AC 2009-849: LINKING DESIGN ACTIVITIES ACROSS PARALLEL FIRST-YEAR ENGINEERING COURSES

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Linking Design Activities across Parallel
First Year Engineering Courses

Abstract

How can instructors ensure linkages across alternate curriculum paths? To address this question, within Michigan Technological University's first year engineering program, similar design activities were developed for use in two separate courses. This program has two parallel paths based on whether or not students are ready to take calculus. Students in the pre-calculus path take a three course sequence (ENG1001, ENG1100, and ENG1102) that allows more time to cover material but is equivalent to the path for calculus-ready students (ENG1101 and ENG1102). This paper will focus on the development and implementation of design activities that introduced students to material re-use and green engineering in ENG1001 (100 students) and ENG1101 (40 students). In both classes, students designed and constructed an object that contained some or only post-consumer materials (i.e., trash). The activities surrounding the designs were vastly different between the courses. In ENG1001, students created their designs as an initial team building activity. Many of the designs were entered in a competition to raise money for Pennies for Peace (an organization that builds schools in Pakistan and Afghanistan). The students completed a basic statistical analysis on the funds collected and summarized the results. In ENG1101, students were introduced to the engineering design process as they progressed through an eight-week, design/construct, team-based project that focused on green engineering. Design constraints for the project imposed a 50% lower limit on post-consumer materials used in construction, and the student teams were instructed to keep the environmental impact of their design very much in mind from the beginning of the design process and as they moved through to prototype construction. This green engineering approach was documented in team design reports that also required analyses on down-cycling, carbon footprint, and product end-of-life for the prototype constructed. The paper will present how these design activities impart to students skills that will be needed in ENG1102, as several design projects in this following first-year engineering course have students investigate opportunities for using waste from a manufacturing facility as a raw material for another process. Additionally, the paper will describe how these skills and experiences will be useful in their engineering academic and professional careers.

Introduction

Since 2000, Michigan Technological University (Michigan Tech) has had a first-year engineering program. Within this program, entering students learn basic engineering and technical skills that are applicable to their engineering and professional careers. Through the completion of the first-year engineering courses, students gain, develop, and improve their skills in:

- Teamwork
- Written and oral technical communication (memos, reports, technical posters, technical presentations, etc.)

- Problem solving
- Engineering design
- Engineering modeling (numerical, graphical, 3-D)
- Engineering analysis (data collection, analysis, description)
- Computer software
- Interpersonal communication with respect to teammates, classmates, and instructors
- Basic university skills ranging from the format of homework submission to time management

The path students take to complete the first-year engineering program is dependent upon their math readiness. The majority of the 900 first-year engineering students are calculus ready. Approximately 30% of the entering class are enrolled in pre-calculus and a few students are enrolled in preparatory math. Students are designated as calculus ready or pre-calculus ready based on ACT and SAT math scores, along with advanced placement and transfer credit. Students with an ACT score above 26 are placed in calculus, while students between 19 and 25 are placed in pre-calculus. There are two course options for calculus, a 4-credit and a 5-credit, but the material covered is the same. The 4-credit course goes at a slightly faster pace as compared to the 5-credit class. The breakdown of the ACT/SAT scores and corresponding math placement is shown in Table 1.

Table 1: Math placement by ACT/SAT scores for first-year students at Michigan Technological University[1]

Course	Test Score Range	
	ACT	SAT
Pre-Calculus	19-25	500-590
5-credit Calculus 1	26-28	600-640
4-credit Calculus 1	29+	650+

Engineering students who are calculus ready are enrolled in the traditional track for first-year students (ENG1101 followed by ENG1102); those who are in pre-calculus are enrolled in an alternate path (ENG1001, ENG1100, and ENG1102). The alternate path was implemented so that students could take an engineering course while they were in pre-calculus. This structure has improved retention of students who are not ready for calculus.[1] The two pathways for students are summarized in Figure 1. As shown in the figure, students who start in pre-calculus take three semesters and seven credits to complete the first-year engineering program, while students on the calculus-ready path are done in two semesters with six credits.

This paper will focus on the first engineering course, ENG1001 or ENG1101, depending on the readiness of the student, and specific design projects that were implemented in those courses. It will describe the design activities and how they differed between the two courses. In addition, the paper will describe how completion of these projects and the concepts involved benefit the students when they take ENG1102, the follow-on first-year engineering course.

Background

Each first-year engineering course involves the development and application of engineering design skills. In ENG1001, students complete two to three design activities that emphasize various course concepts and topics. With the completion of the activities, students learn how to use various software applications and develop different engineering skills. The ENG1101 course

is structured differently. In this course, students learn about software applications and engineering skills and apply them to various course assignments and one semester-long design project.
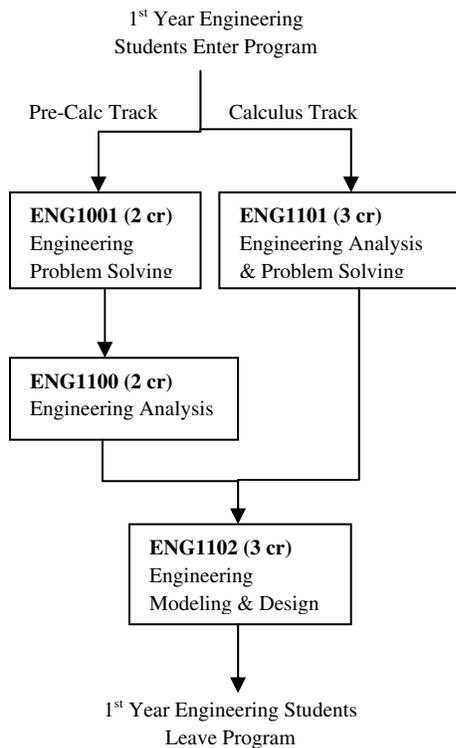
1st Year Engineering
Students Enter Program

Pre-Calc Track   Calculus Track

ENG1001 (2 cr)
Engineering
Problem Solving

ENG1101 (3 cr)
Engineering Analysis
& Problem Solving

ENG1100 (2 cr)
Engineering Analysis

ENG1102 (3 cr)
Engineering
Modeling & Design

1st Year Engineering Students
Leave Program

Figure 1: Michigan Tech's First Year Engineering Program

The implementation of linkages between alternate curricular path courses has not been widely done, though many universities are exploring the connection possibilities of spiral courses where the information from or the project completed in one course is built upon in a subsequent course. Universities, however, have brought global issues, sustainability, appropriate technologies, and green engineering into their first-year engineering programs.[3,4,5,6,7]

At John Brown University, students are introduced to the concept of appropriate technologies by bringing guest lecturers into the classroom to discuss and present technologies or industries that can be integrated into societies without disrupting culture and traditions.[8] Within Drexel University, specific engineering subjects were integrated with other engineering, math, and science courses. This change resulted in higher retention rates throughout the program.[9] At the New Jersey Institute of Technology, some students were randomly assigned to a first-year engineering course that had a strong electrical and computer engineering component, while others took a first-year engineering course without this emphasis. During their sophomore year, while electrical and computer engineering students took their first circuits course, a comparison of three groups of students taking the introductory circuits course was completed. The assessment compared those who took a first-year engineering course with and without the electrical engineering emphasis, and those who did not complete a first-year engineering course. The study found that the students who completed the integrated sequence performed slightly better than those who either did not complete an integrated electrical engineering/first-year engineering sequence or did not complete a first-year engineering course.[10] The Chemical Engineering Department at the University of Akron has had integrated design teams that consist of first-year through senior level students. Within the community college system, Daniel Webster College has created a three-course sequence that replaces "Engineering Graphics, C Programming, and Probability and Statistics and/or Chemistry II."[11] The sequence focuses on concurrent engineering design. As students progress through the sequence, they use concepts, course topics, and software knowledge developed in the previous course(s), and apply them to new problems.[11]

The interesting and unintentional opportunity that Michigan Tech had was to create parallel and similar design activities between the two paths in the first-year engineering program. This initiative let the students in the pre-calculus path know that they were completing activities similar to the calculus-ready students. The following sections show how the concepts of

sustainability and green engineering were incorporated into ENG1001 and ENG1101, and how the students applied these concepts in ENG1102.

ENG1001 Project: Trash-To-Treasure

In ENG1001, as mentioned previously, students complete several design activities that focus on a given topic. The first project, Trash-To-Treasure, focused on constructing something useful or artistic from items that were going to be thrown away. In completing the activity and in documenting their findings, students were introduced to many engineering skills ranging from technical communication to spreadsheet analysis and documentation. Table 2 outlines the various activities and the corresponding course concepts.

Table 2: ENG1001 Trash-To-Treasure Design Activities and Course Topics

Design Activity	Course Concept / Skills Developed
Activity Introduction	Waste=Food, Sustainability
Activity Construction/Description	Team Building, Design-Build, Technical Communication
In-Class Competition	Technical Communication, Impartial Assessment
Public Competition, Data Collection	Technical Communication, Public Communication
Data Analysis	Basic Spreadsheet Skills, Graphing, Technical Communication, Basic Statistics (Mean, Mode, Median, Range, Standard Deviation)
Data Interpretation and Documentation	Basic Spreadsheet Skills, Technical Communication

Initially, students were introduced to how trash can be converted into something useful (Waste=Food), and to the concept of sustainability and sustainable design. To reinforce the Waste=Food concept and to establish positive team interactions, the Trash-to-Treasure design project was completed as a team building exercise. During the second week of class, students were asked to bring five items of "clean" trash to class. In preparation for the project, they learned about the quantity and composition of solid waste in the United States, and the engineering importance of reducing society's impact on the earth.[12] From this information, they had figure out what type of "clean" trash they wanted to bring to class. "Clean" trash was defined as items that they would not mind using or touching. During the next class session, students were assigned to teams. Within the problem handout, they learned that their team had to design and construct an object using all the trash items their team brought to class. Additionally, they could use other materials to hold their object together (tape, glue, staples, etc.) or to decorate/color (i.e., paint) as long as they did not purchase any materials. Students were then required to write a memo to describe their device and to outline the "trash" items used and the materials borrowed. Some of the objects created were: a multi-use bag, games, water filter, and a water warmer. This project was completed in all five sections of ENG1001 (approximately 250 students). In two sections of ENG1001 (approximately 100 students), however, the project did not end with this activity.

Prior to coming to Michigan Tech's orientation week, the first-year students read <u>Three Cups of Tea: One Man's Mission to Promote Peace… One School at a Time</u>. [13] Each year, the university selects a book that first-year students read as part of the "Reading as Inquiry" program.[14] For the past three years, the program has selected books that reflect social or environmental issues. The purpose of this program is to prepare the entering students for college level reading and analysis. During orientation week, students meet with their orientation group and a discussion leader, typically a university faculty or staff member, to discuss the book. The summer 2008 book discussed Greg Mortenson's work over the past 15 years to build schools for girls and boys in northern Pakistan. Additionally, faculty are encouraged to bring the book into the classroom once classes begin.

Discussing or including this type of book in an introductory engineering course was difficult. Instead, the instructor (Hein) decided to find a way to raise money for "Pennies for Peace" that would include the students enrolled in ENG1001 and the university community. "Pennies for Peace" raises money to educate children, especially girls, in Central Asia.[15] Since the two sections of ENG1001 contained 24 teams which translated to 24 designs, the judging of the designs was split into two phases. First, to narrow the number to be judged by the campus community, the top six designs in each section were selected. When students brought their designs to class, they were given a ballot to vote on their favorite two. The top six from each of the two sections went forward to the public competition held in the lobby of Dillman Hall, where the designs were displayed along with their description. In front of each object was a jar where anyone could vote by placing money in the jars. The money collected was donated to "Pennies for Peace."

Prior to the competition, as a class, the ENG1001 students created a PowerPoint slide and an e-mail announcement that was presented in all first-year engineering courses to encourage students to participate by voting. In late September, the competition was held and approximately $150 was raised. The winning design was created by a team consisting of two women and two men; it was a two-handled book bag (see Figure 2).

Figure 2: Trash-To-Treasure winning design and design team.

Instead of ending the project at this point, the students analyzed the amount of money collected in each jar. This involved building on their knowledge of basic statistics and spreadsheets. They calculated the mean, average, mode, median, standard deviation of the money collected in the 12 jars. They created graphs to illustrate the distribution of the money collected.

Within an engineering memo, they interpreted and summarized their results. This documentation was difficult for the students. They were very good at stating the numbers, but they were reluctant to describe the significance of the results and to describe the figures. Many student teams had to re-write or revise their initial memo at least once to meet the requirements of the assignment. For example, students would state that the data were provided in a graph, but they would not state where the graph was or what the data meant.

When the project was completed, the student teams were asked to evaluate and comment on the activities. There were a total of 24 teams in the two sections (Section 2, 14 teams; Section 3, 10 teams). Within the two sections, two teams were formed during the activity. This was due to students being moved from ENG1101 into ENG1001 due to their poor performance on the Calculus Basic Skills Test. At Michigan Tech, all students enrolled in Calculus 1 must take and successfully complete a basic skills assessment. The intent of this test is not to assess a student's ability to do Calculus, but rather to determine how well prepared they are for Calculus 1, thus verifying their math placement as initially determined through ACT and SAT scores (see Table 1). The students who fail this test are moved down to pre-calculus. Since calculus is a co-requisite for ENG1101, and pre-calculus is a co-requisite for ENG1001, students who are moved into pre-calculus are also transferred from ENG1101 into ENG1001.

Overall, the students felt that this project was interesting, helped them work in their team, and learn how to use spreadsheets. Table 3 summarizes the results. The students were unanimous in their opinion that this activity should be repeated next fall. The students rated the activities high and there was a correspondence between sections for the ratings on almost all questions. The description of the competition was ranked lower in Section 3 than in Section 2. The student comments from Section 3 stated that developing a competition description for their team and then also creating a class version of a slide was repetitive. The students were positive about opening the judging to the public. For example, one of the student teams stated: "Public voting got a range of opinions from different aged people and other non-engineering majors."

Because this was the first time this type of project was completed, there is room for improvement. The scheduling of the activities needs better time distribution and the logistics need to be refined. Many of the deliverables were perceived as being "rushed" by the students. Many students had comments like this one for the description of their design: "We would have liked more definition on what the description should be like, such as sales pitch or just a simple description."

Table 3: Student Evaluation of Trash-To-Treasure Design Project

Question	Sec 2		Sec 3		Overall	
	Average	StDev	Average	StDev	Average	StDev
1. Construct something using "clean" trash	4.18	0.60	4.11	1.05	4.15	0.81
2. PowerPoint Slide and Competition Description	4.18	0.75	3.06	1.01	3.68	1.03
3. Team's Description of Device	4.18	0.75	4.22	0.83	4.20	0.77
4. Classroom Evaluation/Voting of "Best" Design	4.00	0.77	4.22	0.97	4.10	0.85
5. Public Competition	4.25	0.97	4.30	1.06	4.27	0.98
6. Should this project be done next year (Yes/No)	All Yes					
Teams Formed after Activity was Completed	1		1		2	
No Evaluation Completed	1		0		1	
# Teams	14		10		24	

ENG1101 Design Project

The idea of introducing green engineering through a first-year design experience was implemented in one section of ENG1101 (40 students). In this calculus-ready class, the instructor (Kampe) presented a more substantial/formal introduction to the engineering design process that incorporated several "design for the environment" concepts such as a material's embodied energy, device carbon footprints, downcycling impacts, and product end-of-life analysis. The student teams were tasked with the design and construction of a useful device or item (their choice) that integrated materials from post-consumer waste streams. Design constraints imposed a 50% lower limit on the use of reclaimed materials in construction, and a team cost cap of $10 for new/purchased materials. In this basic form, the ENG1101 project is very similar to the Trash-to-Treasure project implemented in ENG1001 (pre-calculus-based course). In ENG1101, however, the student teams were directed to fully document their design process and to use the design tools that had been covered in the course. The design reports also required documented estimates on device carbon footprints that took into account the embodied energies for all new/purchased materials, and the required energies for collection, transportation, any alteration or re-fabrication processes, and re-disposal for all reclaimed materials. Teams also estimated the carbon footprint of their device if it were constructed from all new/purchased materials. From this, they discussed the potential environmental impacts of their use of post-consumer waste assuming a production basis of 100,000 units annually. Lastly, students were required to list the end-of-life options for each component in their constructed prototype. The objective in approaching introductory design education in a green engineering framework was to instill a propensity toward product stewardship in our students by imparting and understanding that responsible engineering begins with product design inception and continues through to the consumer's disposal, recycling, or reuse of the product. These ideas, and those of sustainability, were extended further in spring 2009 with many of the ENG1102 design project options, for example the "Green Engineering" and "Alternative Fuels" design projects.

Sustainability/Green Engineering in ENG1102

Many universities are introducing sustainability to their students at all levels of their curriculum,[3,4] and some are adding instruction on green engineering.[6,7,16] The model incorporated into Michigan Tech's first-year engineering program uses both of these content areas to link concurrent courses in alternate paths through the freshman year, and linking such courses is something not widely done. These content areas are excellent vehicles for establishing a linkage across different paths in a first-year program that serves all degree granting disciplines in the College of Engineering because they have relevance in all engineering fields. When the students enrolled in either path reach ENG1102, the themes of sustainability and green engineering continue in many of the available design projects.

In ENG1102, all students complete a semester long design project. Each spring, approximately 11 sections of this course are offered with five to six different design projects. As such, students can select an ENG1102 section that reflects their engineering interests on both a professional and a personal level. Table 4 lists the different design projects, along with how many sections were offered during the spring 2009 semester. Section sizes in ENG1102 range from 48 -64 students, depending on classroom capacities. One design project, New Orleans Flood Control, listed in Table 4 was not offered this past spring but has been offered in other semesters. All design projects involved creating solid models using UGNX5 and numerically modeling their concept/process using MATLAB. Five of the seven options listed below had sustainability or green engineering explicitly incorporated into the projects. The remaining two projects had students reflect on the aspects of sustainability in their design concepts and applications, which is indicated as implicit content.

In the Alternative Fuels project, students investigated the potential of fuel ethanol produced from woody biomass. Students were introduced to sustainability and green engineering concepts in ENG1101 or ENG1001 and ENG1100, and this project allowed students to become more aware of these topics through applying the principles of green design to a biomass-to-ethanol plant. In class, students were shown the "traditional" product life-cycle beginning with extraction of raw materials and ending with disposal of the used product. Students were then reminded of the principles of green engineering introduced in their previous engineering classes and were shown a product life-cycle utilizing green design principles. This life-cycle was designed for materials to be recycled, reused, reclaimed, and re-manufactured instead of ultimate disposal of the end product. Due to the time constraint of only one semester, student designs focused on developing a green manufacturing process by:

- Incorporating renewable energy (solar, wind, geothermal) to power the plant.

- Utilizing the "Waste = Food" concept that was introduced in previous first-year engineering courses to eliminate waste from the production process by finding uses for the process emissions. [17]

Additionally, the ENG1102 Microbrewing design project utilized the same green design concepts through finding uses for spent grains, hops and yeast used in the brewing process.

Table 4: ENG1102 Semester Design Projects – Spring 2009

Design Project	Description	# of Sec	Sustainability/ Green Engineering	
			Explicit	Implicit
Wind Energy	Developed a design concept for a wind turbine(s) to power a university campus dormitory or similar scale need. Michigan Tech or other power consumption data were used to design the turbine(s) and to test the design concept.	3	X	
Human Hybrid Powered Vehicle	Developed a design concept for a commuting vehicle that uses human power as well as power from another source. Design teams consider the "state of the art" for this type of vehicle, then develop ideas to take the design to the "next level".	1	X	
Green Engineering	Designed and constructed a device that played well-known music automatically. From the beginning of the design process to the final construction of the prototype, students considered the environmental impact of this engineering activity. Most of the materials used in the prototype were reclaimed from post-consumer waste streams, and no prefabricated sound making devices or objects were used. Design analysis incorporated life cycle thinking: embodied energy in component materials, virtual water, toxicity, and end-of-life cycle planning (re-use, re-manufacture, and recycling, and design for disassembly).	1	X	
Microbrewing	Developed a design concept for a semi-automated microbrewery to allow part-time brewers to produce batches of basic ale recipes. Design teams researched the brewing process and equipment, and developed an innovative concept design.	1		X
Alternative Fuels	Developed a concept design for a biomass-to-ethanol process using various regional biomass sources. Design teams will research and develop a sustainable process for the production of biofuels.	1	X	
Autonomous Robotic Design	Developed a design concept for a fully autonomous robot. Identified a real need and developed a virtual prototype and control program.	3		X
New Orleans Flood Management	Developed a sustainable flood management system for the New Orleans Region. Modeled a concept design of a flood control system.	N/A	X	

The ENG1102 Green Engineering design/construct project enhanced the "design for the environment" toolkit for first-year engineering students. Following Ashby's approach to a material's life cycle,[18] the concept of a material's embodied energy was broken down to include the energy required to produce a kilogram of usable stock material (H_m) and the energy of

processing required to fabricate a part for device implementation (H_p). Further, the awareness of the environmental impact of device's design and construction was broadened from only a carbon footprint analysis in ENG1101 to also include an understanding of environmental costs in terms of released toxins and virtual water.

Conclusions

Students enjoy learning when they believe the project or analysis is useful. In ENG1001, students learned about the concepts of sustainability through the completion of the Trash-To-Treasure project. While doing this, they raised money for schools in Central Asia. In addition, they also began to include service in their list of engineering skills. In ENG1101, the very basic tools of "design for the environment" were taught in a hands-on application of green engineering. The skills and concepts acquired through the completion of the parallel design activities in ENG1001 and ENG1101 were then used in the following first-year engineering course, ENG1102, where students directly applied these concepts to a semester long design project by developing sustainable or green solutions to a variety of "real-world" engineering problems.

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