Design Considerations in Engineering Physics: Integrating Design Across the Curriculum

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Abstract

Accredited engineering curricula must include a significant engineering design component appropriate to the student's field of study.[1] Non-traditional engineering programs such as Engineering Physics face unique challenges in incorporating design experiences that are consistent with their goals and mission. The Engineering Physics curriculum at Murray State University was recently accredited by EAC/ABET as an engineering program. In response to recommendations from the program evaluators, efforts have been made to successfully integrate engineering design experiences throughout the four-year curriculum. Even those courses typically considered basic science or engineering science now contain problems, projects, and assignments which deal with elements of engineering design. As students acquire knowledge and skills in basic coursework, they are asked to incorporate engineering standards and realistic design considerations in increasingly advanced assignments. This paper will describe the Engineering Physics program at Murray State University and will outline the comprehensive approach taken to integrate engineering design problems, activities, and experiences into the entire curriculum.

I. Introduction

Today's engineer must be versatile in applying his or her skills across traditional engineering boundaries. Employers in corporate research and development report demand for engineers who are intelligent, articulate, and well educated in the basic sciences as well as in engineering topics. The Engineering Physics program at Murray State University seeks to produce graduates with the skills typically developed in traditional engineering programs, while still maintaining the broad, fundamental, scientific background provided by physics. The intent is to provide program alumni with the flexibility to adapt to tomorrow's demands for modern, interdisciplinary careers in a rapidly changing technological society.

Murray State's Area in Engineering Physics curriculum is an alternative to the typical major-minor combination. Students study fundamental concepts from mechanical and electrical engineering along with topics in advanced physics, advanced mathematics, and computer science. The typical four-year program for well-prepared students is included below.

Bachelor of Science Degree in Engineering Physics
Typical Curriculum

Freshman Fall	Hours
PHY 099 Freshman Orientation	1
PHY 235 Mech., Heat and Waves	4
PHY 236 Mech., Heat and Waves Lab	1
MAT 250 Calculus I	5
ENG 101 Composition	3
CIV 101 World Civilizations	3
	Total 17

Freshman Spring	Hours
PHY 255 Elect., Mag. and Light	4
PHY 256 Elect., Mag. and Light Lab	1
MAT 308 Calculus II	5
ENG 102 Composition and Research	3
CIV 102 World Civilizations	3
PHY 195 Methods in Eng. Physics	1
	Total 17

Sophomore Fall	Hours
PHY 140 Intro to Computer Appl.	3
MAT 309 Calc. III	4
CHE 121 General Chemistry I	5
HUM 211 Humanities I	3
PHY 259 Statics	3
	Total 18

Sophomore Spring	Hours
PHY 330 Dynamics	3
PHY 364 AC/DC Circuit Analysis	4
MAT 411 Differential Equations	3
CHE 122 General Chemistry II	5
HUM 212 Humanities II	3
	Total 18

Junior Fall	Hours
PHY 398 Introduction to Design	3
COM 161 Intro. to Public Speaking	3
ECO 230 Economics I	3
Fine Arts Elective	3
Technical Elective	3
Free Elective	3
	Total 18

Junior Spring	Hours
PHY 440 Thermodynamics	3
PHY 375 Materials Science	3
ECO 231 Economics II	3
Technical Elective	4
Humanities Elective	3
	Total 16

Senior Fall	Hours
PHY 498 Senior Design I	3
MAT 442 or	
CSC 420 Numerical Analysis	3
Technical Electives	9
	Total 15

Senior Spring	Hours
PHY 499 Senior Design II	3
PHY 540 Heat Transfer	3
PHY 560 Electricity and Magnetism	3
Technical Electives	6
	Total 15

The Department of Physics and Engineering Physics currently has approximately 90 majors, with 65 of these enrolled in the Engineering Physics program. The department has seven full-time and two half-time faculty, all of whom have their Ph.D. in either physics or engineering. Several faculty also have industry experience as engineers, bringing a very applied emphasis to all programs in the department. While in existence for approximately 30 years, the program sought and gained EAC/ABET accreditation in 1997, making it one of fifteen such accredited programs in the nation. Graduates of the program routinely go on to pursue graduate degrees in a number of engineering disciplines and/or begin careers with defense-related industries, communications companies, semiconductor manufacturers, and other technical firms.

The required engineering design component of the Engineering Physics program originally appeared only in the third and fourth years of the curriculum. During the ABET program review, the ABET evaluators recommended that design experiences be introduced earlier and more broadly across the curriculum. To that end, department faculty have made a conscientious effort to include design considerations throughout the program and as early as the freshman year. These assignments attempt to address broadly the many and varied features of engineering design, including the development of student creativity, use of open-ended problems, formulation of problem specifications, and consideration of alternative solutions. Realistic constraints, such as economic factors, reliability, and aesthetics are also considered.[2] A description of the courses affected by this effort to expand the engineering design activities in the Engineering Physics curriculum follows.

II. Courses Containing Design Elements

Following is a detailed listing of those courses in the Engineering Physics curriculum which now contain elements of engineering design. A brief description of the design features are given for each course, with examples of the types of problems or assignments that students are required to complete.

A. Freshman Orientation (PHY 099)

The course provides an introduction to university practices and procedures, and to the engineering profession in general. Students work in groups of four to complete two engineering design activities. In the first exercise, “Lost on the Moon,” students must use the knowledge they bring from their high school backgrounds to bear on the problem of being shipwrecked on the lunar surface. Fifteen items are evaluated and ranked according to their usefulness in helping the shipwrecked team survive.

In the second exercise, student teams design and build modular homes. Constraints include the number of modules allowed, with building costs rising as complexity increases. The designs are judged based on aesthetics, marketability, and maximizing profit on the sale of the home. Each design is drawn on graph paper and a model is constructed with sugar cubes for ease of visualization.

B. Introduction to Computing Applications in Science and Engineering (PHY 140)

This course introduces students to computational techniques employed in engineering applications. The C++ language is used in programming assignments. Students are required to select a computational problem posed in one of their engineering courses and design a computer algorithm that will solve the problem.

C. General Physics I (PHY 235)

Students in the mechanics section of general physics are asked to design a system which will launch a human cannonball along a trajectory which leads to avoidance of several obstacles and assures a safe landing in a net located at a specified point. Variables include launch speed and angle, maximum height of the projectile, and elevation of the landing net.

Another past project has been to design an instrument to pull nails from a board. The nail puller has to exert a certain amount of extraction force for a given applied force on the handle, lifting the nail out of the board.

D. Statics (PHY 259)

Two design problems are assigned in the traditional engineering statics course. In the first, a roof truss is to be designed so that a specified load is supported as the truss spans a given distance. The maximum height and slope of the roof are constrained, and economic considerations are introduced as a cost analysis of materials is required. A complete force analysis accompanies the submitted design.

The second design problem asks students to develop an aluminum can crusher as part of a recycling system. The applied force is given, and a criterion for good design is ease of use of the apparatus. A force analysis is required for the design, and it must be accompanied by a discussion of the safety and reliability of the instrument.

E. Dynamics (PHY 330)

The engineering dynamics course includes two design projects taken from a supplement of a textbook by Hibbeler.[3] In the first, students are asked to design a marble-sorting device. In a manufacturing plant, marbles of two different mean diameters roll off a production line with velocities that are normally distributed about a mean with a standard deviation. The two marble sizes are each normally distributed about the two mean diameters. Students must design a device to sort the two different size marbles into two different bins. The design is constrained by the percentage of marbles ending up in the wrong bin.

In the second design project, students work in teams to design and build a rubber-stopper launcher. Each team is furnished with the material to be used to build the launcher. The design is constrained by the fact that the kinetic energy given to the

stopper must come from a single rubber band and the launching must take place in a hallway with an 8' ceiling. Calculations must be done to predict the range of travel of the stopper. A contest is held to find the launcher that will send the stopper the farthest distance. Ranges that differ significantly from predicted ranges must be explained in the report.

F. Mechanics of Materials (PHY 359)

Students are asked to design a torsion-spring suspension for an automobile's front wheels. The spring may consist of a hollow or solid circular shaft, must have a given spring constant value, and is constrained as to its weight, length, maximum deflection, and choice of material. Once this project has been completed, it is extended as students are asked to redesign the geometry of the suspension arm, taking into consideration the material used and the bending, shear, and torsional stresses in the material.

G. Linear Circuits I (PHY 364)

This course is the first in a two semester sequence covering linear circuit theory. The first semester covers both d.c. and a.c. steady state circuits with a brief introduction to op-amps, diodes, and transistors. The second semester is more mathematical and covers transient circuit analysis using Laplace transforms as well as Fourier series and transforms. Typical design problems in the first course might require an analog circuit to perform some particular function such as an op-amp circuit that will integrate and sum various voltages (functions) to produce the output. Another problem might ask the student to design a high current driver for an LED using a transistor. Problems are graded such that simple solutions that would be economical to manufacture are given a higher score than solutions that would work but would be economically impractical to realize.

H. Logic Design I, II (PHY 378, 379)

This two-course sequence provides an introduction to binary logic and the electronic implementation of logic functions. The typical design exercise asks students to design a circuit to illuminate a seven-segment numerical display module. Each segment must activate on a low voltage signal. The best designs incorporate the fewest logic gates and hence are more economical to implement and simpler to analyze.

An additional assignment is the design of electronic sensor systems to install electrical components on a printed-circuit (PC) board once the PC board has been properly positioned in on assembly line. Another activity has the student develop a logic circuit for a conveyor system that will recognize when a shipping carton has reached capacity. Once the carton is full, it advances and is replaced with an empty carton. Thus the focus of the project is on the design of practical systems for use in

industry and the applications are easily transferable to a multitude of realistic scenarios.

I. Introduction to Principles of Design (PHY 398)

This course is the first in the curriculum devoted entirely to the engineering design process. Taken by students in the first semester of their junior year, it covers the formulation of the design problem, creative approaches to the solution of design problems, material selection and economic analysis, and design considerations from conception to product testing and marketing. Specific topics and how they are implemented into the design process include: economic analysis and time value of money, optimization techniques, statistical methods, and the design of experiments. One or two major design projects are required each semester. Typical activities have included: the construction of a Pitot tube which would mount outside a car window to measure velocity; the design of an orifice plate fluid flow transducer to measure flow velocity in a pipe; the design and implementation of a strain gauge laboratory where strain gauges measure deflections on a golf club, a cantilever beam, and a pressurized can. A team project asked students to specify, estimate the cost, and assemble the transducers and other equipment necessary to build a test facility for a small engine assembly line. A local Briggs & Stratton production facility was very supportive in this project, in which students designed a system to measure engine temperature, air and fluid flows through the engine, gas concentrations in the exhaust, and engine vibration. The resulting report was a useful guide for the future installation of such a system in the plant.

J. Laser Physics (PHY 450)

This course addresses fundamental principles of laser operation and applications. Students are required to design a laser resonator that yields radiation of a specified wavelength, output power, and mode structure. Cavity length and mirror properties are variable. Calculations supporting the design are required as well as sketches of the resonator.

K. Senior Project Design Sequence (PHY 498, 499)

Senior Engineering Design is the capstone design course for senior Engineering Physics majors. In this course students are tasked with designing an original product or process using the knowledge they have gained during their four years in the Engineering Physics curriculum. In addition to the student projects many topics are discussed in class to supplement the development of design and testing methods, provide career perspective, and to develop communication skills.

Since the project lasts two complete semesters it is imperative that the projects are selected judiciously. Students are provided a list of around 100 ideas pulled from various databases and web sites in the spring before they start the course. In this way students can start to work on their projects almost immediately when classes start in

the fall. Several important criteria have been established in the choice of design projects in roughly the following priority:

1. Feasibility. Is it physically realizable and can it be done with the available resources in the allowed time?

2. Interest to students. In our experience we have found that the student's motivation is the most important factor in determining the outcome of the project.

3. Working prototype. Projects in which students develop some of the design on an experimental basis are preferred. We would like them to actually build something, which may include prototypes, mock-ups, partial system tests and proofs of concept. Projects that have developed working prototypes have given the students a better concept of the difficulties encountered in taking an idea and making it real.

4. Industry interface. Work with local industry is a benefit to our program, may provide resources that we do not have, is favored by ABET, gives students access to real world experiences and expertise, and may lead to eventual co-ops or employment of students. The down sides are that the student may not like the project, there is increased difficulty in scheduling meetings and reviews, industries often desire quick results, and industries may not allow for an open-ended design experience.

5. Faculty research involvement. Projects that would help develop research equipment and methods are encouraged. It must be primarily the student's design, however. The need for open-endedness, as well as resource and time constraints can limit the availability of these experiences.

6. Teamwork. This is sometimes a goal of design projects, but to work well the project has to be both big enough for everyone to have a piece of the problem and yet something that can be done in short order. To date these types of projects have not been too common. Our standard team size is two. Project proposals for groups of 3 or 4 should specifically delineate the responsibilities of each member. In order to evaluate individual effort, each student must submit project notebooks and weekly memos. Students are assigned to design review teams to evaluate another group's project to provide a true team experience. We plan to incorporate students in PHY 398 into the design review teams in the future. These teams meet once during each semester. At these meetings each student provides written input based on his role on the team and the team assembles a design review report.

7. Socially redeeming features. Projects involving occupational health and safety, help to disabled citizens and environmental improvements are encouraged.

8. Potential use as a laboratory experience. Since our program is rather new, any help we can get in developing laboratory experiences is welcome. Some projects may also have additional aspects that can be continued in following years. This is another reason for students keeping the design notebooks. Student-designed labs may also be a source of pride for students when they become alumni.

In addition to the student projects, seminars are given to supplement the theoretical knowledge students have gained in the curriculum. Topics include a six-class sequence on written communication, a series of classes on engineering drawing, and classes and discussions on career development, licensing, creativity, intellectual property, ethics, reliability, maintainability, and quality control.

Most of the student work revolves around their project. They start by writing a letter of inquiry that is followed by a formal proposal and mid-course review during the first semester. In the second semester students submit test reports and a final project report. They also develop a poster presentation for their project and give an oral report.

In addition to the project work, students are also given a common tasking during the first semester to get their feet wet in drawing and budgeting for a project. During this past semester students had to design a platform for removing wallpaper and then convert the materials economically into a picnic table. Students present their designs orally to the rest of the class and the class provides feedback. These mini-projects provide a platform for the class to discuss creativity, drawing technique, and the prioritization of design objectives.

Examples of past Senior Design projects include the following:

- Small engine dynamometer to measure torque and horsepower of an engine
- Plan for land remediation at Eglin AFB, Florida
- Marketing analysis and plan for use of gypsum biproduct at local quarry
- Hall Effect transducer to measure vibrations and displacements of cantilever beams
- Aluminum and paper recycling station emphasizing convenience and portability
- Parking lot monitoring system to alert drivers when lot is filled to capacity
- Window-supported scaffolding system for house painters
- Remote controlled deadbolt lock system for homeowners
- Briggs & Stratton engine assembly line transfer modification
- NASA reduced gravity project (vomit comet)

L. Fluid Mechanics (PHY 532)

The fluid mechanics course covers fluid statics, integral and differential flow solutions, similitude, external and internal flow, and an introduction to compressible flow. The use of similitude and dimensional analysis is taught in a manner that is useful for the design process in fluid mechanics as well as other engineering areas. A

semester design project is assigned usually in the area of pipe or vent flow. This allows the student to make engineering choices such as pipe diameter, pump or fan sizing, and route selection.

M. Heat Transfer (PHY 540)

The heat transfer course includes all three methods of heat transfer: conduction, convection, and radiation. Heat exchangers and mass transfer are also included. The design element and the use of heat transfer in design is emphasized throughout the course. Many design scenarios are posed to the students in weekly assignments as well as on exams. A design project related to heat transfer is also assigned to allow students to work in groups of three or four. This project usually includes problems involving optimization and cost reduction.

III. Conclusion

The introduction of design activities throughout the curriculum has been well-received by students. Design problems help bring engineering science and basic science concepts out of the realm of imposing mathematical equations and emphasize the application of those concepts to accomplish an engineering task. The relationships between variables, the limitations imposed by realistic constraints, and the experience of refining and improving a design are just a few of the practical considerations that serve as a benefit to both engineering and physics students. Design activities also give students and faculty an opportunity to experiment with active learning approaches that are not always attempted in the typical engineering science courses. Many students find that this method of teaching suits their learning and enjoy this addition to traditional teaching methods.

It should be noted that the proliferation of design activities in the curriculum requires significant faculty and administrative support. Faculty must be willing to take the time to thoroughly plan the activity so that while being instructive and realistic, it is also of interest to the student and reasonable in terms of time, effort, and cost. Many textbooks now include open-ended problems and offer suggestions for design activities. However, it is often necessary for the faculty member to use his/her experience to develop appropriate assignments. If the activity includes the construction of a device, materials and supplies will be required. The cost of these must obviously be in line with departmental budgetary constraints.

Any department considering future accreditation of their Engineering Physics programs would be wise to become familiar with issues pertaining to the inclusion of design activities. The authors will be happy to discuss their approaches with interested parties.

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