Teaching Design Skills in the Freshman Engineering Curriculum

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With the mission of introducing engineering early in the undergraduate curriculum, the freshman engineering course has developed the following goals: (1) Introduce an engineering approach for problem-solving through team projects; (2) Demonstrate the importance of graphical, oral, and written communication skills; (3) Incorporate the skill oriented tasks, such as analysis and interpretation of experimental data, into design projects. Essential skills taught in the freshman engineering course are: graphical presentation including sketching and solid modeling, use of engineering principles with physics and math for analysis, construction and testing of working prototypes, and documentation of the solution. Students are also instructed on how to manage their projects and work in teams.

This paper discusses the challenges and opportunities that are involved in instituting a design-driven freshman curriculum at a large university. The paper will discuss issues related to design curriculum development, type and ingredients of a team design project, laboratory preparations, and cost and benefits of implementing the design activities. Although our efforts are ongoing, significant gains have been achieved that are worth sharing with the engineering education community.

Introduction

In order to implement a design curriculum at the first-year level in engineering, several factors must be considered: the student level of prerequisite knowledge of engineering concepts, the breadth of engineering topics to be covered, and the format for presentation of the design. Lack of certain prerequisite knowledge of engineering concepts can be the biggest stumbling block; however if the design includes an application of physics principles or relies on the mathematics that is most commonly encountered in the freshman year, then the design serves the dual purpose of integrating the math and science into the engineering curriculum. Engineering design rarely focuses on one discipline, but is rather a combination of mechanical, electrical, industrial, etc. engineering. A key factor when introducing design at the freshman level is to include these realistic situations and illustrate the inter-disciplinary nature of design from the beginning. Additionally, the format of design must be considered from both instructor presentation and student deliverables. Oral, graphical and written communication are important in conveying design; therefore, instruction in all areas should be included in the course. While having a design described entirely on paper is possible, other alternatives exist: prototype development and a complete working model. The decision as to which is appropriate for a specific curriculum depends on human and financial resources as well as the time available for the activity.

At Penn State, the total enrollment of incoming engineering freshmen (in 18 campuses) exceeds 1000 students per semester. All engineering students are required to take the introductory course, ‘Engineering Design and Graphics.’ This is a 3 credit course with 6 contact hours per week. The class size is maintained at 32 students per section, and 14 to 15 sections are offered per semester at the main campus.

Ourprior design projects were limited topaper designs thatcould rehandled graphically'. Emphasis in those early projects was placed on geometric constraints and the assignment was limited to a set of working drawings. The positive student response and the national increased awareness for open-ended design projects at the freshman level, prompted a more systematic approach to the instruction of design topics. The next effort placed equal emphasis on graphics, CAD, simulation and experiments. A hands-on design project was the culmination of instruction in all those tools and skills. While the individual components in the course structure were becoming better defined, the engineering design component was still weakly linked to the other components. An effort was made to combine some experiments with engineering applications[3] and provide instruction in design, teamwork and creativity. The design activities presented herein strengthen the curriculum that was developed earlier[2]. While topics have been retained, the emphasis is now placed on design and the other course components are treated as skills necessary to effectively communicate design.

The freshman engineering course is expected to fulfill three goals: (1) Introduce an engineering approach for problem-solving through team projects; (2) Demonstrate the importance of graphical, oral, and written communication skills; (3) Incorporate the skill oriented tasks, such as analysis and interpretation of experimental data, into design projects. These goals have been addressed through three interrelated modules, which comprise the engineering design and graphics course. These modules are: Design Graphics, Solid Modeling Presentation / Analysis, and Hands-on Team Design Projects. Each module places an emphasis on design projects, team work and a general appreciation for engineering. However, the team design projects are used as a means for the students to apply the skills learned in the entire course.

Development of a Design Curriculum

Developing a design curriculum for freshman engineering students is a delegate process when one considers that such curriculum must:

(1) give students a sense of what engineering is and what the engineering design is,
(2) accommodate different levels of background in science and math,
(3) emphasize relevance of science to engineering and engineering design,
(4) be easy to understand and apply, yet be interesting and challenging,

Also, the fact that the freshman engineering course is likely to have no pre-requisites mandates that the design curriculum must be self contained. The theme of each design project is not as important as the skills learned by doing the projects. However, having a motivating theme seems to increase students' interest and their degree of involvement in the projects. Therefore, careful planning and piloting are essential before adopting a design curriculum for the entire freshman class.

The freshman design curriculum at Penn State[4] includes problems which focus on an engineering principle, have multiple solutions, encourage the student teams to explore several possibilities, build prototypes of the best ideas, and finally demonstrate and document a working design. The curriculum focuses on teaching students the basic skills needed in engineering design through hands-on experience that eases the transition from theory to applications and working prototypes. Students complete two design projects over the semester, with each project spanning six 2-hour sessions in a laboratory setting. The particular theme of the first project is to build a working prototype of a weighing system using strain gages and a beam. The project is presented and discussed during the first design session of the semester, where the main concept and the necessary instrumentation are identified. The purpose of our design curriculum is to gradually allow the students to master the concept and apply it in their design of the weighing system (Table 1), The students are closely guided during this first project, so that to ensure that each team in the class will achieve a certain degree of success. In the second design project, which is sometimes related to the first project, each team of students must present several possible solutions, analyze and decide based on their analysis on a final solution. A prototype of the best solution is then built, demonstrated in front of their peers, and documented in the form of a presentation and a written report.

Table 1: Schedule of the design curriculum

Weeks	*The Process*	*An Example Project:* A Weighing System
1-3	• Introduction of Theory • Data Acquisition & Experimentation • Develop an understanding of a system performance as a function of key variables • Experiments to verify the performance of a system • Error estimates and calibration • Lab Reports	Strain Gages to Measure Deformation in Beams • Experiments to understand the behavior of resistors • Applying resistor concepts to strain gage • Study the behavior of beams under various loading conditions • Measure of strain using strain gages
4-6	• Design and build a working prototype based on the manipulation of the key variables	Design and build a weighing system using Strain Gages & Beams to measure up to IO lbs. • Build an electrical circuit to convert change in resistance of the strain gage to voltage. • Design a beam system incorporating a strain gage to measure the load applied to the beam. • Demonstrate and present the working design to class.
7	Introduction of the second project • The project has the option of using the theoretical base and experimental knowledge discussed in weeks 1-6 or follow a new approach. • The project has significant industrial and social relevance. • Encourages creative solutions	Design a Bathroom Weighing Scale to weigh up to ***300*** lb. • The students have the option to use any principle of their choice to design the system. i.e. They need not use strain gages. • The design must be functional, user friendly, and marketable.
8-10	Build and demonstrate a first prototype • First crude solution for the design	
11-13	Build and demonstrate a second prototype • Improved version of the first design	
14	Final prototype demonstration	
15	Optimization • Analyze the failures in the final prototype and develop a report incorporating the final modifications.	

Teaching Design Skills "Soft Skills":

The shift to a design driven Curriculum requires that the instruction be shifted from lecture and practice to discovery and presentation. In many ways, this shift is reflected in not only how material is presented but when it is presented. The soft skills are ideally taught "just in time." In this manner they are covered in the context of the current activity and can be practiced immediately. For that reason teamwork and brainstorming are introduced when the first design project is assigned. For example, team building exercises are employed initially to have students understand their role and the roles of their teammates. As a subset of that activity, each student is required to formulate a prescribed number of solutions to the design problem. This requirement forces the participation of each student and illustrates the importance of member involvement. The instruction in these areas is critical to the success of student learning outcomes in teamwork. These activities must be handled in class with proper supervision and structure.

Other soft skills taught in the course includes:

1. Project management- this involves developing and using timetables and milestone charts, where with proper instructions students arc e xposed to the value of schedules and individual responsibility.
2. Effective use of sketching/CAD- Students are required to communicate ideas and solutions and maintain those ideas in their design notebook for reference. Solid models are also created for their best designs. These models are included in their report and presentation.
3. Spreadsheet analysis- This includes the use of spreadsheet and graphs to obtain calibration curves, explore the influence of design parameters on the overall performance of a prototype, analyze test results, and so forth.
4. Preparing a professional presentation- Toward the end of each project, every student team will make a 10 minute oral presentation of their design and respond to questions from their classmates. In order to facilitate the preparation of a quality presentation, students are introd uced to a friendl y but powerful software package that is capable of combining their text, graphs, and drawings in a single document. 'l-he presentation is made directly from the computer to a projection system allowing students to showcase their work in a very professional and impressive manner.

It may sound unrealistic to teach all the above skills within the available time for the course. However, many of the available design tools and software require minimum instructions. We do not feel that it is our role to teach the students all the fine det ails about a particu l ar software. Rather, we consider that it is our responsibility to give the students proper instructions and updated tools that allow them to achieve the main tasks. That way, we get the door opened for thcm and give them the opportunity to explore each tool further not only in their first engineering course, but also in their future courses.

Team Design Projects

Our initial efforts at design projects tended to include an element of fun. Most designs were competitive and focused on best time or farthest distance performance. The relevance to an engineering product was limited or nonexistent in most cases. The lack of industrial relevance or connection to engineering principles that would be of value in engineering: design was viewed as a shortcoming. The opportunity 10 relate engineering principles to products is worth pursuing, not only because it reinforces the material that students are learning in their math and physics courses, but because it illustrates the importance of being literate in multidisciplines.

Ideally, the design project is introduced by the engineers from an industrial sponsor, but if that is not possible, the instructor should relate the design project 10 an industry. As an example, several semesters ago, the freshman design project was presented by engineers from a paper products plant. The design problem **was** to develop an automated system that would sort various wood chips based on size and weight so that the proper combination of wood chips could be processed to make specific weightsand qualities of paper. The students were not given wood chips, but instead twenty-five balls that contained a mixture of three types of balls- Type 1: weight, W, diameter, D; Type 2: weight, W, diameter, d; and Type 3: weight, w, diameter, D. The students' reports focused on automated processing methods and clearly showed that they treated the balls as wood chips and were able to present their ideas in the context intended.

As with the just-in-time approach to presenting the soft skills, the appropriate engineering principles, analysis methods or relevant calculations can be handled as the need arises through the project. Recently, students were asked to maximize the efficiency of transporting bars of soap vertically. Efficiency was measured as the ratio of the potential energy at the end of the cycle to the work put into the system. A well-timed lecture will reinforce the critical design components and illustrate the analysis needed to compute efficiency. Further refinement and analysis can be handled by repeating the calculation.

A well thought and planned project must include several essential as well as complementary ingredients. For the essential ingredients, the project must:

- be doable-with some degree of success and within the time limit
- involve several parallel and inter-related tasks
- have multiple solutions whose concepts can be easily understood
- involve reasonable level of analysis, not just trial and error
- have a measurable and rewarding results
- have an element of challenge

and for the complementary ingredients, it is desirable that a project has:

- a motivating theme
- industrial relevance
- an industrial sponsor
- a competition element

Students Feedback

To assess the new design curriculum, students were surveyed during the transition semester where half of our freshmen were taught the traditional graphics curriculum and the other half were in the new design-driven curriculum. Needless to say that all our sections are now using the new design-driven curriculum, the results of this survey clearly demonstrated that the new curriculum is in the right direction.

The majority of the students (79%) liked working in teams, and most (64%) thought that they learned a lot from working in teams, even though most of the students did not think that working in teams helped their grade. Also, students liked and felt that they learned from the team design projects and competition. When compared with the old curriculum, students thought that they learned more, enjoyed more, and were motivated more by the new curriculum. In fact, students considered the design projects and the competition to be the most motivational component of the course. However, the most encouraging feedback is that almost two-third of the students thought that the freshman course increased their interest in engineering. Obviously, there are some improvements that can still be done to the course to bring up this number.

Concluding Remarks

The rewards of involving first year engineering students in design projects are numerous: early exposure to engineering, learning team work, development of oral, graphical and written communication skills, and learning about engineering instruments and software, are to name j ust a few of the benefits. The focus of the curriculum must be placed on delivering to the students the basic skills and tools in engineering design.. The impact of implementing this module in the freshmen year was felt in many ways. Students carried out their communication skills into the solid modeling project where their performance and ability to document their work showed significant improvement as compared with previous semesters.

There are also challenges in implementing and maintaining such a dynamic curriculum. Instructors may need training in keeping student teams functioning and motivated throughout the semester. Grading team activities is another challenge where performance of the team as well as individual students on the team must be considered. Managing student labs, having a new project every semester, as well as exploring current and emerging software and implementing new teaching techniques all require faculty time and resources.

As a final remark, this undertaking was the product of a team effort by the authors taking into account the advise and recommendations of many other engineering faculty. It is clear to the authors that the benefits of implementing design activities in the first year engineering curriculum much outweigh the costs.

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