A Complete Redesign of Fundamentals of Engineering Course using Backward Design Methodology

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***Abstract* - Engaging students in course content through active learning methods is known to be a more effective methodology for achieving course objectives. Fairfield University's introductory "Fundamentals of Engineering" course required for all engineering majors was recreated and revitalized using the backward design framework. First, the course objectives were identified. Next, the desired outcomes were determined and linked to assessment outcomes for accreditation. Assessment linked directly to outcomes was accomplished through frequent student-instructor interaction and project-based evaluation. Finally, the curriculum was delivered using hands-on, interactive methods carefully chosen to most effectively enhance student learning.**

The active learning experiences used in the course were shown to be effective in achieving the course goals. The primary significance of the course redesign is demonstrated in students achieving the course objectives, such as developing a passion for the engineering discipline. Additionally, the practical significance lies in assessments that directly link to course outcomes, which in turn are directly linked to accreditation outcomes. Each activity in the course is focused on achieving a particular outcome, and so each activity has a clear purpose.

Furthermore, the course was team taught by two professors, one from Mechanical Engineering and one from Electrical Engineering. The content of the course is enhanced by linking directly to the content of other courses in other departments that the students are concurrently enrolled in.

Results of the Fundamentals of Engineering redesign are measured by: feedback from students (anecdotal and survey comments), quantitative student evaluation results, and data collected from class that links to the course's successes.

Index Terms – Backward course design, experiential learning, assessment, outcomes.

MOTIVATION FOR COURSE REDESIGN

Engineering is a diverse field. Careers in engineering span a variety of fields (Mechanical, Electrical, Software, etc.), roles (Test Engineers, Design Engineers, Manufacturing Engineers, etc.), and industries (Automotive, Computer, Energy, Environment, etc.) Answering the question, "What is an engineer?" was the driving force that shaped the newly redesigned EG31: *Fundamentals of Engineering* course at Fairfield University.

In Spring 2011 the charge of redesigning the course began. Throughout the process, faculty from each of the departments in the School of Engineering were involved. *Fundamentals of Engineering* is the first course that all Fairfield University engineering freshmen take, and it is common to all engineering majors, rather than being department specific. Before the redesigned course was offered in the Fall 2012 semester, the course was a two-semester (6 credit hour) sequence. The course content was technically heavy, giving students a taste of many topics they would encounter in each of the engineering majors. Examples of topics included DC circuit analysis, digital logic, stress and strain in solids, and programming. In addition the course provided introductory exposure to engineering software including Excel, MATLAB, Multisim, Working Model, etc.

BACKWARD COURSE DESIGN PROCESS

The redesign condensed the course into one semester and eliminated most of the engineering content and software training. The idea was that the students would learn that content best when they had full exposure later in the curriculum, in a course designed to fully engage the students in that material, particularly within the major. To develop the new course, a small group of engineering faculty, with input from all departments, including the authors (the course team teachers) worked through the backward course design process [1, 2]. The course was viewed as a blank slate to meet the needs of the incoming engineering students. This methodology of course design begins with course goals and ends with curriculum and content. This is backwards from a typical course design which starts out with a set of content to deliver and then fits that content into the course goals and outcomes. Backward course design began by deciding on the goals of the course, asking the question, "What will the students take away from the course 5+ years from now?"

COURSE GOALS

The new focus of the Fundamentals of Engineering course was to first, motivate students to develop a passion for engineering. Secondly, the course would provide them with enough awareness of the broad spectrum of engineering that they would leave the course with an accurate picture of the field. This would help them mold their career path and hopefully help each student decide which engineering program was the best fit for their individual interests. Lastly, the final course goal was for the students to develop skills common to all engineering disciplines, which was defined as engineering professionalism. In summary the three course goals were stated as:

(I) Create a passion for engineering.
(II) Develop an engineering mindset, problem solving skills, and critical thinking.
(III) Develop engineering professionalism.

COURSE OUTCOMES

The next step in the backward design process required establishing measurable outcomes of students' learning that would lead students toward the goals of the course. We asked ourselves the question, "What do we expect the students to learn?"

Nine outcomes were chosen, as shown in Table 1. As ABET accreditation requires demonstration of program specific student outcomes, it was desirous to clearly link the course outcomes to the ABET students outcomes (a-k), while also linking each outcome closely to one of the three course goals as dictated by the backward design methodology [2, 3]. In Table 1, the Roman numeral following each of the course outcomes shows the course goal that it is explicitly linked to. The particular ABET outcomes chosen to guide the development of the course outcomes are listed in the second column of Table 1. Each of the course outcomes in the first column is linked to the corresponding ABET outcome by noting the a-k in parenthesis.

TABLE 1
ALIGNMENT OF COURSE OUTCOMES WITH ABET OUTCOMES

#. Course Outcome (ABET outcome) [course goal]	ABET Student Outcomes (a-k, only listing relevant outcomes)
1. Understand the roles of engineers in different fields and different industries in a global, economic, environmental, and societal context. (h) [I]	(d) an ability to function on multidisciplinary teams
2. Be familiar with the different engineering majors at Fairfield University. [I]	(e) an ability to identify, formulate, and solve engineering problems
3. Develop an awareness of modern technology and its use in the engineering field. (i, j) [I]	(f) an understanding of professional and ethical responsibility
4. Demonstrate effective oral communication about technical content. (g) [III]	(g) an ability to communicate effectively
5. Demonstrate effective technical writing. (g) [III]	(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
6. Be able to work in interdisciplinary teams. (d) [II,III]	(i) a recognition of the need for, and an ability to engage in life-long learning
7. Be familiar with project and time management. (d) [III]	(j) a knowledge of contemporary issues
8. Be able to identify, formulate and solve engineering problems. (e) [II]	
9. Develop an awareness of best practices and ethics in engineering and their use by professionals. (f) [III]	

COURSE ASSESSMENT

Assessment was an integral component in the course redesign process. Instead of approaching assessment after the fact, the backward design methodology indicates that assessment methods and tools be chosen specifically to assess student learning. A variety of assessment methods were chosen, to demonstrate competence in each of the course outcomes. These assessments were chosen prior to deciding upon the actual content that would be delivered or included in the assessment. In some cases, particular assessments were decided upon to address multiple outcomes. Students were required to complete weekly assignments and three projects. Weekly work included an engineering problem set and a short technical writing piece submitted on the class blog. Weekly assignments helped to demonstrate not only achievement of a specific outcome, but also to aid students in developing engineering professionalism by instilling discipline and the ability to complete assignments according to specifications.

Problem Sets

Problem sets (PSs) were chosen as the assessment method best suited to demonstrate outcome 8: be able to identify formulate and solve engineering problems. They effectively focused on the engineering problem solving method and were based on content from their co-requisite physics course. Approaching problem sets in this way allowed us to avoid repetition of content, which was being delivered in the physics class. The focus was on teaching a logical problem solving methodology that would help the students in every engineering course, while also teaching them to link the knowledge learned across their various courses.

Students were provided a basic template for how to approach problem solving. This template asked students to follow straightforward steps such as writing on only one side of the page, restating the problem, clearly stating assumptions, solving algebraically before plugging in numbers, double checking the solution, etc. They were assessed more on their ability to correctly follow the problem solution method than on their ability to find the "correct" answer to the problem. Again, this highlighted the fact that the outcome was being assessed, not content.

Problems were chosen from real-world examples, but that were paced along with the curriculum being taught in physics that same week. The physics instructors were consulted to determine pacing and topics covered. In a more indirect way, this also linked to the calculus skills that they were learning at the same time.

Figure 1 shows a trend from a representative sample of students, of improving grades as the course progressed. Again, each week they were being assessed on their problem solving method, so even though the content was changing, and becoming more difficult, it is clear that the outcome being tested is improving.

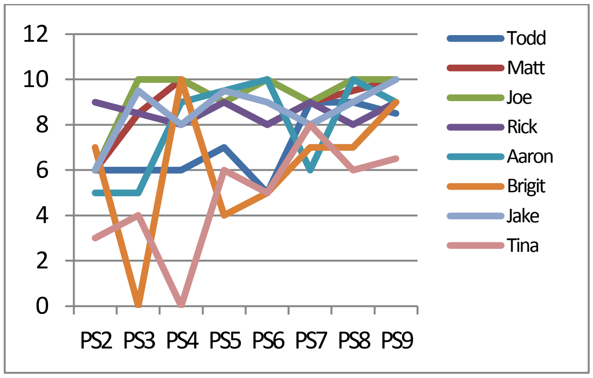

FIGURE 1
GRAPHICAL REPRESENTATION OF THE TREND OF IMPROVING PROBLEM SET GRADES AMONG A REPRESENTATIVE SUBGROUP OF STUDENTS

Writing Assignments

Writing assignments (WAs) were chosen as an assessment method to demonstrate not only that students were improving in their demonstration of outcome 6: demonstrate effective technical writing, but also to assess other outcomes that are not as easily assessed through mathematically based problems. Individual writing assignments addressed topics ranging from "Explain how something works" to "Reflect on your speaking skills". Each WA topic addressed one of the first 5 outcomes. Again, specific content was not as important as demonstrating mastery of the skill or outcome in question. For example, the first writing assignment was designated to address outcome 1: Understand the roles of engineers in different fields and different industries in a global, economic, environmental, and societal context. Students were asked to interview an engineer and discuss these topics with them. It did not matter which field, role, or industry they investigated, only that they demonstrate they *could* learn about these topics through their own personal work and research.

To try to connect the students more to their writing assignments, and to encourage them to learn from each other, the WAs were submitted to the class blog. Each student was asked to post their WA, along with a representative picture. The students were then required to comment on at least two other posts each week. This fostered an environment where students were learning from their peers, not only about the content they presented, but the style and communication abilities used.

Instructor feedback on WAs focused on the technical writing style, as well as, how well the WA demonstrated that the student had addressed the desired outcome.

Individual Technical Writing

The first major project completed early in the semester was a longer individual technical writing (ITW) piece and the topic was open to each student's interest. This project most directly assessed outcome 5: demonstrate effective technical writing. Again, the specific content was not as important as the ability demonstrated. Students were required to use several library resources, which they learned how to do at a library resource class. They referenced journal articles, technical books, and internet sources. They were required to demonstrate proper technical citation using the IEEE citation style guide. For most students, this was their first experience with technical writing, which they learned was different from the writing they had done in their English, history, and other non-technical courses. However, they went through a writing revision process similar to the one they use in their freshman English class. The writing piece went through three iterations of review: self, peer, and instructor review. All reviews were done prior to the final grading of the piece.

Students performed peer review by using an in-class trio read aloud technique adopted from their English classes, where the student reads their paper to two peers, who are each reviewing written copies of the paper while listening. Each of those peers then has to provide corrections and feedback on content, style, and grammar. After these trio read-alouds, each student revises their paper and submits it for draft review to the instructors.

The instructors read the paper and grade the draft, providing extensive critiques and corrections. After the student revises per the instructor's feedback, the final draft is submitted for a final grade. While time consuming for the instructors, and students, this method ensured that the students improved their technical writing. Technical writing is a practiced skill that will benefit them throughout their engineering career.

Individual Oral Presentation

The second early project was an individual oral presentation (IOP) on the same technical topic from the ITW. This project most directly assessed outcome 4: Demonstrate effective oral communication about technical content. Students presented their IOP in class, were peer and instructor reviewed using the new Axiom Mentor peer review system (part of the course management website), and were videotaped for self-assessment later.

Team Design Project

The final project was an end-of-semester team design project (TDP). The assessment method was chosen to satisfy outcomes 6: Be able to work in interdisciplinary teams. 7: be familiar with project and time management, and

8: be able to identify, formulate and solve engineering problems.

Students were challenged to design a device that could "Walk On Water" (WOW). The design goal was that they must be able to travel the length of the RecPlex swimming pool in a walking or running motion above water. Students were put into teams of three and were given the last third of the semester to complete the project. At the end of the semester, both sections (all 54 students) participated in a final EG31 WOW design competition. They competed in first round heats, semi-finals, and finals to determine overall winners. The winning group used parts of a bicycle to create a paddle boat type device. Other creative devices included reconfiguring a treadmill (Figure 2), a human hamster wheel, muffin tin shoes, huge foam shoes, the whale tail design, and foot pump, foot flipper, and ski type propulsion. The event was advertised to the Fairfield University students and faculty and the bleachers were packed with fans. The project and event was a great success and fun for all. While fun and engaging, the project was none-the-less very serious. Students were clearly informed that to pass the assignment, they had to have a device that could traverse the pool according to the specifications. This forced them to identify and solve many different problems, as well as manage the project wisely.

FIGURE 2
ONE TEAM RECONFIGURED A TREADMILL FOR THEIR "WALKING ON WATER" DEVICE.

OUTCOME ASSESSMENT

Selection of specific assessment methods to test for each of the outcomes ahead of time, allowed direct, quantitative analysis of outcomes by analyzing the grades on each of the corresponding assignments. The grades for each assessment method that addressed a particular outcome were averaged, and then a scale was chosen for each outcome to relate the average grade to a 5 point scale of outcome competence which is used across the School of Engineering to enable consistent reporting of outcome achievement during the ABET program review process. Thinking about how to assess each outcome also led to particular choices in curriculum content that would most directly support the actual outcomes of the course.

CURRICULUM ELEMENTS

The course outcomes were achieved through a combination of unique, hands on, experiential learning based on science and engineering education research [4]. Students engaged in several short in-class design projects like programming an Arduino, building a prosthetic leg (Figure 3), and building a device to transfer radioactive golf balls (Figure 4). They also participated in various other interactive class activities such as working in teams to "cross a river" with a limited amount of supplies and under set rules. They estimated the height of the engineering building without the use of sophisticated measuring devices.

FIGURE 3
TEAMS WORKED IN-CLASS TO DESIGN AND TEST A PROSTHETIC LEG

Additionally, there were a variety of in-class activities with a focus on team building, listening skills, communication skills (both oral and written), and creativity and brainstorming. These included blind building, reading technical articles with clicker quizzes to follow, one-minute technical speeches, writing instructions for using electronics (students picked toaster ovens, hair dryers, iPods, and many more), and brainstorming uses for a wire coat hanger. Professional engineers visited the class to give students an industry perspective. The class was visited by engineers from Covidien, ASML, and Yale ROTC. Additionally, they were given the opportunity to take a field trip to Sikorsky Aircraft for a tour of the facility. Other career oriented, professional engineering activities included a visit from the on-campus career center, resume writing, an engineering ethics discussion, case studies from real engineers solving real engineering problems, and introduction to project management.

FIGURE 4
THE FIRST DAY OF CLASS STUDENTS IMMEDIATELY PARTICIPATED IN A TEAM DESIGN ACTIVITY TO DESIGN A DEVICE USING SIMPLE MATERIALS TO QUICKLY TRANSFER "RADIOACTIVE" GOLF BALLS.

REFLECTIONS ON REDESIGN

The redesign of EG 31 proved to be a superior learning experience for the Fairfield University freshmen engineering students. Student feedback was positive. Student evaluations from the IDEA survey showed that 96% and 88% of students in the two sections ranked 4 or 5 out of 5 for "Acquiring skills in working with others as a member of a team" (defined as one of two Essential characteristics by the instructors). ,. On the other Essential characteristic "Developing skills in expressing myself orally or in writing", in the two sections, 92% and 77% of students ranked 4 or 5 out of 5. On the instructor defined Important characteristic (the next level below essential) of "Developing specific skills, competencies, and points of view needed by professionals in the field most closely related to this course", across the two sections, 80% and 81% of students ranked 4 or 5 out of 5. Retention and future success of students will be tracked and assessed through the coming years.

In addition some changes will be made to the course for future years to address small problems or things that did not work perfectly. We will identify two "tracks" through Fundamentals of Engineering, Physics I, and Calculus I, with a cohort of students in each track to maximize the benefit of these students being in a freshmen living and learning community (called a Cornerstone course at Fairfield University). We will also use the Axiom Mentor course management site to more fully integrate the blog into the course instead of using third party sites. An undergraduate teaching assistant, who has already been through the course, will be hired to serve as a peer mentor for the freshmen. Students will also be given more time for the final project, while also having them check- in or turn in project progress reports. As many activities are done in-class, more rigorous assessment of in-class participation, which accounts for 10% of the final grade, will be done.

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