Rethinking Optical Engineering Capstone Design Experience

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ABSTRACT

We developed a three quarter capstone project course sequence for our ABET accredited optical engineering program. In the first course of the sequence we teach design methodology based on a mini-project done concurrently with lectures outlining the product development process. The mini-project is centered on the design of an imaging system. The kit used for this design project consists of a webcam, 20 lenses, and a collection of lens tubes and adaptors. Over the next two quarters the students choose from a selection of client-based projects, where the focus is on team work that culminates in a functional prototype.

Keywords: education, design, engineering

1. INTRODUCTION

A capstone design project is a fundamental component of any accredited engineering curriculum.[1] The optical engineering degree program at Rose-Hulman has a long history of using a project-oriented approach to teach capstone design, similar to many other institutions.[2,3] For four years we used a traditional one-year long (three quarters) course sequence to provide our students with a senior-year capstone design experience.[4,5] However, assessment of student learning outcomes during this time indicated that we needed to boost our student's ability to elicit customer needs and work in teams.

We decided that problem-based learning pedagogy incorporated into the existing project-oriented framework of our course sequence would benefit the students and address the teamwork issue.[6,7] To improve the customer needs issues we decided to focus the course sequence on product development processes and deliverables oriented projects.[8] The changes in our course sequence were introduced three years ago and continually refined. This paper describes the course sequence organization along with several exercises and activities that we use in teaching design for optical engineering majors that we think will be useful to other optics educators.

2. OPTICAL ENGINEERING DESIGN COURSE SEQUENCE

2.1 Outcomes of the design course sequence

The specific outcome related to design that all engineering programs accredited by ABET must demonstrate states that students will attain "(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability."[1] While a capstone design course is not the only course in a curriculum covering elements of design, it is the course where students often encounter a range of realistic constraints. In addition this course sequence must also cover other outcomes such as communication, teamwork, contemporary issues and ethics. All students taking this course have already had courses in physical optics, optical systems, graphical communications, technical communications and introduction to design. Specific course outcomes for the Rose-Hulman optical engineering design course include:

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- Conceptualize and build a prototype product subject to customer needs and constraints
- Work in teams
- Learn the design process and apply it in a product development project
- Plan project activities, set milestones and meet deadlines
- Analyze costs of developing and building a product
- Deliver technical reports and presentations

2.2 Course sequence structure

Using cooperative and problem-based learning requires that students have a problem posed, identify what they need to learn, learn needed topics and apply their knowledge to the problem at hand.[7] We decided to use our first course in the sequence for students to learn design methodology and teamwork using a short term (2 week) design and then repeating the process with another longer term (6 week) mini-project design.

Topics in this course include identifying customer needs, prototyping, product planning, product specifications, concept generation, concept selection, patents, intellectual property and product development economics. Lecture sessions are only given as needed to support problems posed. In addition, we invite a guest speaker from industry to discuss how they approach a product development project and we invite a patent attorney to discuss intellectual property and patents.

The next two courses in our sequence follow a more conventional client-driven capstone design project and encompass the first two quarters of the student's senior year (20 weeks long). Experience from the first course allows the students to quickly form project teams, assign team roles, perform project planning, meet with the client to elicit customer needs, translate customer needs into engineering metrics and develop high-level design concepts. The focus of the project is on team work that culminates in delivery of a functional prototype, final report and presentation. Student teams manage the projects with faculty members acting as mentors for each team. At this point most teams encounter a need to understand issues associated with design for manufacturing, product architecture, robust design and industrial design. We use lectures and class activities to cover these topics.

3. FIRST COURSE IN THE DESIGN SEQUENCE

3.1 Short-term design: optical mount design

The first problem posed to the students is on prototyping. Groups of two to three students are formed to design a mount for an optical component that will support the component in the center of a 2 inch prototyping tube.[9] Students research commercial mounts, brainstorm mount concepts and then design a mount to hold their specific component. Drawings are made of the parts and fabricated using a rapid prototyping facility. Examples of a few parts designed and made by students are shown in Fig. 1. Deliverables for this design include a final memo describing the process followed in arriving at their final design, a CAD drawing of the part, and the completed mount supporting the optical component. On delivery, the optical element must fit and be held securely into the prototype mount.

Figure 1. Examples of optical component mounts that are made using a rapid prototype facility.

3.2 Mini-project: GradeCam

Optical systems are excellent examples to use to illustrate many design principles. For the mini-project problem posed to each team, we needed a design that contained some constraints but one that could also be prototyped and tested in the six weeks available. The problem posed to the students is: “Design a lens for your webcam that will image one of the lines of text on the target chart provided. The target will be placed at a distance of 20 feet from your imaging system. The tube length shall be less than 17 cm and you must only use lenses that are provided. The system must function under normal room lighting conditions.” For prototyping, we developed a kit specifically for this purpose that consists of a webcam, 20 lenses of known and unknown focal lengths, and a collection of lens tubes and adaptors that include focusing tubes and adjustable irises.[9] Figure 2 shows the components of the kit. The line of text with the smallest font says, “If you can clearly read this entire line on the screen you get an A.” Thus, the students coined the name “GradeCam” for this project.

Figure 2. Components of the lens design kit.

The first design task for the student teams is to convert this descriptive problem into a set of engineering metrics, magnification and system focal length. This is probably the most difficult lesson. They always want to immediately begin experimenting by placing lenses in front of the camera without going through a design process or preliminary layout. To avoid this we initially do not give them the entire kit but only provide component specifications, forcing the students to analyze the problem and devise a solution. Once they have a design and optical layout we provide the complete kit to each team. Figure 3 shows an image of a completed GradeCam prototype and the resulting image of the test target.

(a) (b)

Figure 3. Image of the (a) student designed lens prototype and (b) target line captured by the webcam.

4. COURSES TWO AND THREE IN THE DESIGN SEQUENCE

4.1 Course topics and structure

As mentioned earlier, the two remaining courses in our optical engineering design sequence are client sponsored and/or student proposed capstone projects. The additional time allotted for this second stage, two quarters, allows for more comprehensive projects in which the students can fully develop their design and conceptualization abilities. This longer exposure to a single project allows for stronger development of teamwork and other project-related skills. We typically have 4-5 project teams with an average of four students per team. As the project teams are being organized, they often need to learn about product architecture, industrial design, design for manufacturing and assembly, robust design and product development economics. These topics are covered in parallel with the project work and taught using our problem-based approach. Typically, a short lecture is given in class; a problem is posed in some area followed by an activity. For example, reverse engineering a disposable camera teaches the students about design for manufacture and product architecture.

The structure of these courses includes time for formal weekly team meetings where minutes are taken and reported to the faculty. In addition, teams have periodical project review meetings with faculty in which design problems are discussed. Team work experience includes the rotation of team roles among the members of the team. This is carried out during the first half of the second course to ensure each student exercise the critical leader role. After midterm of the second course a permanent team leader is elected by the team and remains fixed until the end of the project

Communication is also covered through multiple assignments in this stage of the course sequence. Teams perform midterm and final presentations in both the second and third courses. The final presentation at the end of the third course also includes a prototype demonstration. In both courses teams must deliver a written report containing a review of the design process followed and a description of the technical aspects of the design. The comprehensive final report deliverable at the end of the third course also includes the project plan, high level design document, product design specification, and economic analysis.

During the past three years we have had several types of projects, some provided from external sources (companies and organizations) while others were internally generated by faculty and/or students. We encourage students to propose a project especially if they are interested in entrepreneurship. In externally sponsored projects, industry representatives define the project requirements, provide guidance to the student team during both quarters by meeting or contacting the student team periodically for progress reviews, and attend the final presentation at the end of the second course. In the case of the internally generated projects, limited funds are provided by the department and project requirements are provided by the faculty.

4.2 Examples of capstone projects

Below are short descriptions and general requirements for a few of the projects completed during the last five years along with the client company sponsoring the specific design project.

Polymer photonic crystal test stand development (Client: CLiPS[10]):

The Center for Layered Polymeric Systems (CLiPS), based at Case Western Reserve University, has developed a method for the production of multi-layered polymer films. These films display unique transmission and reflection spectrums due to their multilayered structure. In order to study these films it would be helpful to be able to accurately measure the transmission spectrum of the film at various positions and angles. To do this, CLiPS requested the design of a test stand to hold a sample of the film within a spectrometer and allow the sample to be both translated and rotated. The design includes a rotation/translation stage, with integrated optical components, for use in the investigation of thin polymer film transmission spectra (see Figure 4a). The design includes the capability of accepting films mounted either between two glass plates, or held by a retaining ring assembly

Dispersive Hall Lighting (Client: Stray Light Optical Technologies[11]):

The goal of this project was to create an optical reflector system for a light emitting plasma source to spread white light uniformly onto a 5' by 20' area of ceiling covered with diffuse material to provide indirect white hallway lighting for clients such as art galleries, museums, or industrial settings. The designed reflector system was modeled using LightTools software and the alpha prototype constructed by the student team met all the design criteria.

Dynamic billboard display system (Entrepreneurship project):

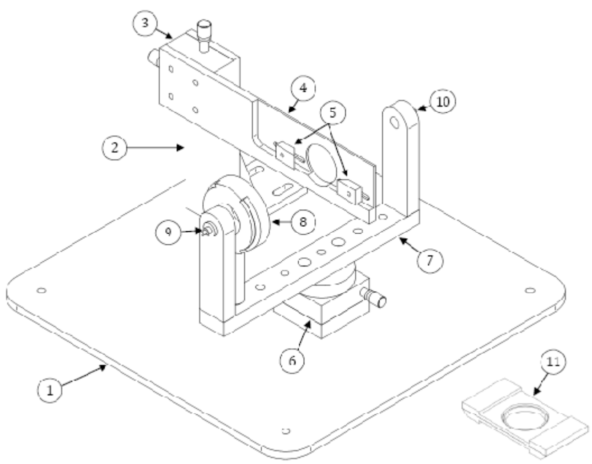
The Dynamic Billboard Display System project was proposed by students to investigate unique attention-getting alternative methods for information display. The approach used for the display was a spinning persistence of vision device utilizing 24 RGB LED's to display an image or message to a person viewing the display (see Figure 4b). The RGB LED's are driven by a microcontroller that can be programmed to customize the displayed message. The device uses an electric motor to spin a blade to which the RGB LED's are attached.

Retinal illuminator (Client: Indiana University School of Optometry)

This device - necessary for proper functionality of an adaptive optics retinal imager - illuminates the eye during imaging for diagnosis. The developed product replaces a laser and fiber optic setup with one based on high brightness light emitting diodes. The device is designed to produce diffuse and uniform illumination without speckle.

Frustrated Total Internal Reflection Touch Screen (Entrepreneurship project)

A simple prototype touch screen display that responds to multiple inputs was developed. The touch screen is comprised of a piece of acrylic that serves as an infrared wave guide. When a user touches a finger to the screen, the position is detected as a decrease in light detected at the waveguide's output. Illumination is accomplished using modulated infrared light emitting diodes and signal detection done using a number of infrared photodiode detectors. In this prototype, eight simultaneous positions could be determined and shown on a computer screen using a computer interface and LabView software.



(a)


(b)

Figure 4. (a) CAD drawing for the "Polymer photonic crystal test stand development" project. (b) Example of a display output for the "Dynamic billboard display system" project.

5. CONCLUSIONS

In summary, optical systems are excellent examples to use to illustrate many design principles. After several years of experience teaching a senior capstone design sequence in our optical engineering undergraduate program we changed the structure of the courses. The motivation for this change was driven by the results of our assessment of the educational program. These results indicated that students needed a more complete understanding of the design process prior to embarking on their capstone design project. To accomplish this we revamped our course sequence in order to teach design methodology using a one quarter mini-project that is directed, and is done concurrently with lectures outlining the product development process. Thus, the students are primed for the capstone design project done in the last two courses in our design sequence.

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[10] http://clips.case.edu/

[11] http://www.straylightoptical.com/