Introducing the Engineering Design Process to First Year Engineering Students

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Abstract – **In response to fourth year students not applying the engineering design process as expected during capstone courses, a new course was developed to introduce the engineering design process to first year engineering students that does not rely on students having an understanding of engineering concepts. Introduction to Engineering Design is a required course that was initially offered in the spring semester of 2012 (seven sections; 140 total students) and is designed to introduce students to the engineering design process. Course sections were divided into semester long teams of three or four students. Teams were presented with four project statements during the course, which required an engineered solution, with each project designed to emphasize different step(s) in the design process. After completing each project, students provided peer reviews and completed surveys on various aspects of the project. Additional assessment was obtained at the end of the course using a team work assessment tool, a student self-assessment of their mastery of the course objectives, and direct assessment of the final project presentation. While all survey and assessment results indicate that the objectives of the course were effectively met, the feedback will be used to make improvements to future offerings of the course.**

Index Terms – Engineering design process, first year students, project based learning.

INTRODUCTION AND BACKGROUND

East Carolina University's (ECU) engineering program admitted its first class in August 2004. The program is a general engineering program (all graduates receive a BS in Engineering) with concentrations in biomedical, bioprocessing, electrical, industrial and systems, and mechanical engineering. When the program was being planned, the curriculum was designed to incorporate best practices from the National Science Foundation's Engineering Education Coalitions [1]. Among these best practices was the "Implementation of 'engineering up front': the exposure of freshmen to hands-on, real world engineering practice early in their undergraduate education, ranging from 'professional level' laboratory facilities to realistic design projects" [2]. Over the eight-year history of the program, assessment of individual courses and program outcomes has resulted in significant changes in the curriculum, particularly during the freshman year [3]. Beginning with the 2007 fall semester, the freshman sequence included an engineering graphics course in the fall semester and introduction to engineering and engineering computations courses in the spring semester. Most students also took an optional, one-credit study skills course in the fall semester. The introduction to engineering course (ENGR 1014) included a semester-long robotics design project.

Assessment of program outcomes is performed annually by evaluating student work samples from selected courses, capstone design project reports, student surveys from relevant courses, and a senior exit survey. The data for each program outcome (ABET a-k plus a concentration-specific outcome) is evaluated by a faculty member designated as the outcome coordinator, and the achievement of the outcome is rated on a scale of 1 to 5. The outcome that has consistently received the lowest ratings is outcome 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" [4]. Most of the evidence that has led to the low ratings of achievement for this outcome has been from the capstone project reports: often there are problem statements without clearly-defined requirements and constraints, little evidence of research into alternative solutions, and no clear demonstration that the proposed solutions meet the requirements and constraints. In discussions among the program faculty, it was noted that while many aspects of design were included at various points in the curriculum (and assessed satisfactorily), the design process was introduced in the freshman ENGR 1014 course and likely not revisited again until the senior capstone design course. Our curriculum was similar to most engineering curricula that Dym [5] characterized as emphasizing engineering science over engineering design.

The curriculum revisions implemented in the 2011 fall semester were intended to help bridge the gap from the freshman design course to the senior capstone courses by utilizing the spiral curriculum approach developed by Bruner [6]. In the spiral approach, basic concepts are introduced early and serve as the foundation for more advanced concepts later on. The concepts are revisited on multiple occasions, continuing to build on the foundation of the previous concept to advance the overall concept. In the freshman year, the one-credit fall semester study skills course was renamed ENGR 1000: Introduction to Engineering and is now required for all students. The ENGR 1014 course was renamed and renumbered to ENGR 1016: Introduction to Engineering Design. This new course puts a greater focus on the engineering design process than ENGR 1014. A new sophomore level course, ENGR 2000: Engineering Design and Project Management 1, will be offered in the 2012 fall semester. This one-credit class will be taught in a seminar format, with a focus on historical engineering achievements and failures. In the junior year, a two-credit class, ENGR 3000: Engineering Design and Project Management II, will replace a three-credit project management course. In ENGR 3000, students will continue building on concepts from ENGR 1016 and ENGR 2000 to incorporate more advanced concepts, such as functional decomposition and complex design spaces, into a semester long project used to guide them through the engineering design process and the preparation of a design report. This course is intended as a stepping stone to the senior capstone project.

The engineering design process is often taught after students have completed engineering science courses. Our new curriculum utilizes the spiral curriculum theory by including a course each year that emphasizes the engineering design process with increasing complexity. This paper focuses on the first course in the series, ENGR 1016, and evaluations of students meeting course learning objectives.

METHODS: ENGR 1016 DESCRIPTION

Seven sections ENGR 1016 were offered in the 2012 spring semester to 140 students. The course met twice per week for two hours. The course followed a lab format with approximately 30 minutes of lecture to begin each class, followed by the remaining 90 minutes for hands-on exercises. Each class section was divided into semester long teams of three or four students. The course was designed to introduce students to the engineering design process along with project management tools and team building skills.

Team building and engineering design process content were introduced during the initial five weeks of the course so that students would begin to apply these concepts and skills during the first project. Concurrently, teams began working on the first project during the second week of the course.

The engineering design process was presented as five steps:

1. Define the problem
2. Research the problem
3. Develop alternative solutions
4. Evaluate and select a solution
5. Implement and test the solution

A central topic of team building material was the transformation of teams as they operate. Tuckman's model of teamwork phases [7] (Forming, Storming, Norming, and Performing) was used to illustrate these transformations in the course and provided the basis for team assessment at the end of the course.

In planning the projects, the faculty followed the concepts as explained by Summers et al. [8] that class projects are much more valuable when students are taught basic project management skills and then expected to use those skills in all projects, regardless of the project size. Project management concepts and techniques were introduced after the first project. Waiting until after the first project enabled the instructors to discuss with students the problems their teams encountered with time allocation and distribution of work among team members, which provided a platform to introduce project management tools. Teams were required to develop Gantt charts for each project beginning with the second project. Other than introducing new projects, the final ten weeks of the course consisted of essentially no lectures.

During the course, teams were presented with four project assignments that required an engineered solution. Each project was designed to emphasize different step(s) in the design process. Each project concluded with teams presenting their project design process and final designs. Project grades accounted for 40% of the final grade. Each project grade was determined primarily from the team's project presentation. Projects were weighted so that teams could achieve passing grades without meeting all of the design requirements for a project. This prevented team members from earning failing grades in the event that design problems arose, thus emphasizing the engineering design process over the design itself. The remaining 60% of the final grade was based on individual work, including homework assignments, attendance and participation, one formal lab report, and the mid-term and final exams.

I. Deck Design

In the first project, each team was tasked with designing a fictional home owner's deck that complied with a simplified set of state building codes. Students were provided with a SolidWorks® file depicting the back of the home to use as reference for their designs. A fictional home owner attended each class to vaguely describe the desirable features of their deck. No cost or size limitations were placed on the deck designs, other than a minimum size of 250 square feet.

A specific focus of this project was for students to develop a detailed problem statement that included requirements and constraints identified from the building codes and interpreted from a home owner's description. Students were also required to research deck designs online to generate designs to meet their preliminary problem statement. The homeowner reviewed each team's design alternatives and provided feedback. Teams then refined their problem statements further to incorporate additional homeowner input. Final designs were presented to the home owner at the conclusion of the project.

II. Line Following Robot

In the second project, students were tasked with developing a line-following robot using a programmable microcontroller and three sensor options. Each team was provided a Parallax Board of Education® (BoE) [9] and required to build a line following robot that could complete a course designed by the course instructors. Each team‘s robot was timed to add a competition element between teams. Students were introduced to the BoE through a presentation and a lab designed to walk them step-by-step through programming, building signal conditioning circuits, and controlling motors. Students were also provided with instructions for building a Parallax Boe-Bot as shown in Figure 1.

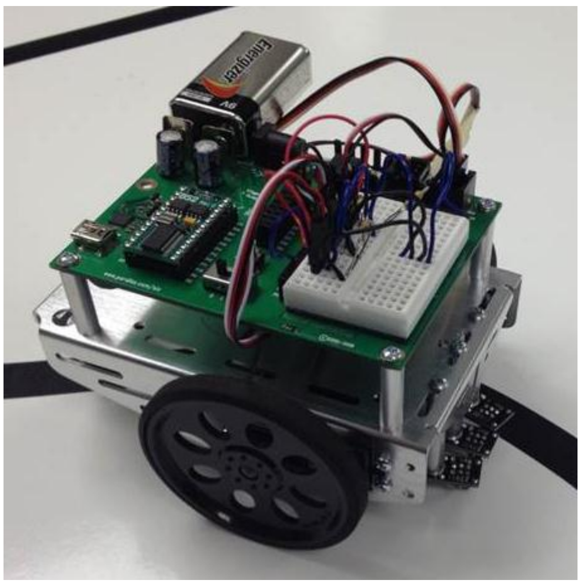

FIGURE 1
BOARD OF EDUCATION ROBOT (BOE-BOT) BY PARALLAX ON LINE COURSE

The primary focus for this project was evaluating design alternatives. Students were introduced to the decision matrix tool and each team developed a decision matrix for three television options as part of an in-class exercise. As a lab exercise, teams then evaluated two types of sensors, photoresistors and infrared emitters with detectors, in digital and analog modes based on effectiveness of detecting color gradients. Students were required to write individual lab reports based on the sensor evaluations that included the presentation of a decision matrix.

At the introduction of the line follower project assignment, a third sensor, essentially a neatly packaged infrared emitter/detector including the signal conditioning circuitry, was made available. Compared to the third sensor option, the first two sensors were initially less consistent and required additional circuit components (capacitors and resistors). The third sensor was considered ideal for this type of project; it was essentially a plug-and-play line detecting sensor. In addition, code for incorporating the third sensor into the BoE was readily available online for students to access. To incentivize use of the first two sensors or a combination of the two, use of the third sensors resulted in time penalties, while use of the initial two was rewarded with course time bonuses. Upon completion of the project students presented their designs and demonstrated them through time trial competitions.

III. Live-catch Mouse Trap

In the third project, students were tasked with developing a live-catch mouse trap. Students researched live-catch mouse traps comparing three examples in a two page individual research memo. Mouse traps were required to use the BoE and could use more advanced components included in GEARS robotics kits [10]. The trap was required to sense a simulated mouse, isolate the mouse using an actuator, and indicate that a mouse had been trapped. Teams could earn bonus points for incorporating additional features in their designs, such as automatic reset, multiple mouse capacity, and lights indicating the number of trapped mice. The foci of this project were to develop alternative solutions and implement and test whether a solution satisfies the problem statement. Teams were required to consider and evaluate two alternatives for sensing the mouse and for trapping the mouse. Since live mice were not allowed for actual use in this project, teams were required to devise their own test mouse that would demonstrate that their trap met the requirements included in the project statement.

IV. Final Project

In the final project, teams were allowed to select their project, contingent upon instructor approval obtained via a project proposal presentation. Unlike previous projects, students were required to develop their problem statements and establish the design need. Projects were required to incorporate a BoE, a functional sensor, and an actuator. Project designs ranged from enhancing of a line-follower robot to a mobile target tracker and projectile launcher. Upon project completion, each team presented and demonstrated their designs in which they emphasized all five aspects of the engineering design process.

RESULTS AND DISCUSSION: COURSE ASSESSMENTS AND EVALUATIONS

The overarching objective of ENGR 1016: Introduction to Engineering Design was to develop the students' understanding of the basic engineering design process as described above. Several assessment tools were utilized to evaluate the achievement of the design objective as well as evaluating teamwork and giving the instructors an understanding of the students' perceptions of the projects. The design objective was evaluated through the use of a survey administered at the end of the first thee projects, an end-of-semester survey evaluating the students' perceptions of their achievement of the course level objectives, and an evaluation of the final project presentation against the design process. Teamwork was assessed at the end of the semester using a survey tool developed by Clark [11].

I. Project Surveys

A short survey was administered after each of the first three projects. (The final project was not surveyed in order to reduce the survey load on students at the end of the semester.) The surveys allowed for the evaluation of the students' perceptions of the learning value for given aspects of the design process and provided insight on whether the students thought the projects were useful and fun. Combined, the surveys had ten questions, with five common questions and two or three project specific questions that asked about the design foci of the project. The students were also given an opportunity to provide open-ended feedback. The combined survey questions for all three projects were:

1. I found formulating the problem statement of the project to a valuable learning experience.
2. I found creating a Gantt chart of the project to be a valuable learning experience.
3. I found generating design concepts for the project to be a valuable learning experience.
4. I found creating a decision matrix for the project to be a valuable learning experience.
5. I found completing the detailed design of the selected concept to be a valuable learning experience.
6. I found testing and implementation of the final design to be a valuable learning experience.
7. I found preparing and making the final presentation of the design to be a valuable learning experience.
8. I found the project to be a valuable experience in working as a team.
9. Overall, I believe that the project was a valuable learning experience?
10. What do you think about the amount of time that you had to complete the project?

The responses for questions 1 through 9 were measured on a Likert scale of 1 to 7 corresponding to responses of: strongly disagree, disagree, somewhat disagree, neither agree nor disagree, somewhat agree, agree, and strongly agree. The response for question 10 was measured on a Likert scale of 1 to 5 corresponding to responses of: we would have been fine with a lot less time, we would have been fine with a little less time, the amount of time was just about right, we needed a little more time, and we needed a lot more time. Table 1 shows the average rating for each question by project. Note that empty data indicates that the question was not surveyed for the given project.

The survey results generally indicate that the projects were successful in providing the students a project in which they could implement the design process and were successful activities for exercising team work. Interestingly, the students thought less of the Gantt chart the second time they were required to utilize one (Question 2). This was likely driven by a perceived value when the Gantt chart is first introduced with the line follower project, but a realization during the mousetrap project that the tool was not very useful on short duration projects. Similarly, the perceived value of a decision matrix (Question 4) also dropped from its introduction to second use, probably because many teams likely applied the tool after the fact on the mousetrap project, rendering its value somewhat useless. (However, it should be noted that on the final exam, the students were extremely adept in creating a Gantt chart and decision matrix.) The value of the completion of the line follower design was ranked somewhat low (Question 5), likely due to the fact that design solutions were fairly easy to find on the internet, so the students did not feel as if they really solved the design problem on their own. In fact, in the open ended comments many students stated that the penalties should have been more severe for easy to implement solutions. Finally, the students placed more value on the presentation (Question 7) and teamwork (Question 8) between the first and third projects and felt as if the time allotted was more appropriate (Question 10). These last results all indicate that the students were working better as teams as the semester progressed.

TABLE I
PROJECT SURVEY AVERAGE RATINGS

Project/Question	Deck	Line Follower	Mousetrap
1	6.0	6.0	--
2	--	6.0	5.0
3	6.0	--	--
4	--	6.0	5.5
5	6.0	5.6	6.1
6	--	--	6.5
7	5.6	6.0	5.9
8	6.0	6.1	6.2
9	6.0	6.0	6.1
10	3.9	3.9	3.4

II. End-of-Semester Course Objective Survey

All courses at ECU are assessed using an end-of-semester survey of the students' perceptions of their achievement in meeting the course objectives. The responses are measured on a 1 to 5 Likert scale corresponding to responses of: strongly disagree, disagree, neutral, agree, and strongly agree. An objective is considered achieved when greater than 70% of the students agree or strongly agree (a rating of 4 or 5) that they mastered the objective. Five course level objectives; describe the engineering design process, develop the requirements and constraints for the solutions of an engineering design problem, compare feasible alternative solutions and select the best solution for an engineering design problem, and document the testing of a solution to an engineering design, are mapped to outcome c. All five of these objectives were rated a 4 or 5 by at least 94% of the students, strongly indicating that the students feel they developed an understanding of the engineering design process.

III. Final Project Evaluation

The final design project was assessed for the achievement of outcome c using the project presentation. The students' mastery of the design process was rated on a 1 to 4 scale using the following rubric:

1. The team does not follow the design process. The need is not established, the problem statement is weak, no alternatives are presented, a flow chart is not utilized, and final design does not satisfy the requirements.
2. The team does not clearly or completely follow the design process and three or four of the following details may be missing: The need is not clearly identified, the problem statement only includes superficial requirements and constraints, design alternatives are presented but not selected using a decision matrix, the flow chart does not accurately communicate the program, or the final design is not shown or demonstrated to meet the key requirements.
3. The team follows the design process, but one or two of the following details may be missing: The need is not clearly identified, the problem statement only includes superficial requirements and constraints, design alternatives are presented but not selected using a decision matrix, the flow chart does not accurately communicate the program, or the final design is not shown or demonstrated to meet the key requirements.
4. The team clearly followed the design process. The need or motivation is clearly communicated. The problem statement includes all key requirements and constraints. Design alternatives are presented and at least one aspect of the design is chosen using a decision matrix. An accurate flow chart of the code is utilized to explain the program. Tests or demonstrations are utilized to show how the design satisfies the key requirements.

Teams rated a 3 or 4 were considered to have successfully achieved the outcome. Ninety-six percent of the teams were rated a 3 or 4 with about 75% receiving a 3 and 25% receiving a 4. The remaining two teams were rated a two, primarily due to only superficially following the design process. The assessment of the final project strongly supports that the students have a firm understanding of the engineering design process.

IV. Teamwork Survey

Teamwork was assessed through a survey instrument that determines in which stage of Tuckman's teamwork model a team is predominately operating by grouping responses to 32 questions. The surveys were completed by and analyzed for each student, rather than on team basis. Thus, surveys provided students' perceptions of how their team was performing. It was reasoned that a poorly functioning team would be still in the storming phase by the end of the semester, a weakly functioning team would be in still in the forming phase, a satisfactorily functioning team in the norming phase, and a highly functioning team in the performing phase. Based upon this reasoning, performing was assigned a rating of 4, norming a rating of 3, forming a rating of 2, and storming a rating of 1. A rating of 3 or 4 was determined to be satisfactory achievement of the teamwork outcome and was achieved by 89% of the students. While surveys were anonymous within each course section, the number of unsatisfactorily functioning teams was comparable to the approximately one team per section (about 15%) as reported by instructors to be performing below expectations. This was the first time that this instrument was used by ECU's program, but the results were very encouraging and plans are in place to use this as a mid-semester feedback tool as well as an end-of-semester assessment tool.

CONCLUSIONS AND FUTURE CONSIDERATIONS

A new course, ENGR 1016, Introduction to Engineering Design, was developed to introduce freshmen engineering students to the engineering design process along with basic team building skills and project management techniques primarily through team projects. Based on student self-evaluations and instructor team evaluations, the course was very successful in teaching students the engineering design process with 94% and 96% of students, respectively, having either a high degree of confidence in understanding the course material or effectively demonstrating an understanding of the material. Evaluations of team development also indicated that 89% of student responses at the end of the course indicated that their teams satisfied team work objectives.

Due to the effectiveness of this course in satisfying its objectives, it is anticipated to be offered again with only minor changes to the structure as listed below:

1. To improve student valuation of Gantt charts, teams will be required to develop a work breakdown structure for each project as well.
2. While deck designs for the initial project were in many cases elaborate, teams encountered problems working with such large designs within Solidworks® and time management. In the next offering, a maximum deck area and the addition of lot lines (spatial boundaries) will be specified.
3. To encourage students to use the more challenging sensors on the line-follower project, penalties will be steeper and additional requirements may be placed on the programming for plug-and-play sensors.
4. A course packet or text will be developed and required for future classes, which will include a revision of Parallax materials used to familiarize students with programming. Since learning to program is not a main

objective of this course, these materials will be simplified and tailored to the students' needs for accomplishing projects more efficiently, rather than spending excessive time learning extraneous programming using the Parallax manual that is more appropriate for a programming focused course.

Subsequent courses will need to be evaluated to fully determine whether the spiral curriculum approach to the engineering design process is sufficiently effective to affect capstone students' understanding and use of the engineering design process. However, evaluations from the initial offering indicate that ENGR 1016 was effective introducing freshman engineering students to the engineering design process. Promising results from this course suggest this approach may have the potential to improve graduates' understanding and implementation of the engineering design process.

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REFERENCES

[1] Coward, H., Ailes, C., and Bardon, R., "Progress of the Engineering Education Coalitions," *Final Report prepared for the Engineering Education and Centers Division*, National Science Foundation by SRI International, May 2000. Accessed from: www.sri.com/policy/csted/reports/sandt/documents/Coalition.pdf.

[2] Kauffmann, P., Rogers, R., and Lunsford, P., "A Case Study: Development of a Practice Oriented Engineering Program with Implications for Regional Economic Development," *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition.* Salt Lake City, UT. June 20-23, 2004.

[3] Williams, R. and Howard, W, "Assessment-Driven Evolution of a First-Year Program," *Proceedings of the 2010 American Society for Engineering Education Annual Conference & Exposition*. Louisville, KY. June 20-23, 2010.

[4] Accreditation Board for Engineering and Technology, Inc. (ABET), "Criteria for Accrediting Engineering Programs: Effective for Reviews During the 2012-2013 Accreditation Cycle," Accessed from: www.abet.org.

[5] Dym, C., "Learning Engineering: Design, Languages, and Experiences," *Journal of Engineering Education*, 88, 2, 145-148.

[6] Bruner, J., *The Process of Education,* Cambridge, MA. Harvard University Press. 1960.

[7] Tuckman, B., "Developmental sequence in small groups," *Psychological Bulletin*, 63, 6, 1965, 384 – 399.

[8] Summers, D., and Edmonson, C., "Are we asking our students to do too many projects? It depends," *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition.* Salt Lake City, UT. June 20-23, 2004.

[9] Parallax Inc., "The Boe-bot Robot", *Parallax Inc.,* Accessed from: http://www.parallax.com/go/boebot

[10] GEARS Educational Systems by Depco (GEARS), "The GEARS Invention and Design System", *Gears Educational Systems.* Accessed from: http://www.gearseds.com/gears-ids.html

[11] Clark, D, "Teamwork Survey", *Big Dog and Little Dog's Performance Juxtaposition,* 2004. Accessed from: http://www.nwlink.com/~donclark/leader/teamsuv.html

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