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A design approach in an Introduction to Engineering course

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Abstract

Design is the essence of engineering. Because of its core values in engineering education and research as well as in industry, I decided to incorporate engineering design as the main theme of the Introduction to Engineering course at Eastern Mennonite University (EMU). Following a five-stage prescriptive model (problem definition, conceptual design, preliminary design, detailed design, and design communication) in their design process, students worked on two collaborative projects: the design and construction of a solar-powered cell phone charger and a persistence of vision wand. In addition to designing and building functional devices as end products, the students developed plans of work, kept records in their lab notebooks, considered alternative designs, wrote final reports including market analysis, and presented their work in visual aided presentations. In the process, students learned to use the design software Autodesk Inventor to design the cases housing the circuit boards of the solar-powered chargers and the wands encasing LED circuits. The cases were then printed out on a three-dimensional printer. They also learned to design, construct, and test electronic circuits. Moreover, students learned to program a microcontroller, an Arduino board, to control the LED displays. Testing and evaluating of designs as well as teamwork self-assessment and peer evaluations were carried out through the process.

Introduction

While engineering is an exceptionally broad field, design is the central activity shared within many, if not all, engineering disciplines. Recognized as an essential part in many fields of study, design has become valued in engineering education. A series of two semesters or more of design courses in the curriculum is very typical in many engineering schools. Engineering design has been one of the major themes in the curricula of engineering schools in many universities and colleges. For example, James Madison University[1] has a six-course sequence in engineering design, Stanford University integrates design activity in aspects of teaching and research[2], and Harvey Mudd College offers an Engineering Clinic to solve real world problems for clients in the public[3]. After all, everything made by humans is the result of the engineering design and manufacturing process.

Since EMU is a small liberal arts university where the engineering program is embedded in the Mathematical Sciences Department, there are only a few engineering courses offered, and there was no design course in the curriculum in the past. Because of its important role in engineering education and research as well as in industry, I felt that I had an obligation to integrate design into the program by incorporating engineering design as the main theme of the Introduction to Engineering course. In fact, I consider the introduction course a perfect spot to usher in this theme for the following reasons. First of all, the goal of the introductory course is to inspire and excite students to learn about engineering. Design, sometimes regarded as an art, is an intriguing venture where students experience turning an idea into a product. Secondly, students in the class are typically in their first or second year of college. I can teach them the design tools and techniques without requiring high-level mathematical knowledge. Thirdly, no matter what the students decide on pursuing, the design tools, communication skills, and project management experience they acquire in this course will serve them well in the future.

Teaching/learning design

How should design be taught and learned? Engineering design is defined by Dym and Little in *Engineering Design: a Project-based Introduction* as a thoughtful process for generating plans or schemes for devices, systems, or processes that attain given objectives while adhering to specified constraints[4]. By this definition, design involves thinking and doing. Moreover, in his *Signature Pedagogies in the Professions*, Shulman pinpointed the three fundamental dimensions of professional work – to think, to perform, and to act with integrity[5]. A signature pedagogy for engineering design, therefore, should be taught with the requirement that students think, do, and evaluate as professionals would. To this end, well-chosen design projects for students to work on become essential.

The world of engineering includes such a diverse set of topics that it would be impossible to cover them in one lifetime. It is unreasonable to cover the many engineering disciplines in one introductory course. Instead, an uncoverage approach should be taken as suggested in Calder's *Uncoverage: Towards a Signature Pedagogy for the History Survey*[6]. Thus, the design projects which are aimed to inspire students to learn about engineering and train them for challenging and creative career opportunities should be carefully determined in regard to the discipline areas of focus. Subject areas in mechanical, electrical, and computer science surface due to their fundamental roles in serving other disciplines. After much consideration, I finally settled on two projects – the design and construction of a solar-powered cell phone charger and a persistence of vision wand. These two projects bring together the signature pedagogy of promoting thinking and collaborating, while incorporating basic skills in conceptual design, mechanical drawing, electronic circuitry, and programming. These projects also allowed me to introduce cutting-edge technologies – 3D printing and the Arduino microcontroller. With these experiences the students are well-prepared for jobs after college.

The design projects and process

In introducing students to the design process of engineering projects, I focused on the following five aspects: defining the design problem; developing a project statement; generating and evaluating ideas and specifications; leading and managing the process; and communicating the outcomes. Students formed teams following these procedures to complete two projects over one semester. The course objectives are as follows:

1. Turn an idea into a final design.
2. Develop a problem statement, analyze proposed solutions and evaluate the final design.
3. Find a solution that meets technical, ethical, environmental, legal, etc. requirements.
4. Build ethics into the design process.
5. Use computer aided design software Autodesk Inventor.
6. Work with the Arduino platform, an open-source electronics prototyping platform.
7. Develop creativity and innovation skills.
8. Work effectively on a team and negotiate group dynamics.
9. Communicate effectively through written reports and oral presentations.

The two projects and their implementation are discussed in this section with the course timeline detailed in Appendix A. The bills of materials for both Projects 1 and 2 are presented in the Appendices B and C, respectively. At the beginning of the semester, I spent four lectures and discussions on the design process – a five-stage prescriptive model (problem definition, conceptual design, preliminary design, detailed design, and design communication), managing design process, team work, and engineering notebook (the textbook used in this course is *Engineering Design: a Project-based Introduction* by Dym and Little[4].) Students then started working on their projects.

Design project #1 – solar-powered cell phone charger

The first project was to design and build a solar-powered cell phone (and small electronic devices) charger. Students followed the design process they learned to develop a problem statement, and design, build, and test the charger. In the process, they needed to consider alternative solutions. They needed to have a plan of work, keep an engineering notebook, and hold team meetings at least once a week. We had evaluations in class to provide feedback and a written report and final presentation in the last phase of the project.

The two areas of focus in this project were learning the basic electronics and learning computer aided design. Students first learned how to use a multimeter, solder, and build simple circuits on breadboards. At the brainstorming stage of the project, by bouncing questions and answers around, students found that it would be ideal if they used a rechargeable battery to store the solar energy instead of using solar panel to charge a cell phone directly. Hence, two charging circuits were required, one to charge a phone, and another to charge a battery using a solar panel (Fig. 1). They also wanted their devices to be portable and small. Teams documented such decisions in their notebooks. For the circuit board supplying 5 volts from a battery to charge a phone (Circle "1" in Fig. 1), MintyBoost 3.0 kits (sparkfun.com) were used. Students soldered the circuit following the step-by-step instruction from Adafruit learning system[7]. They tested it using two AA batteries to make sure a phone can be charged by the batteries through the circuit. The next task was to build a circuit to charge a battery using solar power. The circuit board (Circle "2" in Fig. 1) the class used was a USB LiPoly Charger board (sparkfun.com) which was designed to incorporate USB input. Students needed to test the circuit and determine where to connect the solar panel onto the circuit board since solar power was to charge a polymer lithium ion battery. I found the sequence of the two tasks involving circuit building to be a successful approach in that the first circuit was rather attainable for beginners, whereas the second circuit required thinking and testing.

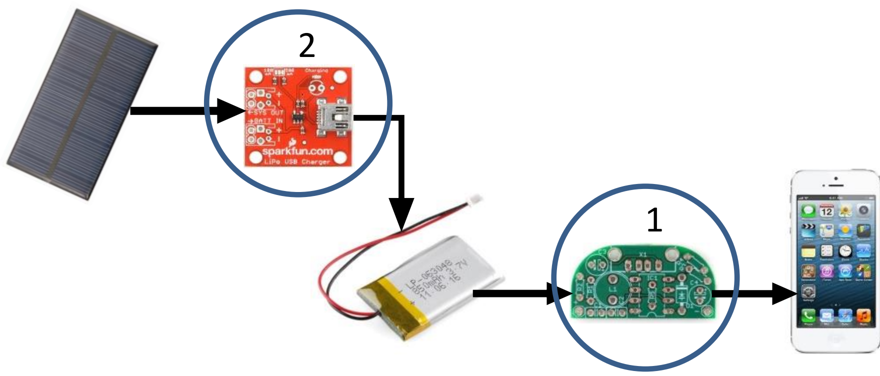

Fig. 1 The sequence of building a solar-powered cell phone charger. Solar panel (http://www.parallax.com) is connected to a battery charger (http://www.sparkfun.com). The battery then provides power to a cell phone through another charging circuit.

After the circuitry was built and tested, the students were introduced to the computer aided design software Autodesk Inventor. I lectured on the basic functions of the design software and concepts in mechanical drawing, and demonstrated a simple design. Students then started exploring the features and soon jumped into the design of the cases housing the electronics of the charger. Two teams decided to use the solar panel as the top face of their chargers, where the third team designed a sunk-in lid to hold the solar panel. Each team had undergone about three to five designs communicated through the drawings in their engineering notebooks. Their designs were then printed out through a 3D printer. Only one team kept the micro USB port accessible in their design for charging the battery directly from regular power supply in addition to the solar panel, which came with USB LiPoly Charger board (Circle "2" in Fig. 1). My students did an impressive job for their first trial. Only one design needed changes and a re-print. Figure 2 shows the design by one of the student teams[8] and Figure 3 shows a final assembled solar-powered cell phone charger[9] (125×63×31 mm).

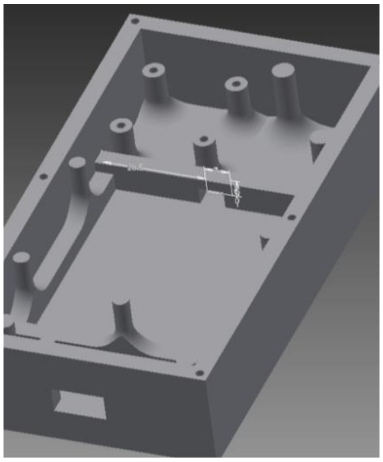

Fig. 2 A design of a case housing charging circuit boards developed by students in the course.

Fig. 3 An assembled solar-powered cell phone charger developed by students in the course.

The solar-powered cell phone chargers have been tested. The results ranged from four hours of sunlight for a full charge of a phone to two days of sunlight for a half charge. The students concluded that the direction of the Sun with regard to the solar panel, the intensity of sunlight, and the different types of phones and their years in service all contributed to the charging efficiency.

Design project #2 – persistence of vision wand

The second project was to design and build Persistence of Vision Wands that display messages and/or graphics. The wand consists of a single row of LEDs controlled by an Arduino. When it is moved quickly back and forth, one will see text or an image appear (Fig. 4). In addition to following a design process similar to the one in the first project, students were required to design the wand using Autodesk Inventor, build the LED display circuits, and program an Arduino board. While a team structure was maintained for this project, each team member designed and built his/her own wand with a unique message displayed. After all, one should have his or her own wand!

Fig. 4 A Persistence of Vision Wand with its image display.

After the team planning period, students spent several class sessions learning the Arduino platform, an open source physical computing platform based on a simple input/output board and a development environment that implements the Processing language[10]. Students took their initial step by building a simple LED circuit with an Arduino board and a breadboard. It is not easy to learn another language, including a computer language. None of my students had prior experience with programming. It took some effort to just get started with their very first Arduino Sketch. The first program students tried was “Blink a LED”. Then they added a pushbutton to control the LED. Through these exercises, they learned that the Arduino can take input and send output. Then students ventured to manage more than one LED. One team generated a Knight Rider, making a chase sequence with multiple LEDs[11] (Fig. 5). After I showed them how to program a letter E, they took off from there to create their own messages for display. Once students tested their program on an Arduino board, they uploaded it to an ATtiny84, a little processor, supported by Arduino platform, which was eventually used to control LED displays in the wand.

In addition to the challenge of Arduino programming, building the LED circuit was no easy task. Students had to think and understand that the circuit composed of a 9V battery, a switch, a voltage regulator, an ATtiny84, LEDs, and resistors. Moreover, they had to carefully construct the circuit. Finally they had to design the wand that held the whole circuit in Autodesk Inventor. In this 2nd round of design, students created a variety of wand designs such as the cylindrical[12] (Fig. 6) and rectangular structures, and a flat board.

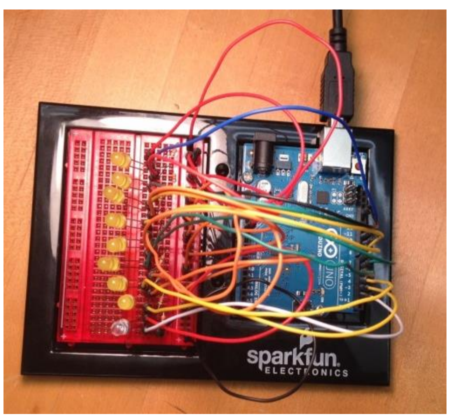

Fig. 5 Knight Rider layout, a student’s practice with the Arduino board in the course.

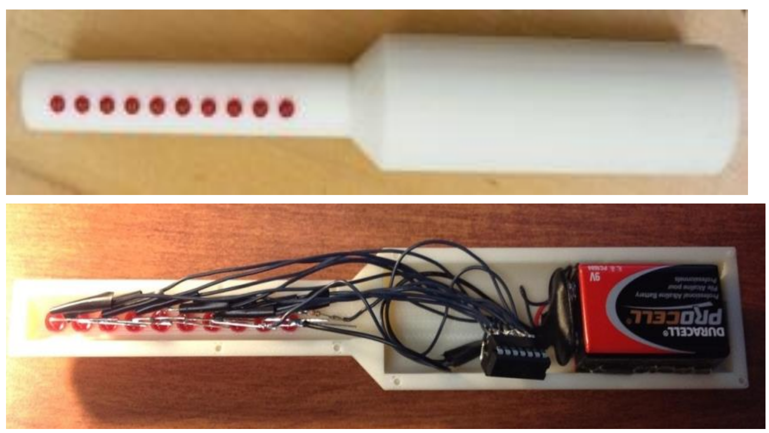

Fig. 6 A design of a Persistence of Vision Wand developed by a student in the course.

Team selection

The eight students enrolled in this course formed three teams, two teams with three students each and one team with two students. Although I offered the opportunity for them to consider choosing teammates, they decided to follow my suggestions on team formation. For the first project, I evened out the teams based on my observation of their work ethic, their intellectual ability, and hands-on experiences. For the second project, in order to allow students to have a chance to work with a different group of people, teams were assigned based on a random selection.

Design communication and management

I have discussed the details about students working on the two projects. In addition to designing and building a functional product, students were also trained in terms of communication and management skills. To enhance team performance, team members signed a team contract including goals, expectations, policies and procedures, and roles. At the beginning of each project, teams were required to turn in a plan of work including a work breakdown structure and schedule. Throughout each project, there were also teamwork self-assessment and peer evaluations to promote collaboration. About two weeks into a project, team members filled out self-assessment forms reflecting on teamwork, with questions including "What are we doing well in terms of teamwork? What are we not doing well and how to improve? Are the assigned roles appropriate, and if not, what changes should be made? Is every member contributing at an acceptable level?" In the middle of a project, an informal discussion was held among teams. Students and I provide feedback on design issues. Towards the end of a project, team members rated themselves and teammates on showing initiative, preparing for and attending scheduled meetings, making positive contributions and helping team achieve objectives, producing high quality work, supporting each other, managing conflict, etc. Each student filled in an evaluation form. After I compiled their input and combined with my observation, I held a discussion session with each team reviewing their progress and areas needing improvement.

Each team also kept an engineering notebook documenting summaries for team meetings; design development ideas, drawings and design decisions; test results; reviews of completion of action items; and suggestions for next meeting. I embrace the philosophy that oral and written communication is the key to being a competent engineer. For the final report of a project, both written report and oral presentation were required. The written report consisted of (but was not limited to) an abstract, introduction, market analysis, detailed design, alternative design, conclusion, and references. On one report, the team thoroughly analyzed the potential market for their solar-powered cell phone charger in comparison with cheap chargers available from online sellers and expensive brand chargers. In the oral presentation, teams reported on their design process including project objectives, desired functions, design alternatives, the selected design, decisions made at a variety of stages of the project, problems encountered and their solutions, highlights in the process, demonstration of a final product, and conclusions. And they also analyzed cost reduction and described potential customers for the products. The presentations were evaluated on meeting time guideline, presentation dynamics – organization, flow, transitions, voice quality, and equitable participation of all group members.

Discussion

Overall, through an emphasis on engineering design in an Introduction to Engineering course, I was able to introduce my students to the design process of an engineering project, facilitate their development of creativity and innovation skills, utilize state-of-the-art technologies such as 3D printing and Arduino microcontroller platform, and allow them to get a taste of different fields of engineering such as mechanical, electrical, computer, environmental, etc. At the end of the course we had a survey and discussion session. We discussed questions like the most difficult aspect in the projects, the biggest problem encountered, the most beneficial part, the most enjoyable experience, which project they like better and why, and suggestions for future classes. My students found that working with people as a team, learning through trial and error in engineering design process, and programming were most rewarding, while programming was voted as the most difficult aspect in the project. Their most enjoyable moments were seeing their designs processed to products through 3D printing, testing LED patterns controlled by Arduino, and having their finished working product in hands. A majority of my students liked the 2^{nd} project better because it was more challenging. They liked designing their own circuit and learning the Arduino platform although some found programming Arduino frustrating at times. They also offered suggestions for future classes. They would like to see both projects continued. They think that there should be more time allotted for learning the design software Autodesk Inventor and the Arduino microcontroller.

Another outcome of this introductory course was that my students applied the knowledge learned in the course in a grant proposal. After seeing the eagerness of my students working on projects in this course, I suggested that EMU start a chapter in the organization of Engineers for a Sustainable World (ESW). We did this, and EMU turned out to be the first school to join ESW in Virginia. Our club then applied the skills learned in this course and wrote a proposal to build a greenhouse for Sustainable Food Initiative in our university. In the proposal, my students wrote a nice problem statement with a detailed design, along with budget analysis. Not only was the proposal granted, but more funds than we asked for were awarded.

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Appendix A. Class Schedule

	Date	Topic	Assignment and Due
1	8/27	Introductions & Course syllabus	Read Chapter 1 and complete in-class questionnaire
2	8/29	The design process	Read Chapter 2
3	9/3	The design process and discussion of Project #1	Read Chapter 10 and quiz on reading
4	9/5	Team work and Lab notebook	Form teams and start project planning
5	9/10	Basic electronics	Turn in the team contract
6	9/12	Work on circuits	Turn in the work plan
7	9/17	Complete circuit building & team self-assessment	Read Chapter 8
8	9/19	Autodesk Inventor	Study the design software
9	9/24	Design the case of the charger and team feedback	Design and quiz on reading
10	9/26	Design the case of the charger	Continue with the design
11	10/1	Guest speaker (on patent)	Write a reflection and complete the final design of the case
12	10/3	Visitation to UVa labs	Writing assignment on engineering topics
13	10/8	Assemble the charger	Read Chapter 3
14	10/10	Career path talk, finish up Project #1, and peer evaluation	Turn in the lab notebook and work on the final report of project #1
15	10/15	Presentation of Project #1	Turn in career topics, final report, and an electronic copy of the presentation
16	10/17	Assign and discuss Project #2	Form teams and read Chapter 4
		Mid-semester recess	
17	10/24	Introduction to Arduino	Read about Arduino
18	10/29	Arduino programming	Turn in writing assignment and read Chapter 5
19	10/31	More about Arduino programming	Quiz on reading and turn in the work plan
20	11/5	Continue to practice Arduino programming	Read Chapter 7
21	11/7	Design the circuit of the wand & team self-assessment	Read Chapter 9
22	11/12	Design the case of the wand	Read Chapter 11
23	11/14	Continue to design the case of the wand	Complete the design of the case of the wand
24	11/19	Engineering ethics and team feedback	Read Chapter 12
25	11/21	Program the wand	Quiz on reading
26	11/26	Complete constructing the circuit of the wand	Turn in the lab notebook
		Thanksgiving recess	
27	12/3	Career presentation and peer evaluation	Turn in an electronic copy of the presentation

28	12/5	Finish up assembling and testing the wand, end-of-course survey	Turn in the final report of project #2
	12/10	Final Exam: Final presentation	Turn in an electronic copy of the presentation

Appendix B: Bill of materials of project #1 – solar-powered cell phone charger

Item	Description	QTY per assembly	Note	Est. Cost
1	Solar cell 6V 1W	1	http://www.parallax.com/product/750-00030	$9.99
2	MintyBoost 3.0 Kit	1	https://www.sparkfun.com/products/10094	$19.95
3	USB LiPoly charger	1	https://www.sparkfun.com/products/10161	$14.95
4	Polymer lithium ion battery	1	www.sparkfun.com/products/8483	$16.95
5	Hook-up wire	As needed		
6	Hexagonal screws	As needed		
7	Electrical tape	As needed		
8	3D printing thermoplastic	As needed	http://www.stratasys.com	

Appendix C: Bill of materials of project #2 – persistence of vision wand

Item	Description	QTY per assembly	Note	Est. Cost
1	AVR 14 Pin 20MHz 8K 12A/D - ATtiny84	1	https://www.sparkfun.com/products/11232	$2.95
2	DIP sockets solder tail - 14-Pin 0.3"	1	https://www.sparkfun.com/products/7939	$0.50
3	Voltage regulator - 3.3V	1	http://www.amazon.com	$0.89
4	LED - super bright	As needed	https://www.sparkfun.com/products/9979	$19.95/100
5	Resistor 330 Ω 1/6 W	As needed	https://www.sparkfun.com/products/11507	$0.95/20
6	Mini power switch	1	https://www.sparkfun.com/products/00597	$1.35
7	9V battery	1	Duracell Procell, http://www.amazon.com	$1.50
8	9V snap connector	1	http://www.amazon.com	$0.60
9	Hook-up wire	As needed		
10	Hexagonal screws	As needed		
11	Electrical tape	As needed		
12	3D printing thermoplastic	As needed	http://www.stratasys.com	