	4
HSS	Elective	4
OE 417	***Opt Eng Des III***	***4***
	Elective	4
	Total	16

TOTAL 194

*Only one of OE171 or OE172 is required for graduation. If not taken during the freshmen or sophomore year, the requirement must be replaced with a 300 or 400-level OE course of at least 2 credits