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Promoting Innovation in a Junior-level, Multidisciplinary, Electro-Mechanical Design Course

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Abstract

Junior students in engineering and engineering technology programs at Western Carolina University (WCU) take a multidisciplinary design course as a key component of their four-year project-based learning (PBL) sequence. The course is designed to capitalize on the students' diverse technical backgrounds and build on the skills they developed in the freshman- and sophomore-level PBL courses. The junior-level course, ENGR 350 (Engineering Principles and Practices III), hosts students from all four undergraduate programs in the school, spanning electrical and mechanical realms. ENGR 350 is in its fourth academic year and introduces students to the product development process by allowing them to design, build, and test alpha prototypes that are student-generated ideas. Students propose ideas that are electro-mechanical in nature; they are grouped into teams; and they go through the product development cycle of a subset of the project ideas. Not only has this course become an outstanding opportunity to assess each program at a common point, it has served as a key feeder to the senior capstone project, a two-semester sequence that is industry sponsored. Projects that have been implemented in ENGR 350 have been wide-ranging in nature, such as a motor-driven fishing reel for anglers with the use of one arm; an inexpensive water-filtration system for countries with water challenges; a self-propelled longboard (skateboard) with braking capability; a flounder-gigging pole designed for night use; an emergency cell phone charger that is shaker-activated; autonomous robots for regional competitions; and a bicycle-powered lighted safety device for bikers. In addition to its key role in the PBL course sequence, this ENGR 350 course has satisfied a need expressed by the school's Industrial Advisory Committee (IAC), which meets annually to provide feedback on the engineering and engineering technology programs. The IAC had encouraged WCU to promote innovation in multidisciplinary engineering design. The ENGR 350 course was in its infancy at the time, and has developed into a strong example of what the IAC had requested. This paper showcases a few projects to demonstrate the effectiveness of this course in the project-based learning curriculum.

Introduction

The School of Engineering and Technology at Western Carolina University has four undergraduate programs and a masters program. The undergraduate programs are taught primarily as resident courses on the main campus, while one program is taught as a distance course. The four resident undergraduate programs include Electrical Engineering (BSEE), Electrical and Computer Engineering Technology (BSECET), Engineering with multiple concentrations (BSE), and Engineering Technology (BSET). These programs include 569 students – 105 BSEE, 92 BSECET, 211 BSE, and 161 BSET – distributed rather evenly across the freshmen through senior years.

The two engineering programs, BSEE and BSE, combine a strong foundation in engineering theory with a focus on the application of that theory in practice. The engineering technology programs, BSECET and BSET, emphasize an applied engineering approach, preparing students

well for roles in manufacturing, design, quality, or testing. All four of these programs share a common set of courses, called the Project-Based Learning (PBL) core, starting with a freshman introductory engineering course and culminating with a senior capstone experience. This paper focuses on ENGR 350, which is the junior-level PBL course. It covers the structure of the course and examines how electro-mechanical design projects in the junior year prepare students for their senior capstone experience.

Project-Based Learning Structure

Engineering and technology programs have sought to establish the correct balance of theory and practice to maximize student learning. It is often difficult to overcome preconceived notions that students bring with them, such as the comparative speeds at which objects of different weights fall under the force of gravity [1]. By engaging students through demonstrations, hands-on design and fabrication projects, and physical laboratories, misconceptions can be overcome, thus reinforcing the fundamental principles needed in engineering education [2], [3].

Eight years ago, the School of Engineering and Technology restructured its undergraduate curricula to include the PBL core in each program. Each academic year BSEE, BSECET, BSE, and BSET students experience one or more PBL courses, in the following sequence:

Freshman year: ENGR 199 - Introduction to Engineering Practices and Principles I
Sophomore year: ENGR 200 - Engineering Practices and Principles II
Junior year: ENGR 350 - Engineering Practices and Principles III
Senior year, fall semester: ENGR 400 – Engineering Capstone I
Senior year, spring semester: ENGR 450 – Engineering Capstone II

These PBL courses have been designed to focus on engineering topics common to all disciplines, such as systems of units, conversion of units, problem solving skills, communications, teamwork, and project management. Topics introduced in the early portion of the sequence are reinforced in the latter courses, providing students with a level of proficiency that will serve them well in industry.

The freshman and sophomore PBL courses, ENGR 199 and ENGR 200, introduce projects with relatively straight-forward solutions and a minimal amount of autonomy. The junior PBL course, ENGR 350, is a platform for product development of open-ended projects. The senior PBL courses, ENGR 400 and ENGR 450, are a two-semester sequence with industry-sponsored open-ended projects; the first semester is dedicated to the design of a product or solution, while the second semester is used to implement and test [4].

ENGR 350 Course Structure

ENGR 350, Engineering Practices and Principles III, is structured around a product development approach, using the Ulrich and Eppinger text on product design and development [5]. ENGR 350 is a three credit course that is taught in a lecture/lab format. The contact time is divided into two sessions of 100 minutes each, every week of the semester. One of the two sessions is typically used for team meetings and tasks related to the project. The course was developed with

several key objectives in mind. First, it needed to provide a bridge in the PBL sequence from the first two courses, which contained a great deal of guidance, to the open-ended, autonomous format of the senior capstone. Second, it was important that it provided the structure for students in all four undergraduate programs to learn project management and product development, as it applied to their disciplines and interfaced with others'. Finally, ENGR 350 provided the vehicle to assess several ABET student outcomes that are often challenging to assess for EAC and ETAC accredited programs [6], [7].

Given these goals for the course, the following course learning objectives were established: At the successful completion of this course, the student will be able to:

- develop a problem statement and a requirements matrix for a relevant industry problem
- perform a preliminary design analysis using appropriate computer and mathematical tools
- synthesize a technical solution to design specifications utilizing tools and materials
- quantitatively analyze multiple alternatives and down select to one approach
- develop a Project Plan, including a Work Breakdown Structure (WBS) and Master Schedule
- apply the project plan to monitor, control and report task status and completion
- assess risk and develop a risk plan with mitigation strategies
- create a process for requirements verification and validation
- identify and perform tests and methods to evaluate a design to the original specifications
- identify and evaluate design shortfalls and improve the design in terms of meeting specification including failure mode analysis
- demonstrate effective written and oral communications in project documentation and presentations
- demonstrate an understanding of and a commitment to professional and ethical responsibilities, including a respect for diversity
- demonstrate an understand of the impact of engineering solutions in global, economic, environmental, and societal context
- demonstrate a knowledge of contemporary issues in engineering

While this paper focuses on the electro-mechanical product development aspect of this course, it should be noted that the last three learning objectives, map directly into ABET student outcomes for both EAC and ETAC accredited programs. Professional and ethical responsibilities are assessed using the teaching modules in *The Incident at Morales* [8]. Developed through NSF funding by the National Institute for Engineering Ethics (NIEE), this short movie presents a fictitious, but realistic story that places a young engineer in the middle of multiple ethical situations. The video allows for breaks to discuss subtle and egregious ethical events in the *Morales* story. The last two ENGR 350 course objectives are met by requiring student reflection papers on topics covered by guest speakers from industry. The other learning objectives are achieved through the project-based approach.

Early in the semester each student pitches an idea for a new product that combines electrical and mechanical design content. The instructor reviews each of the ideas and selects approximately one fourth of the ideas, modifying them, as appropriate to fit the scope of the course. The instructor also divides the students into multi-disciplinary teams of four, and launches the teams

into the product development process. The class learns about the product development process inside and outside the classroom, as the teams walk through that process with their projects. Each team submits a series of reports, presentations, and demonstrations, which guide them from an idea and a blank sheet of paper to a finished alpha prototype and the design documentation to build it. The team assignments for the semester are:

Project Report 1: Project Planning
Project Report 2: Conceptual Designs
Project Report 3: Conceptual Design 'Down Selection'
Project Report 4: Preliminary Design
Project Report 5 (Presentation): Detail Design Review
Project Report 6: Fabrication, Assembly, and Testing
Final Demonstration
Final Presentation

In Project Report 1 the teams lay out customer requirements and a preliminary project plan. Report 2 requires the project teams to document initial concepts and identify target specifications. In Report 3 students employ a technique of concept screening and down selection to pick the best conceptual design. Teams submit their preliminary designs in Project Report 4, and then undergo a detailed design review in Report 5, structured as a team presentation. The final written assignment, Report 6, documents the fabrication, assembly, and testing plan for the alpha prototypes. The semester concludes with a final demonstration of the functional prototypes and an oral presentation.

Electro-Mechanical Design Projects

ENGR 350 has proven to be a rewarding challenge for students, as well as instructors. The course provides an opportunity for students to innovate in an environment where it is safe to try new ideas without the performance pressures experienced in industry. This gives them the opportunity to develop their creative design skills and to produce new products that reflect this creativity such as:

- a motor-driven fishing reel for anglers with the use of one arm
- an inexpensive water-filtration system for countries with water challenges
- a self-propelled longboard (skateboard) with braking capability
- a plant watering system to maintain healthy, unattended house plants
- an aluminum can-crushing device
- a lighted, flounder-gigging pole designed for night use
- an emergency cell phone charger that is shaker-activated
- autonomous robots for regional competitions
- a 3D puzzle that lights up and plays music when solved
- a snowboard that lights up on the side the snowboarder is leaning toward
- a bicycle-powered lighted safety device for bikers
- a space-saving LED mountain bike light
- a dynamic, accelerometer-integrated, lighted juggling ball

The scope and technical challenge of the projects has proven very important to gauge appropriately. Being a one-semester course at the junior level, it is critical that the projects do not contain technical content beyond the capabilities of the students, yet provide enough challenge to stretch them outside their comfort zones. The course also contains objectives that focus on topics that are not purely technical in nature – ethics, professionalism, teamwork, etc. – and thus, appropriate contact time must be allotted to allow these to develop.

Conclusions

The ENGR 350 course, Engineering Practices and Principles III, has proven to be a successful addition to the PBL course sequence, based on feedback from faculty, students, and industry partners. Student feedback is generally positive, as noted in the student assessment of instruction (SAI) administered at the end of each semester. While many students do not appreciate the number of written reports, most of them acknowledge the importance of this documentation, as they progress to senior capstone and then into their professional careers. Most students thoroughly enjoy the product development process, especially when they develop alpha prototypes that come from student-generated ideas. As senior capstone students, many of them point back to their junior PBL experience as the foundation for their preparation for capstone.

Faculty generally provide positive feedback on the course. Instructors have noted the same benefits that students identified, as well as several others. The teaming aspect has provided many students with their first significant experience in which their grade is dependent heavily on people other than just themselves – a scary proposition for many. The end-of-project peer evaluation, which includes both self and peer evaluations, give the instructor an effective tool to identify students who did not pull their weight. The ability to assess student outcomes across multiple programs in areas that are often difficult to assess has proven invaluable. The quality of most team projects has been exceptional with many prototypes approaching professional grade products. Instructors of the senior capstone have also noted an improvement in student preparedness, as they have completed the ENGR 350 course. The senior capstone sequence had been in place for approximately three years prior to the introduction of ENGR 350. As the PBL sequence matured and students progressed through the full range of courses, the benefit of this structured approach became clear.

Industry partners have provided encouraging feedback on several occasions. Two years after the introduction of ENGR 350 the industrial advisory committee (IAC) was meeting with the faculty in the School of Engineering and Technology. One of the major suggestions from the IAC was to provide an environment for students to practice multi-disciplinary innovative product development in our curriculum. The faculty pointed to this course much to the delight of the IAC. On another occasion the IAC was meeting one year after the completion of the first ENGR 350 course; they were viewing the capstone projects of the first students to have completed the entire PBL sequence from freshman through senior. One of the IAC members pointed out that the projects that year tended to be of a higher caliber than those of previous years, noting that these students were the first to finish the entire PBL sequence.

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