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Designing and teaching multidisciplinary project-based courses to satisfy the ABET 2000 Engineering Criteria

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ABSTRACT: One important educational outcome required of any engineering programme, as per ABET 2000 Criteria 3, is the ability of engineering graduates to function in multidisciplinary teams. In order to address this requirement, the curriculum committees of the engineering programmes at Indiana University-Purdue University Fort Wayne (IPFW), Fort Wayne, USA, have designed several multidisciplinary project-based courses. These courses involve computer, electrical and mechanical engineering students. Five multidisciplinary project-based courses, which are distributed over the freshman, sophomore and senior years, have been developed and implemented. In these courses, real world multidisciplinary design experiences are used to prepare IPFW graduates to enter today's workforce. In this article, the authors present a brief description of these courses along with the authors' experiences in the development and teaching of the five multidisciplinary project-based courses.

INTRODUCTION

ABET 2000 Criteria 3 requires that for an engineering programme to be accredited, it must demonstrate that appropriate educational outcomes are met. In 2000, ABET changed from a *bean counting* approach to an outcome-oriented approach – EC2000. Engineering programmes must now demonstrate that their graduates have 11 specific outcomes known as (a) through (k). According to these criteria, all undergraduate engineering programmes need to provide for design experience and multidisciplinary activity. This fact is stated in outcomes (c) and (d), respectively: *an ability to design a system, component, or process to meet desired needs* and *an ability to function on multidisciplinary teams* [1]. The approach utilised to achieve these two outcomes varies considerably at different institutions [2-6]. However, in most of these approaches, the multidisciplinary experience is limited to the capstone senior design project.

To meet the requirements of the ABET accreditation criteria, the curriculum committees of the engineering programmes (namely: computer, electrical and mechanical) at Indiana University-Purdue University Fort Wayne (IPFW), Fort Wayne, USA, have designed several multidisciplinary project-based courses. These courses involve computer, electrical and mechanical engineering students. Five multidisciplinary project-based courses are distributed throughout the curriculum (freshman level: ENGR 199 *Introduction to Engineering Design*; sophomore level: ECE 280/ME 280 *Electronics and System Engineering through Robotics*, and ECE 281/ME 281 *Electronics and System Engineering through Robotics Laboratory*; and senior level: ENGR 410 *Multidisciplinary Senior Design I* and ENGR 410 *Multidisciplinary Senior Design II*). These were developed and implemented in autumn 2002. In these courses, real world multidisciplinary design experiences are used to prepare IPFW graduates for entry into today's workforce.

For an engineering curriculum to be successful, it must give students the opportunity to become exposed to engineering disciplines by introducing problem situations that force them to link theory to practical real-world problems involving areas outside their own engineering disciplines. A multidisciplinary team environment forces students to interact with people that do not necessarily think like themselves and value the skills that other team members provide.

The goals of these newly developed multidisciplinary project-based courses at the IPFW are to broaden the students' concept of engineering problems to include more than one engineering discipline, to encourage students' creativity, to enhance their communication skills, and to provide a valuable educational experience for students to function in multidisciplinary teams.

The objective of this article is to describe the five multidisciplinary project-based courses and present the authors' experiences in the development and teaching of these courses.

FRESHMAN YEAR

ENGR 199 *Introduction to Engineering Design*

ENGR 199 is the first multidisciplinary project-based course in the five-course sequence. Freshman students majoring (or expecting to major) in engineering are introduced to the design process by applying it to both minor (2-week) and major (8-week) projects, as well as numerous exercises throughout the term.

Most freshmen have declared themselves to be computer, electrical, or mechanical engineering majors by the time that they enrol in ENGR 199. Some students remain undeclared in their selection of major. Given that they are freshmen without little or no formal academic experience in any of these disciplines, one objective of the course is to introduce them more fully to their chosen fields. The challenge, then, is to focus on project themes and applications that require little or no knowledge of a particular discipline but, nevertheless, serve as valuable introductory learning experiences in open-ended, team-based problem-solving.

The minor project is two weeks in length, during which students work in two-person teams on a specific design problem. In spring 2004, students were required to design, fabricate, test and demonstrate an innovative human-powered airfoil design. Some teams developed variations on the Aerobie flying ring and Frisbee disk designs, while others produced variants of airplane configurations. Students were required to base their designs on aerodynamic principles summarised in the design textbook used for the course [7]. This minor project focuses on the following primary learning themes:

- Scientific principles of physical behaviour, summarised in mathematical models, should be used to guide effective and functional engineering designs;
- Conceptual designs need to be fabricated and then tested under a variety of conditions;
- Test results should be presented in the most effective and useful formats; in the case of the airfoil designs, students presented their test results in the form of spreadsheets and graphs;
- Test results provide the engineer with the opportunity to improve a conceptual design in vital ways so as to enhance performance;
- Designs must be presented in the form of project reports, oral presentations and prototype demonstrations in public fora.

Airfoil prototypes were required to meet certain performance criteria, such as travelling a minimum distance and passing through a specific target area. The results were gratifying: students not only demonstrated creativity in the design of their airfoils, but they were diligent in using their test results to further refine and improve their prototypes. This exercise also proved to be an effective introduction to some of the team skills that would be needed in their major project.

Students were allowed to select any theme or problem of their choice for the major project. They worked together in teams of two or three students. They were encouraged to focus on project themes that would be multidisciplinary in nature, preferably involving computer, electrical and/or mechanical engineering elements to varying degrees. The final project themes included a superior information display system for campus activities, child-safe doorways in homes and offices, a more effective mechanism for installing and removing pierage in lake waters, a successful theft prevention system for shopping carts, an innovative and safer device for jump-starting automobiles, improved auxiliary computer storage devices, advanced fastening devices, and a modern emergency management system for crowd control.

Students followed the engineering design process from a needs assessment through the fabrication and testing of final prototypes (when appropriate). Throughout the semester, they were encouraged to use a variety of creativity stimulation techniques and analytical tools, including brainstorming, bionics, check-listing, inversion, synectics, morphological charts, Kepner-Tregoe situational analysis, and decision matrices. They also were introduced to a number of issues in successful team dynamics and project management, such as using of peer and self-assessment tables to ensure greater mutual accountability and equitable workloads, recognising the importance of clear and accurate communication linkages and archival records, facilitating successful and efficient meetings, establishing shared leadership roles, and generating timely and useful reports. Each team was required to produce a set of deliverables throughout the project, including an initial project proposal which identified the client population to be served, the needs of this group, the actual problem to be solved, the expected impact of a design solution, a set of general and specific design goals, design specifications and constraints, and a background summary of the problem or situation to be addressed, together with existing or historical solutions. Additional deliverables included a mid-term progress report that included proposed conceptual design solutions, a final project report detailing all work including test results and methodologies, as well as a final team presentation to the class and invited guests.

Once again, the results were very gratifying. Some of the final designs were so remarkable that the instructor encouraged certain teams to explore the possibility of commercialisation; discussions are ongoing with external partners about further development of these designs.

The learning objectives for the major project, in addition to those associated with the minor project, include the following:

- The ability to function on multidisciplinary and cross-functional teams;
- The ability to organise and manage open-ended projects;
- The ability to communicate effectively through written, graphical and oral presentations.

Each of these learning objectives is intended to prepare IPFW freshmen for further work on multidisciplinary projects in succeeding coursework.

SOPHOMORE YEAR

ECE 280/ME 280 *Electronics and System Engineering through Robotics*
ECE 281/ME 281 *Electronics and System Engineering through Robotics Laboratory*

ECE 280/ME 280, a three-hour lecture course and its associated one-hour laboratory (ECE 281/ME 281), are a component of a multidisciplinary class designed at the sophomore level. The main purpose of offering this course has been the integration of multidisciplinary design activities in the engineering curriculum at the IPFW. The multidisciplinary design courses in an engineering curriculum usually appear at the freshman and senior levels. However, in order to integrate such an activity throughout the curriculum, it is plausible to also provide intermediate courses – either at the sophomore or junior levels.

However, offering a multidisciplinary project-based course at the sophomore level has its own challenges. In particular, the selection of appropriate material based on students' technical background and a lack of proper textbooks are the two major difficulties one is likely to face in this endeavour. In this section, the authors briefly discuss their experience in designing such a course for the engineering curriculum at the IPFW.

The Department of Engineering at the IPFW currently offers three programmes: computer engineering, electrical engineering and mechanical engineering. Students enrolled in each of the three programmes take exactly the same freshman courses and thus enjoy the same background upon entering the sophomore level. Students' backgrounds at the sophomore level include a two-semester calculus-based mathematics course, as well as physics, English and a number of introductory engineering courses. Taking these facts into account, and noting the Engineering Department's budget constraints, it was decided that a course involving mobile robots might well be suitable for this project. For one thing, these students have already been exposed to the mobile robot projects involving LEGO pieces at the freshman level, the equipment can be acquired on a low budget basis, the technical level of the projects seems to be quite appropriate for sophomore level students, and the computer, electrical and mechanical engineering components can be easily integrated into the projects at once.

However, after the initial consideration, it was decided that students would gain a greater benefit if the topics were to be broadened, while also paying special attention to the subject of mobile robots. To this end, the designed lecture course was given the title of *Electronics and System Engineering through Robotics.* It covers a number of topics in areas of automation, mechatronics and robotics. In particular, this three-hour lecture course includes five separate modules, detailed below.

Module 1: Microcontrollers reviews number systems and arithmetic. Then a canonical computer (ie the processor, bus, memory and ports), with an emphasis on the MC68HC11 microcontroller, is introduced. The remainder of the module covers expansion methods, hardware-software interfaces, an introduction to a processor's internal registers and assembly language, as well as real time control. Microcontrollers were introduced in the first module in order to allow students to start their mobile robot projects early in the semester.

Module 2: Motion Actuators and Sensors introduces students to a number of motion actuators for converting rotary to linear motion and vice versa, as well as electric linear actuators, DC and stepper motors, and fluid-power linear and rotary actuators. Various types of electric position sensors (ie limit switches, mercury and reed switches, photoelectric and ultrasonic sensors, inductive, capacitive and magnetic sensors, as well as pneumatic position sensors) are also discussed.

Module 3: Electric Circuits and Interference, Electronics Devices and Interfacing presents basic electric sources and elements, and fundamental laws of circuits are reviewed. Among the topics examined are the node-voltage method of solving electric circuits, and the sinusoidal steady-state response and frequency response of two-port networks. The module ends with a discussion of noise and interference in electric circuits, as well as noise reduction and elimination techniques. In the second part of the module, diodes and bipolar transistors are introduced. Following this, electronics and sensor interfacing with a view to electronics interfacing for mobile robots are considered. In particular, interfacing microswitches, photo-resistors and DC motors are discussed in detail, and software for driving the motors are developed.

Module 4: Switching Theory and Industrial Switching Elements initially presents basic logic gates and their circuit design using Karnaugh maps. The module then continues with the introduction of electric logic gates, encoder, relays, pneumatic valves, moving part logic elements and fluidic elements. The applications of these devices in automation and robotics disciplines are also discussed.

Module 5: Electric Ladder Diagram, Pneumatic Control Circuits and Programmable Controllers advances ladder diagrams and various methods of designing them (ie sequence chart method, cascade method and Huffman method). Also, different methods of pneumatic control circuits (ie cascade method, flow table method and Huffman method) are studied. The module ends with an introduction to programmable controllers, their basic features and their programming using logic elements.

As was mentioned earlier, there is a one-hour laboratory associated with the *Electronics and System Engineering through Robotics*' course. The purpose of this laboratory is to give students *hands-on* experience with what they have already learned in the classroom. However, the scope of the course is narrowed down and focused on the applications of mobile robots. In particular, the Handyboard, including its motor kits and various sensors, are utilised to demonstrate how mobile robots work. This choice was made due to versatility and the low cost associated with Handyboards.

The laboratory consists of two phases. The first phase takes five weeks to complete and involves four regular laboratories. The purpose of these laboratories is to familiarise students with the fundamentals of mobile robots and help them to carry out their projects in the second phase more efficiently. In the second phase, students work on their semester projects. Phase one includes only 25% of the student's grade, while the remaining 75% of the grade is allocated to the project. In the first laboratory session, students are divided into a number of groups. Each laboratory session can handle up to four groups and each group consists of 2 to 4 students. Each group includes at least one electrical/computer engineering student and one mechanical engineering student so that groups can participate in multidisciplinary activities in a natural way. Each group is required to choose a leader who coordinates the efforts among the team members, as well as a secretary who keeps track of the team's activities and records them in a logbook. The instructor initials the logbook at the end of each laboratory session. Each group is provided with a LEGO kit and a Handyboard, including its motor kits and sensors.

There are currently four stations in the laboratory and, consequently, up to 16 students can enrol in each session of the laboratory. Each station is equipped with a personal computer and a set of test equipment that consists of a function generator, a power supply, a multimeter and a scope. In addition, there are two soldering stations for the purpose of hard-wiring circuits on breadboards and prototyping. Finally, there are two standard size tables similar to those utilised in the First LEGO Tournament. The laboratory facility provides students with a means by which they can build, program and test their mobile robots in a convenient manner.

The first portion of the laboratory includes four regular experiments, which are described below.

Laboratory 1: Build Your First Robot. In this laboratory, students build the Handy Bug 9719 Robot according to a set of pre-specified instructions. The purpose of this laboratory is to familiarise students with the components of a mobile robot and, in particular, the wheel arrangement and gear system. Upon completion, the robots are tested by the instructor at the end of the laboratory session. No laboratory report is required for this experiment.

Laboratory 2: Program and Test Your First Robot. In this laboratory, students learn how to program their robot using the Interactive C (IC) program. To this end, a sample program for testing the bumper system is provided by the instructor. Writing the source code, downloading the program into the Handyboard, and testing and modifying the program are among the main items learned in this experiment. A formal report is to be submitted by each team one week after the laboratory's completion.

Laboratory 3: Learn How Motors Work. Learning the basics of DC and servomotors are essential for a successful realisation of any mobile robot project. In this laboratory, students learn the speed/torque characteristic of motors, interfacing motors to a microcontroller and writing software drivers for motors. Each group receives six motors: two LEGO motors, two DC motors, and two servomotors. This permits students to compare the characteristics of different motors, as well as those of the motors from the same category. After building a test platform, each motor is mounted on a student-built platform and is supplied with an input voltage. The input voltage is then varied with the help of software and the motor shaft angular displacement is measured with a protractor. The data is then plotted using a spreadsheet. This laboratory takes two weeks to complete. Each team submits a formal report one week after the finishing this laboratory.

Laboratory 4: Shaft Encoders. This laboratory is similar to the previous one except that students learn more advanced sensor interfacing and, in particular, interfacing shaft encoders. Again, a formal report is submitted by each team one week after the completion of the laboratory.

The second phase of the laboratory takes approximately 10 weeks to complete and involves a team project. The project is taken from the First LEGO League Competition. In autumn 2004, it was *the Mission to Mars* project. The project involves seven different missions with various degrees of difficulty. Each team selects five missions and submits a pre-proposal within the first two weeks. The instructor reviews the pre-proposals, and recommendations are made. Teams then incorporate the feedback and submit their final proposal. They start prototyping their design once they receive the go ahead by the instructor. After five weeks in the project, teams are required to compete in a Skill Test that involves one selected common task for all teams. This allows a team to see how its design performs in the early stages of the project, compare its design against those of the other teams, and make the necessary corrections. At the end of the semester, all teams participate in the final competition, make an oral presentation of their project, and submit their reports. One of the robots built by a group in spring 2004 is shown in Figure 1.

A team's score depends on a number of factors, including the robot's size and weight, the time it takes to accomplish all missions, the difficulty of the missions chosen, electrical and mechanical design considerations, efficient programming techniques employed, oral presentation, final report, and teamwork.

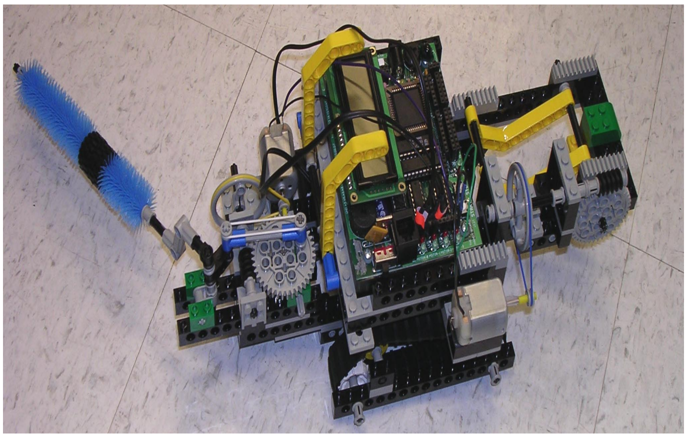

Figure 1: Robot constructed by students in spring 2004.

The *Electronics and System Engineering through Robotics Laboratory* has already been offered three times by the Department of Engineering so far and students' feedback has been very positive. In summary, students enjoy working with robots, feel that this top-down approach helps them to better understand how various engineering topics are tied together, and believe that the course provides them with the skills necessary to function effectively as a member in a multi-disciplinary team.

SENIOR YEAR

ENGR 410 *Multidisciplinary Senior Design I*
ENGR 411 *Multidisciplinary Senior Design II*

In Spring 2001, a committee was formed to assess the capstone senior design and address the issue of multidisciplinary design projects. The committee consisted of four faculty members: two from mechanical engineering and two from electrical engineering. The committee developed new guidelines for the capstone senior design courses that included: the creation of two new courses (ENGR 410 and ENGR 411) for the multidisciplinary senior design projects; the formation of a multidisciplinary committee to handle the multidisciplinary design projects; the involvement of most, if not all, of the faculty in advising the design projects; and the assignment of a faculty member to coordinate these activities.

The capstone senior design project at the IPFW spans two semesters. In the first semester (ENGR 410), the problem statement is formulated and basic conceptual designs are generated and evaluated. The best conceptual design is then selected, and a complete and detailed design is generated by the end of the first semester. In the second semester (ENGR 411), a prototype of the finished design is built, tested and evaluated. Final report and oral presentation to faculty and students are required from all design teams at the end of each semester. Some of the senior design projects are multidisciplinary. In addition, students are exposed to real life design problem experience by getting them involved and work on design projects provided and supported by the local industry or professional societies.

The main objectives of the capstone senior design are: to apply knowledge learned in other courses; to enhance the thought and planning process; to expose students to a team design and implementation similar to that encountered in industry; and to improve students' written and oral communication skills.

Project suggestions may come from a number of different sources, such as senior design students, faculty members or industry. Project suggestions must meet certain criteria in order to be accepted as a potential design project. Each project must be sufficiently complex, yet simple enough to be accomplished within the allocated time to the project team, with the understanding that a worthwhile product – or at least a functioning prototype – would result from the project.

The cost of constructing a prototype of finished design is usually high. This is especially true when the design projects deal with practical and real life problems [8]. For small undergraduate engineering programmes with limited resources, such as the one described here, the high cost of building these projects tends to cause problems and hampers the selection of good quality capstone senior design projects. This becomes more pressing when senior design projects are multi-disciplinary. Recently, Abu-Mulaweh reported on the need for outside support of capstone senior design projects [9]. Whenever possible, students are exposed to real life design problem experiences through involvement and work on design projects provided and supported by local industry and professional societies, such as the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE).

Examples of Multidisciplinary Capstone Senior Design Projects

Case Study 1: Increasing the Capability of a Geothermal Heating/Air-Conditioning Unit Test Laboratory

Water Furnace International Inc. in Fort Wayne, USA, wanted to increase the capacity of their test facility from 50 GPM to 100-150 GPM and to automate the control system. The test facility is used to determine the flow capacity, flow restrictions and heat transfer of water-to-water cooling and heating units, in order to determine the heating or cooling capacity of newly designed high efficiency comfort systems for residential, institutional and commercial applications. The current system was originally designed with a peak capacity of eight tons. With the demand for larger units, the need arose for a larger capacity test facility. The total design and development cost of this project was approximately US$20,000.00.

Water Furnace was very pleased with the results of the design. In fact, they hired one member of the design team upon graduation. The design team consisted of four students: two from electrical engineering and two from mechanical engineering. Two faculty members (one electrical and one mechanical) served as advisors for this multidisciplinary capstone senior design project.

Case Study 2: Portable Experimental Set-Up for Demonstrating Air-Conditioning Processes

A grant of US$4,990.00 was obtained from ASHRAE's (American Society of Heating, Refrigerating and Air Conditioning Engineers) Undergraduate Senior Project Grant Program to support the above-mentioned multidisciplinary capstone senior design project.

The designed air conditioning system, like other commercial products, must have the ability and capacity to adequately control a thermally loaded space to preset limits of temperature (5-25^{o}C) and humidity (5-50 %RH). The designed system must also fully monitor, control and record fluid properties throughout the vapour-compression and air circulation cycles in an effective and ergonomic manner to facilitate the study of thermal science. In order to serve as an effective instructional tool in both a laboratory and classroom environments, the system must be capable of operating in two capacities. Laboratory use requires that the system be interfaced with a computer for desired data acquisition and control; classroom use requires that the system be easily transported and operated/monitored without computer support.

To further enhance the instructive characteristics of the system, the processes of humidification, dehumidification, heating and cooling can be isolated and demonstrated independently of the entire air conditioning system. The design team consisted of four students: one from electrical engineering and two from mechanical engineering.

This project resulted in a state-of-the-art functioning experimental set-up that is currently being used by the faculty of mechanical engineering at the IPFW in several classes. The design team consisted of four students: one from electrical engineering and three from mechanical engineering. Two faculty members (one electrical and one mechanical) served as advisors for this multidisciplinary capstone senior design project.

CONCLUSION

Multidisciplinary team environments pose several challenges that include team communication, project management and team problem-solving. However, based on the experiences of the past two academic years, the multidisciplinary project-based courses at the IPFW have been considered an outstanding success by both faculty and students.

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8th Baltic Region Seminar on Engineering Education: Seminar Proceedings

edited by Zenon J. Pudlowski, Norbert Grünwald & Romanas V. Krivickas

These Proceedings consist of papers presented at the *8th Baltic Region Seminar on Engineering Education*, held at Kaunas University of Technology (KUT), Kaunas, Lithuania, between 2 and 4 September 2004. Eight countries are represented in the 29 papers, which include two informative Opening Addresses and assorted Lead Papers. The presented papers incorporated a diverse scope of important and current issues that currently impact on engineering and technology education at the national, regional and international levels. The level of Lithuanian participation indicates the nation's commitment to advancing engineering education in the higher education sector.

In this era of globalisation, much needs to be done and achieved through creating linkages and establishing collaborative ventures, especially in such a highly developed area as the Baltic Sea Region, and the KUT definitely leads the way in these endeavours. Hence, the aim of this Seminar was to continue dialogue about common problems and challenges in engineering education that relate to the Baltic Region. Strong emphasis must be placed on the establishment of collaborative ventures and the strengthening of existing ones.

It should be noted that the Baltic Seminar series of seminars endeavours to bring together educators, primarily from the Baltic Region, to continue and expand on debates about common problems and key challenges in engineering and technology education; to promote discussion on the need for innovation in engineering and technology education; and to foster the links, collaboration and friendships already established within the region.

The papers included in these Proceedings reflect on the international debate regarding the processes and structure of current engineering education, and are grouped under the following broad topics:

- Opening addresses
- New trends and approaches to engineering education
- Quality issues and improvements in engineering education
- Specific engineering education programmes
- Innovation and alternatives in engineering education
- Important issues and challenges in engineering education
- Case studies

All of the papers presented in this volume were subject to a formal peer review process, as is the case with all UICEE publications. It is envisaged that these Proceedings will contribute to the international debate in engineering education and will become a source of information and reference on research and development in engineering education.