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Blending Sustainable Design, Systems Thinking, and Engineering Science Concepts in an Introductory Engineering Course

Dr. Robert L. Nagel, James Madison University

Dr. Robert Nagel is an Assistant Professor in the Department of Engineering at James Madison University. Dr. Nagel joined the James Madison University after completing his Ph.D. in mechanical engineering at Oregon State University. He has a B.S. from Tri-State University (now Trine University) and a M.S. from the University of Missouri-Rolla (now Missouri University of Science and Technology), both in mechanical engineering. Dr. Nagel has performed research with the United States Army Chemical Corps, General Motors Research and Development Center, and the United States Air Force Academy. His research interests are in the area of conceptual design and engineering design education. Specifically, Dr. Nagel's research activities include understanding customer needs, the use functional and process modeling to understand design problems, design for sustainability, and design for accessibility.

Dr. Kyle G. Gipson, James Madison University
Jonathan Howard Spindel, James Madison University
Dr. Elise M. Barrella, James Madison University

Dr. Elise M. Barrella is an Assistant Professor of Engineering at James Madison University, focusing on transportation systems and sustainability. Prior to joining the JMU Engineering faculty in 2012, Dr. Barrella was at Georgia Tech completing her Ph.D. research as part of the Infrastructure Research Group (IRG). She also completed a teaching certificate and was actively involved with the Center for the Enhancement of Teaching and Learning (CETL) at Georgia Tech. Her academic interests focus on two primary areas of sustainable transportation: (1) community-based design and planning and (2) strategic planning and policy development. Dr. Barrella is also interested in investigating how to best integrate these research interests into classroom and project experiences for her students.

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Introduction

The relatively new James Madison University (JMU) engineering program has been designed based on the Engineer of 2020[1,2]. To train the Engineer of 2020, the program blends engineering science fundamentals with sustainable engineering design and systems thinking while maintaining the university-wide liberal arts core. This program, which has recently completed its fourth year and graduated its first class, emphasizes problem based learning throughout the curriculum[3] and provides students with hands-on design opportunities during all four academic years[4]. Our goal is to expose students to their future role as global engineers where they will be required apply technology to balance impacts associated with the three pillars of sustainability—economic, environmental, and societal—to create safe and sustainable designs.

As our first graduating class became seniors, we recognized that we could improve on the students' ability to discover and understand their identity as the Engineer of 2020. Consequently, we became aware of the need to revamp the introduction to engineering course. While the initial course focused on developing strong analytical skills, creativity, communication, strong sense of professionalism, and versatility—all skills of the Engineer of 2020[1]—the offering of the course lacked cohesive integration. These prior course iterations were team taught with individual faculty having responsibility for four to six week modules taught simultaneously across all sections, and faculty assigned to teach the course were not consistent from year to year. This paper represents an initial effort at executing an integrated course offering where course topic areas are interwoven throughout course, and faculty instructors are common throughout the entire semester. The new version of the course was taught experimentally to three course sections during the Spring 2012 semester.

The Introduction to Engineering course is laid out in modules: Engineering Science (ES), Engineering Design Process (EDP), and Components of Sustainable Design (CSD). Students begin in the ES module learning initially about the engineering profession and foundational elements of engineering analysis. The common theme through the ES module is the flow of materials and energy whether in mechanical, electrical, or chemical systems. Students follow the theme of *flow* as the course transitions into the EDP module. During the EDP module, students reverse engineer an electromechanical product studying how electrical energy stored in battery is converted to mechanical energy through the lenses of customer needs and functional attributes. The second portion of the EDP module exposes the students to basic manual (hammer, screw driver, hand saw) and powered (electric drill, power screw driver, mitre saw) hand tool operation through a project that requires students to perform fundamental engineering analysis. Following the EDP module, students transition into the CSD module where they are introduced to the idea of life cycle thinking. Students are taught to consider the entire product life as a complex dynamic system that begins with material extraction and ends with disposal and/or material recovery. This is reinforced by the team project focusing on the flow of material and energy in a transportation system. The course culminates with the integration of ES, EDP, and CSD into a single project where students are instructed to produce a physical prototype based on a customer design solicitation. Students are required to develop multiple designs; evaluate trade-offs between each design; justify decisions using engineering science calculations; develop computer aided models of the selected design; construct a physical prototype; and test and refine their design prototype. Following testing and refinement, students present their designs during a formal presentation and submit a formal design report.

In this paper, we provide an overview of our engineering curriculum, descriptions of the ES, EDP, and CSD modules, and a description of the final course project. We conclude the paper with data related to course learning outcomes, and a reflection on the lessons learned.

Curriculum Background

In order for engineers to be able to work toward a sustainable future, as students they must be trained to think flexibly and to be adaptive as it is unlikely that their future will have them working in one domain. We must train them to instead be versatilists. Versitalists, as popularized by Friedman, can "apply depth of skill to a progressively widening scope of situations and experiences, gaining new competencies, building relationships, and assuming new roles."[5 p. 291] Our engineering program has been developed from the ground up based on the Engineer of 2020 to provide this general engineering training with an emphasis on engineering design, systems thinking, and sustainability. Our goal is to train this engineering versatilist.

To train the engineering versatilist, the curriculum, shown graphically in Figure 1, combines a campus-wide, liberal arts general educational core with courses in math, science, engineering design, engineering science, business, systems analysis, and sustainability[6]. Individual skills taught developmentally through the curriculum, beginning with the freshman year, are blended with engineering design theory and utilized in projects in the design sequence.

YEAR 1	Calculus 1	Liberal Arts Core	Liberal Arts Core	Liberal Arts Core	Physics 1
	Calculus 2	Liberal Arts Core	**Introduction to Engineering**	Liberal Arts Core	Physics 2
YEAR 2	Calculus 3	Liberal Arts Core	Engineering Design 1	Liberal Arts Core	Chemistry 1
	Linear Algebra & Different Eq.	Statics & Dynamics	Engineering Design 2	Engineering Management 1	Chemistry 2
YEAR 3	Thermal-Fluids 1	Instrumentation & Circuits	Capstone Design 1	Engineering Management 2	Liberal Arts Core
	Thermal-Fluids 2	Materials & Mechanics	Capstone Design 2	Liberal Arts Core	Liberal Arts Core
YEAR 4	Sustainability Fundamentals	Systems Analysis	Capstone Design 3	Technical Elective	Liberal Arts Core
	Sustainability & Design (LCA)	Technical Elective	Capstone Design 4	Technical Elective	Liberal Arts Core

Figure 1: Schematic illustrating the curriculum of the program[6].

The engineering design sequence is meant to be the core or spine of the engineering curriculum. We believe that exposure to engineering design can help students develop their problem solving skills, teach them to better synthesize information, and exercise skills required to integrate and analyze knowledge. During the engineering design courses, students not only learn engineering design tools and methods but also learn about creativity, sustainability, business, ethics, values, engineering science, math, and manufacturing. It is during this engineering design sequence where students are provided with a hands-on environment to apply the theory learned in other courses.

For much of the engineering curriculum in our program, instruction is based on a three-dimensional problem based learning model designed to promote diverse cognitive experiences. The PBL pedagogy is based on the premise that problem-based learning experiences can be tailored in each of the three dimensions—structuredness, complexity, and group structure—to meet different learning outcomes. Each of these three dimensions are represented as a side of the PBL Classification triangle in Figure 2. Structuredness measures how well a problem is defined or identified as well as how well the problem solving process is structured in terms of the methods and analysis used[6]. Complexity measures the required domain knowledge to solve the problem, the intricacy of the solution path, and the depth of integration of varying domains[6]. Group structure measures the level to which student collaboration is promoted in a PBL activity. Crafting problem-based learning experiences that vary each of these three dimensions exposes students to different types of problems leading to students that are versatile, adaptive experts, and approach problems with cognitive flexibility. Please refer to prior publications[3,6-9] for more details about our adaptive PBL model.

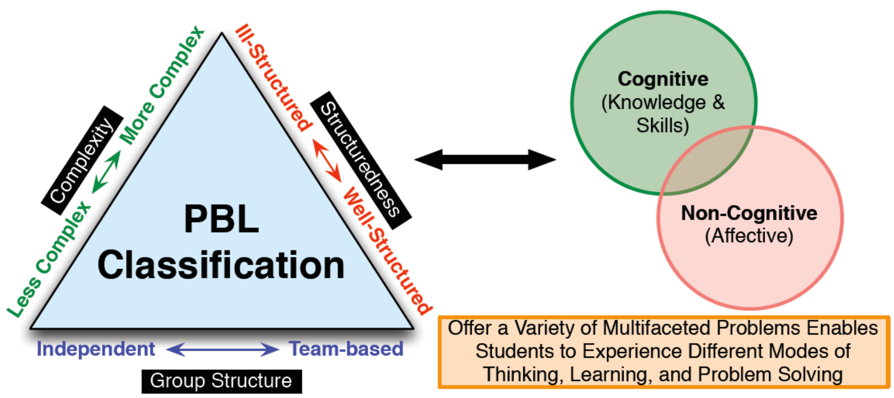

Figure 2: Schematic illustrating the Problem-Based Learning model [6].

Introduction to Engineering (ENGR 112) Course Description

Introduction to Engineering (ENGR 112) is the first course in the engineering curriculum taught both during the fall and spring semesters. The course is meant to introduce students in the engineering program to engineering at JMU. To meet the goal of introducing students to the engineering program, the course has been developed to mirror the curriculum integrating key elements of the curriculum—such as fundamental math and science, engineering science, sustainability, and engineering design— as common themes through the course. These key elements come together as the Engineering Science (ES) module, the Engineering Design Process (EDP) module, and the Components of Sustainable Design (CSD) module. In addition to these modules, the course integrates the strong PBL foundation of the engineering program through a variety of hands-on exercises, small and large team-based projects, and campus excursions.

A fundamental challenge in teaching the course is ensuring accessibility; students are enrolled in either first or second engineering science (physics or chemistry) course as well as either calculus 1 or 2. Currently, the course has no prerequisites. To overcome this challenge, course outcomes have been defined broadly. The course outcomes are:

1. Describe and discuss problem solving processes as related to design
2. Apply engineering processes to short design projects
3. Analyze and evaluate products and processes based upon economic, environmental, societal, and technical characteristics (the four pillars of sustainability)
4. Describe and explain the engineer's role in a project
5. Identify the role ethics, group processes, and collaborative learning have in the professional development of an engineer
6. Perform elementary machine operations such as layout, cutting, drilling, and tapping
7. Perform elementary drafting operations such as three-dimensional visualization, orthographic sketching, dimensioning, and two dimensional computer aided design
8. Perform elementary analysis operations using analytical software
9. Effectively convey technical solutions orally and in writing

Additionally, all course topics have been designed to build off algebra and high school science while introducing students to high-level systems and design thinking necessary to understand engineered systems. Specific course topics include:

1. Elements of Engineering Analysis including Force, Weight, Mass, Energy, and Unit Analysis
2. Chemical Energy
3. Parallel and Series Circuit Analysis
4. Gearing Analysis
5. Reporting, Documentation, and Presentations
6. Solid Modeling
7. Reverse Engineering
8. Concept Generation & Concept Selection
9. Hand and Power Tools
10. Systems Thinking, Life Cycle Thinking, Sustainable Design Fundamentals
11. Controls Engineering
12. Design of Experiments with respect to Detailed Design

The following four subsections describe in more detail each of the three course modules—ES, EDP, and CSD—as well as the course project. Each of the following subsections represent the modules as taught during the first run of the course.

Engineering Science (ES) Module
The purpose of ES module is to supplement and support student understanding of basic concepts in physics and chemistry as they are applied in engineering. The theory and practice of these concepts are introduced under a framework that centers on engineering as a discipline that harnesses, redirects, and manipulates of energy. The ES module sections, therefore, use energy conversion as a general theme to reinforce theoretical concepts that students will encounter throughout basic science coursework. Through in-class experiences that demonstrate fundamental concepts, students are able to observe how basic science translates through the manipulation of energy to real-world applications.

As in other areas of the ENGR 112 course, students break into teams to gain hands on experiences in ways that reinforce concepts taught as part of the class. Subjective observations, objective measurements, along with pre- and post-hoc calculations during these experiences provide the students a feel for how these basic concepts are applied. There are four sub-modules that comprise the ES module. Sub-modules include Force/Work/Energy, Chemistry/Chemical Energy, Electricity/Electrical Energy, and Mechanical/Mechanical Energy, and each of the sub-modules incorporating PBL opportunities. Descriptions of each sub-module follow.

<u>Force/Work/Energy (Make It Drop):</u> In this sub-module, students review concepts of force, work, power, and energy and are directed, using engineering examples, to see how these concepts are applied by the engineer in finding engineering solutions. As a starting point, each student team is provided a block of clay of differing mass. As a class, interactive discussions center on reviewing basic concepts related to mass, force, work, power, and kinematics specific to their clay mass. Using these sample masses, students perform calculations of force on their block due to gravity, calculate potential energy with respect to the floor, and determine the theoretical velocity associated with a drop of that distance.

"Make It Drop," shown in Figure 3, is the exercise that the students perform to observe these concepts. Student teams drop their blocks from the table top taking time measurements and making estimates of the velocity at impact. Discussions around "Where does the energy of impact go?" allow the introduction of basic concepts of mechanical deformation, heat transfer, and sound as energy coming out of the system. Comparing team measures of drop time and velocity provides a framework to discuss concepts of data variability and sources of error. Use of linear measurement tools of differing precision provides for discussions related to precision and accuracy of measured data.

Figure 3: "Make It Drop" to explore concepts of force, energy, and kinematics.

Chemistry/Chemical Energy (Make It Rust): In this sub-module, students review basic concepts of chemistry including atomic structure, atomic mass, atomic weight, ionic bonds, and basic analysis of chemical reactions. As an example, the oxidation reaction equation for iron is discussed including the resultant formation of iron oxide (rust) and the release of thermal energy.

"Make It Rust," shown in Figure 4, is the exercise designed to demonstrate the concept of creating thermal energy from chemical energy. Each student team is provided steel wool, vinegar, and a thermometer. The steel wool is rinsed in vinegar. A thermometer is placed within the steel wool ball, and the temperature is measured over time. The resultant exothermic reaction is noted by taking temperature measurements over a ten minute period. The oxidation process is readily observable by rust that quickly forms on the steel wool during this time. Plotting temperature against time provides a framework for discussions related to appropriate graphing of experimental data and discussions around differing sources of error between groups provide good material for discussing experiment design. As a final point to bring the exercise back to a real-world application, the students are then introduced to the product Hothands®[10] , a commercial product that uses a similar exothermic, iron-based oxidation reaction for use as a hand warmer.

Figure 4: "Make It Rust" to explore conversion of chemical energy to thermal energy.

Electricity/Electrical Energy (Make It Boil): In this sub-module, students learn basic concepts of electricity including current, voltage, resistance, power, and series and parallel circuits. An in class example using small coffee cup immersion heater coils provides a framework to discuss the conversion of electrical energy to thermal energy.

"Make It Boil," shown in Figure 5, is the student exercise designed to show how voltage, current, resistance, and power relate while providing an example of the conversion of electrical power into thermal power to boil water. Each student team is provided a volt-ohm meter, a beaker of water, a thermometer, a small coffee cup immersion heater coil, and the power monitoring device, Kill-A-Watt®[11]. The Kill-A-Watt® device has the ability to measure voltage, current, and power use of any household 120 V-AC device. To begin, students first measure the resistance of the immersion coil directly using the volt-ohm meter. The immersion coil is then placed into the beaker of water and plugged into power through the Kill-A-Watt® device into a ground-fault protected 120 V-AC outlet. Voltage, current, and power is recorded from the Kill-A-Watt® device. The temperature of the water is measured and recorded over a ten minute period. Calculation of power based on measured voltage and resistance is compared to that obtained directly from the Kill-A-Watt® device, and comparison of theoretical power use to measured provides for introduction of concepts of percent error. Plotting of thermal data reinforces discussions related to the graphical presentation of data, and comparison of group data provides further material to discuss variability of experimental data as well as sources of experimental error.

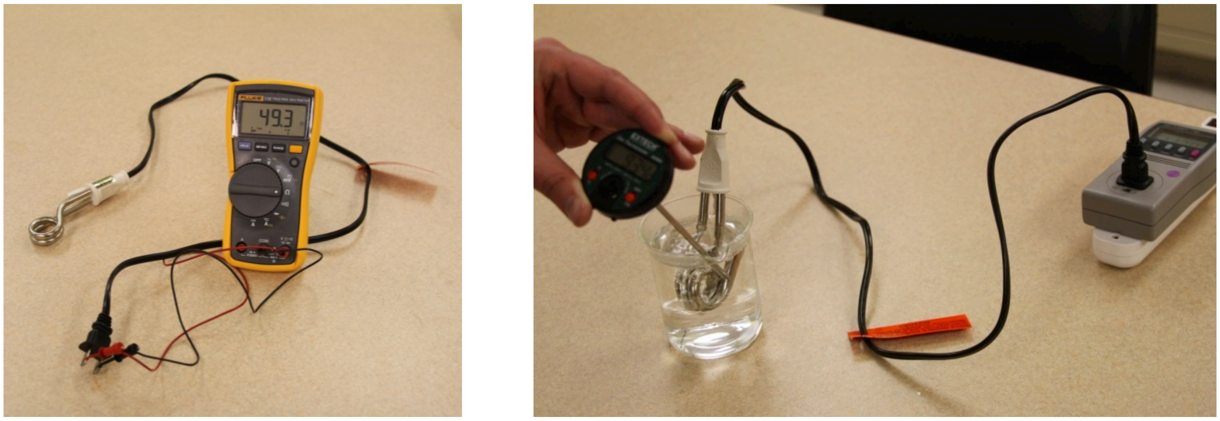

Figure 5: "Make It Boil" using an immersion coil heater and Kill-A-Watt®.

<u>Mechanical/Mechanical Energy:</u> This part of the ES module provides a brief overview of gears and gear ratios used to manipulate rotational mechanical energy to achieve variable levels of mechanical power and speed. Discussions in this section focus on linear and angular velocity as related to gear size and provides an overview of gear trains and related calculations. Direct student "hands-on" experiences associated with this material come from both the Reverse Engineering experience (see EDP Module), and the end-of-course project (see Culminating Project).

In the reverse engineering exercise, students physically take apart an electro-mechanical toy, the Bumble Ball®[12], shown in Figure 6. The bumble ball contains an off-center rotating mass which causes the toy to bounce around on its plastic knobs. Once students take apart the bumble ball, they find a simple electrical circuit and a gear train. As part of this process, students are able to observe the application of a DC motor to convert electrical energy from the batteries to mechanical energy. Students calculate the gear ratio of the Bumble Ball® gear train and use this to determine the rotational speed of the motor. While this provides a first direct insight into the use of gears, the more direct application of this ES materials is found as part of the end of semester project where students are required to select an appropriate gear ratio to meet performance requirements as part of the project criteria. The use of the Bumble Ball® toy for the reverse engineering module was adapted from a reverse engineering activity performed at Missouri University of Science & Technology and developed by Dr. Robert Stone.

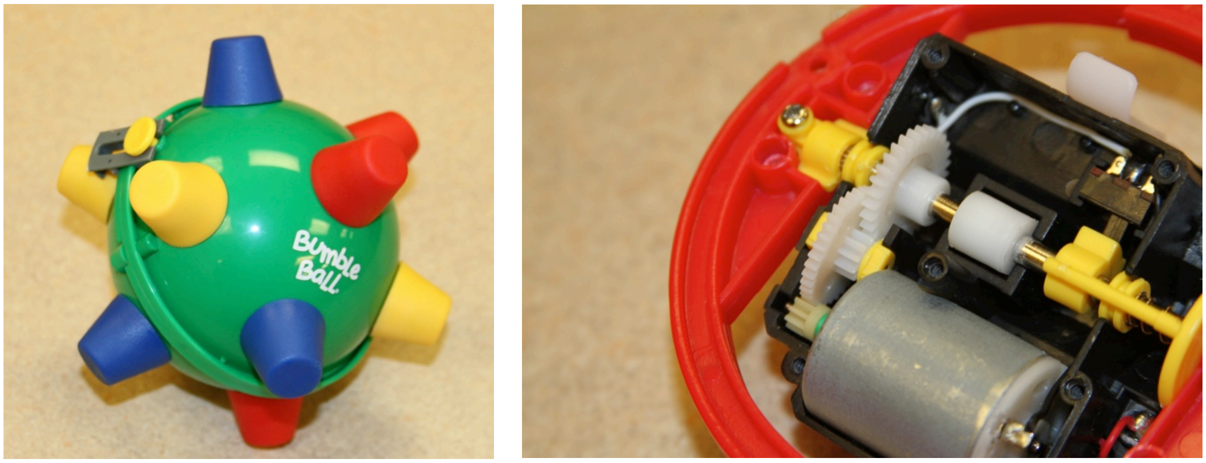

Figure 6: Bumble Ball® with exposure of motor and gearing.

Engineering Design Process (EDP) Module

The EDP module is meant to introduce students to the engineering design process through three key sub-modules: (1) reverse engineering, (2) product redesign engineering, and (3) technical drawing.

During the first EDP sub-module, reverse engineering, students are introduced to the concept of customer needs and function through the formation of customer needs statements and function statements. Students are taught a six step reverse engineering design process which directs them to (1) Identify the Purpose, (2) Develop a Hypothesis, (3) Disassemble, (4) Analyze the Elements, (5) Prepare the Report, and (6) Redesign (adapted from *Engineering Design: An Introduction* by Karsnitz, O'Brien, and Hutchinson[13]). Students then engage in following the reverse engineering process through the aforementioned disassembly and exploration of the Bumble Ball® toy. This also provides the link between the EDP and ES modules.

The second EDP sub-module teaches the students about creative concept generation and Pugh chart based concept selection. During this module, students are led in an in-class discussion concerning the both the artful and functional aspects of design as well as the differences between lateral and vertical thinking. Students brainstorm with their teams to generate concepts that improve upon the Bumble Ball® and might represent a win in the market. Students systematically evaluate their concepts based on the customer needs identified during reverse engineering using a Pugh chart[14]. The deliverables at the end of this project include: four hand drawn concepts generated through reverse engineering; a Pugh chart (with ten selection criteria based on customer needs) comparing each concept to the Bumble Ball® done in MS® Excel[15]; a computer generated graphic of your chosen concept; a short presentation (five to ten minutes) given using MS® Power Point[15] to show the design, selection process, and computer generated concept; and a memo describing the entire process.

To ready students for the generation of the computer generated concept of their Bumble Ball beating product, students complete the third EDP sub-module covering technical drawings and Solid Works®[16]. During this final sub-module, students are walked through the construction of two boxes and mating lids; one is built using only an extruded shape and an extruded cut. The other box requires students to set constraints on dimensions and then build the box as an assembly. Both mating lids have handles that require four additional skills be learned—using the revolve tool, using the sweep tool, using the chamfer tool, and placing a reference plane.

Components of Sustainable Design (CSD) Module

The CSD module imparts the basics of sustainable design, initiates systems thinking and analysis, and introduces life-cycle thinking in three sub-modules. The first sub-module familiarizes the students with the classic definition of sustainable development established during the World Commission on Environment and Development at the United Nations in 1984 which states, "Sustainable development is development that meets the needs (and aspirations) of the present generation without compromising the ability of future generations to meet their own needs"[17]. Students are then engaged in a discussion about the essence of the World Commission definition versus variants. The goal of the discussion is to help students with understanding the interconnectedness of components and concepts associated with sustainability. The students are then presented with the Madison Engineering Model of Sustainable Design illustrated in Figure 7 where sustainable design is nested in the middle of four spheres: Social, Technical, Environmental, and Economical.

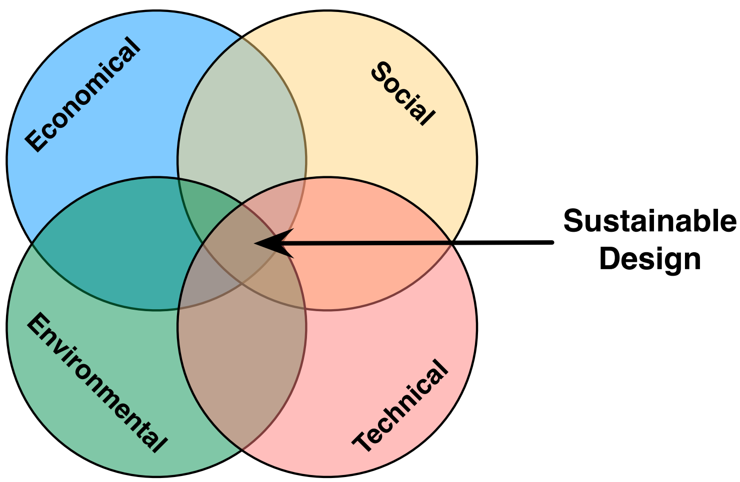

Figure 7: Schematic illustrating the Madison Engineering Sustainable Design Model[18].

The second sub-module focuses on defining a system, understanding the concepts of open and closed systems, and developing a technique to analyze a system. The students are led through defining the five basic elements of a system: purpose/function, boundary, components/relationships linkages, and performance via definitions and examples presented in-class. Then the five iterative steps of system analysis: (1) problem articulation/boundary selection, (2) formulate dynamic hypothesis, (3) develop a model, (4) testing and formulate policy options, and (5) evaluate are presented to the students through in-class case studies (adapted from *Business Dynamics: Systems Thinking and Modeling for a Complex World* by Sterman[19]).

The third CSD sub-module concentrates on creating a foundation of life-cycle thinking. After defining that life-cycle thinking is a holistic approach that should be implemented at the beginning of product/process design, students are given an in-class case study on determining what type of cups (disposable versus reusable) should be used in the on-campus dining facilities through a life cycle approach. This exercise is a springboard to introduce the impacts of population, consumption, and technology on our environment and design decisions. Students are then engaged to consider how they personally impact sustainability by identifying their personal environmental footprint based on their lifestyle choices through the Personal Footprint Calculator provided by The Global Footprint Network[20]. This module is based on lectures developed during prior course iterations by Dr. Bradley Striebig at James Madison University.

To link all three sub-modules of CSD, the students complete an observational exercise to understand the elements of population, consumption, and technology within an on-campus dining facility. Students form into teams of four and have to create a hypothesis around the following variables within the categories of people, consumption, and technology: people – rate, quantity, gender, age; consumption of food, packaging and utensils – input and output; technology – phones, computers, the family of "i" (pods, pads, etc.), writing, communications, cooking implements, and cash register. During this exercise, a boundary area approximately ten cubic meters where people are eating is established for observation. Students observe the area for a minimum of sixty minutes without interaction with or impacting other students' ability to observe dining hall activities. Teams are told to sit more than three meters to the focal point of another team. Deliverables for the group project are an engineering memo and a presentation. The memo has to include the problem statement or hypothesis related to sustainability, an account of parameters via defining the system (area location and assumptions), an MS® Excel[15] spreadsheet containing observed activities in the dining hall, a discussion of results, and a reflection. The time limit for presentation is approximately five to eight minutes. Students are tasked with defining their system, summarizing their observations, explaining problems observed in terms of sustainability, and providing potential engineering solutions for described problems. The goal of this project is to get students thinking about challenges associated with sustainability in "their own backyard." Students need to understand that the challenges discussed globally are equally present right on here on their college campus.

Culminating Project

The final course project is designed to incorporate aspects of the ES, EDP, and CSD modules together into one project. The current project is to design an automated cart capable of moving ten bricks 25 feet distance between the "manufacturing facility" and the "packaging facility." Teams are given five minutes to complete the task. Each student design is evaluated based on an overall performance score, *P*, calculated using the following formula where *G* is the overall greenness of the design, *B* is the number of bricks transported in the designated time, *T* is the number trips required to transport the bricks, and *t* is the time (in seconds) required to transport the bricks.

$$P = G + 2 \cdot (B - T + 1) - \left(t/30 \right)$$

The performance score is be calculated as follows: For *G*, ten points is awarded for automated carts with the only power circuit being solar, five points is awarded for automated carts with a battery circuit using solar power to supplement the battery power circuits, zero points is awarded for automated carts with the only power circuit being battery-based. Other "green" alternatives are evaluated on a case-by-case basis. *B* is the sum of bricks successfully transported from the starting location to the end location 25 feet away. *T* is the number of trips required to transport the bricks. The time, *t,* is calculated in seconds from 0 to 300 (five minutes). Time for all teams is stopped at five minutes. Each time a cart goes off-track and has to be manually readjusted ten seconds is added to time score. Also, if the bricks are transported individually, ten seconds are added for each unloading/loading and readjustment of the cart, and the five minute clock will not be stopped during these periods.

All teams are provided with solar panels, batteries, battery packs, planetary gear motors with variable gear ratios, wheels, and wire. Devices constructed of off-the-shelf components are not accepted. Images of exemplar student designs are provided in Figure 8.

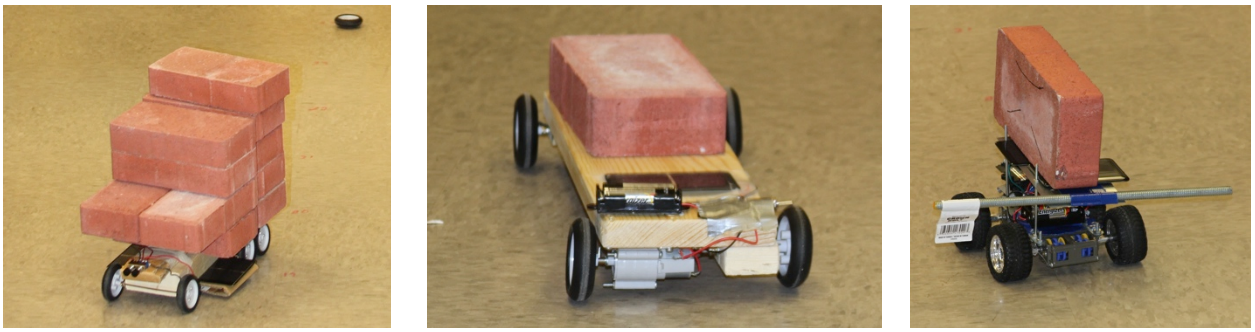

Figure 8: Exemplar brick mover designs from ENGR 112.

In addition to testing, students must incorporate aspects of the ES modules calculating the force required to move a brick as well as calculate the equivalent gear ratio used in their cart. Students are not explicitly expected to take into account rolling resistance as it is not covered during the ES modules; however, many students do account for rolling resistance as it is covered in the students' physics course. Students are also given scenarios at the start of class that they must work through; some examples follow:

1. If you have a single solar panel that ideally produces 500 mA with a voltage potential of 1.5 V, how could you wire two solar panels to produce a 1 A with a voltage potential of 1.5 V?

2. What would be the current draw of a simple circuit consisting of a 3 V constant voltage supply with a 500 kΩ load?

3. If a 400:1 gear box is placed on the motor provided, would more torque be generated as compared to a 4:1 gear box placed on the same motor? What would happen to the rotational velocity?

At the end of the project, students write a memo documenting the process taken to design their cart. The memo consists of: (1) identification of the purpose; (2) identification of key specifications including force required to move one brick, the work performed on the brick when moving it from the manufacturing to the packaging facility, and the power required (based on your team's estimate of the time required to move a single brick); (3) demonstration that at least eight alternate solutions were considered including sketches of the eight alternatives; (4) systematic evaluation of the alternatives; (5) testing and refinement to assist with arriving at a final design including a solid model generated in Solid Works®[16] and prototype testing; and (6) construction and testing of the final design including a picture of your final constructed prototype and an evaluation of percent difference between anticipated power requirements and actual power requirements.

Assessment of the Engineering (ENGR 112) Course

In Spring 2012, approximately 67 students in three experimental sections experienced the new version of ENGR 112 as described in this paper. The three course instructors coordinated on daily lessons, hands-on labs, and assignments so that students across their sections would have a common, foundational learning experience. Instructors intended the course to present an overview of engineering as taught at JMU, and in doing so, help students broaden their perspective of what it means to be an engineer and the nature of engineering problems. In addition to reinforcing math, science, and engineering principles with hands-on exercises, the course instructors encouraged students to reflect on the broader implications of their decisions and the role that engineers play in society.

At the end of the semester, students had the opportunity to assess their learning experience with respect to these objectives and the course outcomes described earlier in this paper. Thirty-six students across the three sections provided feedback on the course. Responses were fairly consistent across sections, though there was greater variability when students were asked to assess their ability to apply certain concepts. Table 1 summarizes students' self-reported competencies for the course learning outcomes. For the most part, students self-reported abilities were consistent with collective results from course assignments.

Table 1: Self-reported student competencies from course evaluation

	Student Ability				
Course Outcome	*High*	*More than adequate*	*Adequate*	*Limited*	*No Ability*
Describe and discuss problem solving processes as related to design	19%	47%	31%	6%	0%
Apply engineering processes to short design projects	31%	44%	22%	3%	0%
Analyze and evaluate products and processes based upon the four pillars of sustainability	28%	44%	25%	3%	0%
Describe and explain the engineer's role in a project	25%	42%	31%	3%	0%
Identify the role ethics, group processes, and collaborative learning have in professional development	31%	39%	22%	8%	0%
Perform elementary machine operations	53%	22%	25%	0%	0%
Perform elementary drafting operations	28%	25%	33%	14%	0%
Perform elementary analysis using analytical software	22%	22%	42%	14%	0%
Effectively convey technical solutions orally and in writing	33%	36%	28%	3%	0%

In terms of high-level course objectives, 94% of students agreed or strongly agreed that the course gave them a better understanding of engineering, and 92% agreed or strongly agreed that it gave them a better understanding of what engineers do. Further, 89% of students agreed or strongly agreed that the course broadened their interest in engineering. When asked to rate their ability to apply course concepts (i.e., design, sustainability, engineering science, technical communications), all students reported having at least a limited ability in each category and a majority reported at least an adequate ability.

The results in Table 1 do reveal a couple of competency areas (elementary drafting operations, elementary analysis using analytical software) in which student ability is relatively lower than in other areas. These areas represent opportunities for improvement in future iterations of the course, or opportunities for reinforcement in subsequent courses in the curriculum.

Unfortunately, since prior iterations of the course were taught by a rotating faculty set with each faculty member being responsible for different modules and the modules changing from year to year depending on assigned faculty, the results of this new course cannot be directly compared to prior course iterations. Instead students will have to be compared downstream in the program as this new cohort of students are completing their senior year. Empirical results, however, show promise, and consequently, the faculty responsible for developing this course plan to continue to teach following the structure discussed herein.

Conclusion

Based on the course survey data and student performance, students in ENGR 112 met or exceeded expectations for the course outcomes. The course instructors are therefore confident that the new model for ENGR 112 successfully introduced students to what it means to study engineering at JMU, and are committed to continuous improvement of the model in future semesters. In an end-of-semester reflection, course instructors identified two primary areas for improvement. First of all, we would like the students to make stronger connections between the ENGR 112 experience and future engineering work both in the classroom at JMU and in the profession. One way to accomplish this is to better highlight concepts that will be reinforced in future classes. For example, we plan to add a new lesson and learning activity on free-body diagrams, which will reinforce concepts from physics while introducing an engineering application that students will encounter in the sophomore year's statics and dynamics class. Another way to help students make connections is to have them explore projects that engineers are working on in the real world, and reflect on how principles of sustainable design and ethics are essential to those projects regardless of engineering disciplines.

A second area for improvement is to identify ways to scaffold learning within the course to help students integrate material from different modules into the mini and major design projects. In ENGR 112, we should guide the students toward this integration, whereas in advanced classes they will be expected to recognize opportunities for integration of prior knowledge. In the first iteration of this new course, students had difficulty with parallel and series circuits during the engineering science module. Thus, they had difficulty applying those concepts to the cart design project. In order to improve student learning of circuits concepts, we plan to introduce an in-class lab that will help students practice constructing and testing basic circuits so that they can apply those skills to designing and building the carts.

We want JMU students to be versatile engineers, which starts with being successful in our engineering program. The introduction to engineering course can help students develop realistic expectations of the challenges they will encounter in future courses and the nature of engineering work so that they can make an educated choice to pursue an engineering degree. In the spirit of continuous improvement, we will monitor student achievement of course outcomes in ENGR 112 as well as subsequent courses and make modifications accordingly.

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