Using the Maker Concept to Promote Multidisciplinary Skills in a Freshman Engineering Program

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Introduction

This paper addresses the lack of student interest in topics outside of their discipline; this is even true for some students in all courses regardless of topic. However, all topics, especially fundamental ones are important in an engineering education because engineers are facing increasingly complex challenges and opportunities; consequently, collaboration between engineers of multiple disciplines becomes very important. ABET goes as far as to list "an ability to function on multidisciplinary teams" as a required student outcome for an undergraduate engineering program to be accredited. Engineering curriculums are somewhat designed to address this, but they often emphasize multidisciplinary teams at the end of the program in a senior design class. However, this develops the mentality in students that there will always be someone else to do the part that they are not comfortable with. As a result, engineering students have a tendency to lack comfort in cross-disciplinary topics (topics outside of their chosen discipline), despite taking fundamental courses in such topics.

All engineers specialize as they progress through their education and their career; however, many find that they are never comfortable with the fundamentals of cross-disciplinary topics. For example, mechanical engineers often receive some basic training in circuits and are somewhat competent in the area, but they are never truly comfortable enough in the area to exercise that knowledge professionally. They doubt themselves or see little value in correcting such a knowledge deficit.

This paper presents the results of a survey, which shows that this issue starts in the freshman year. At that point, all of the students are relatively the same; they have taken the same classes. Somehow they presort themselves and tend to devalue various topics being taught to them. This perceived lack of value that is placed on topics leads to a lack in motivation to learn some topics. There is a lot of research showing the dramatic effect that motivation can have on learning.[1,2] It is important that students of all engineering disciplines understand the value of a broad multi-disciplinary knowledge base in their future career as an engineer.

This paper proposes a solution to this problem through the use of the maker space concept in a freshman design course. The course in question is currently being revamped and is making use of Project Based Learning. However, addition change is being considered to embrace the maker approach, encourages people to understand how things work, to experiment, invent and redesign things through multiple iterations, to democratize and understand processes of engineering, science, and innovation, and to commercialize new products by developing and testing prototypes quickly and in a cost-effective manner. Making frequently takes place in social contexts, often called Maker spaces, where collaborators, mentors, advisors, and others can be found.

The goal will be to integrate the maker approach into freshman engineering curriculum, to emphasize the multi-disciplinary nature of real-world engineering projects. Students will get an idea of what it is like to work on a project that has elements from multiple disciplines and witness first-hand what knowledge they lack as they first attempt a project that they are not equipped to solve. Then, in the Maker Style, the students will be motivated to “seek” the knowledge that they lack. After learning various topics such as programming and Computer Aided Design (CAD), the students will be better equipped to make a second attempt on the project. In doing this, they will have the opportunity to “tinker” and get comfortable with topics that they would not otherwise be motivated to learn. The desired end result is for students with the Maker Experience to show an increase in confidence in their cross-disciplinary knowledge.

Student Motivation

Student motivation is necessary for them to perform in a class.[1] Some students find motivation due to the fact that a class is required to graduate or for certain goals associated with grades. However, not all students are motivated to learn in this way or to the same extent. Students tend to make decisions on how to apply their effort. If they see a high pay-off with a low cost, they will tend to put forth the effort. On the other hand, if they see a low pay-off with a high cost, they will be less likely to put in the effort. This can be visualized in Figure 1. If a course or content is viewed to be of high value and the effort is reasonable, it would land in Region 1, and the students will naturally want to participate and be motivated to perform. However, if the effort is higher than the perceived value, then it would land in Region 2 and students will not feel motivated to learn the topic and will only participate to fulfill requirements.

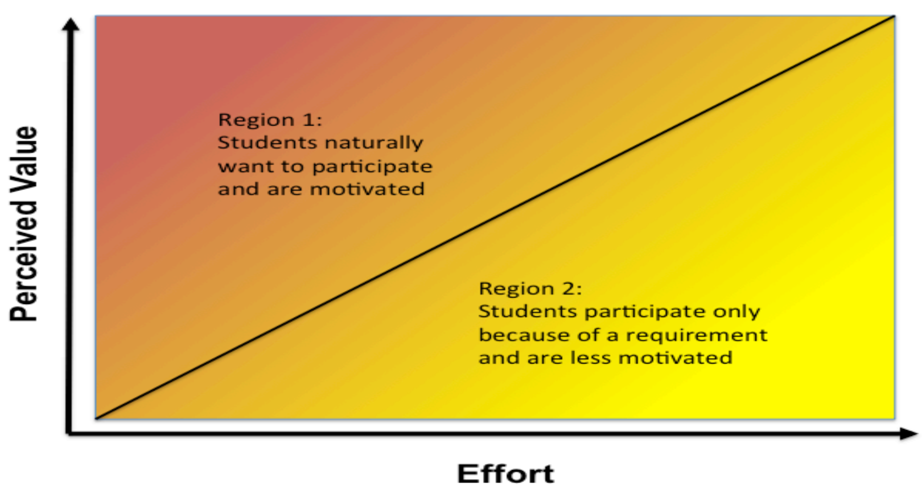

Figure 1: Value vs. Effort

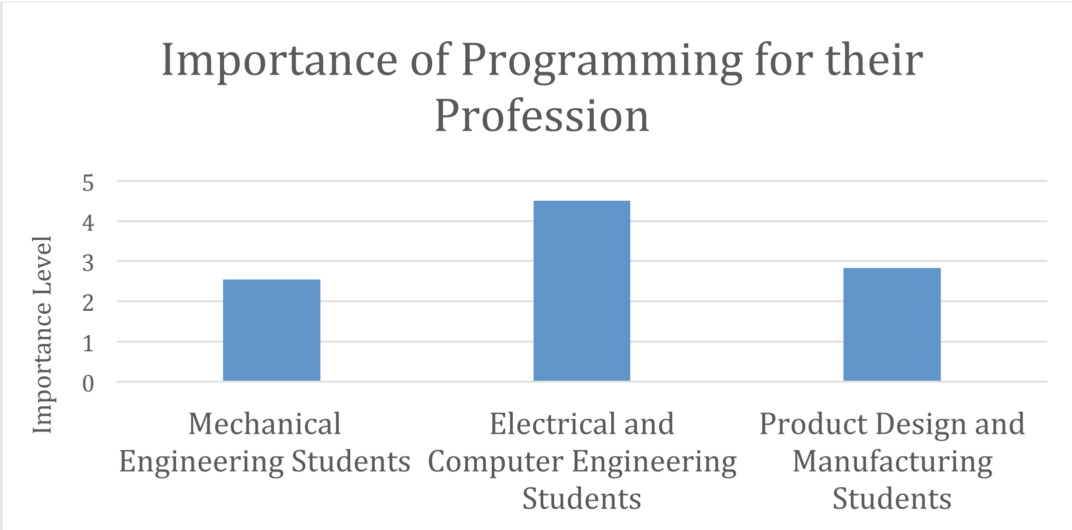

Figure 2: Survey results of engineering student responses to the question, "How important is computer programming to your profession?"

One example of this can be seen in the perceived value and difficulty of computer programming to different groups of engineering students. In Figure 2, the results of a survey question given to engineering students are shown. Eighty sophomore and junior engineering students (who have completed a programming course) were asked to rate how important computer programming was to their profession, with 5 being extremely important and 1 being not important. Electrical and computer engineering students rated it a 4.5, between important and extremely important. Mechanical and PDM (Product Design and Manufacturing) engineering students rated it below 3 (Neutral). It is clear that they have a different perceived value in the knowledge gained in a programming class, despite the fact that programming is a required skill for all engineering majors and is valuable to all engineering professions.

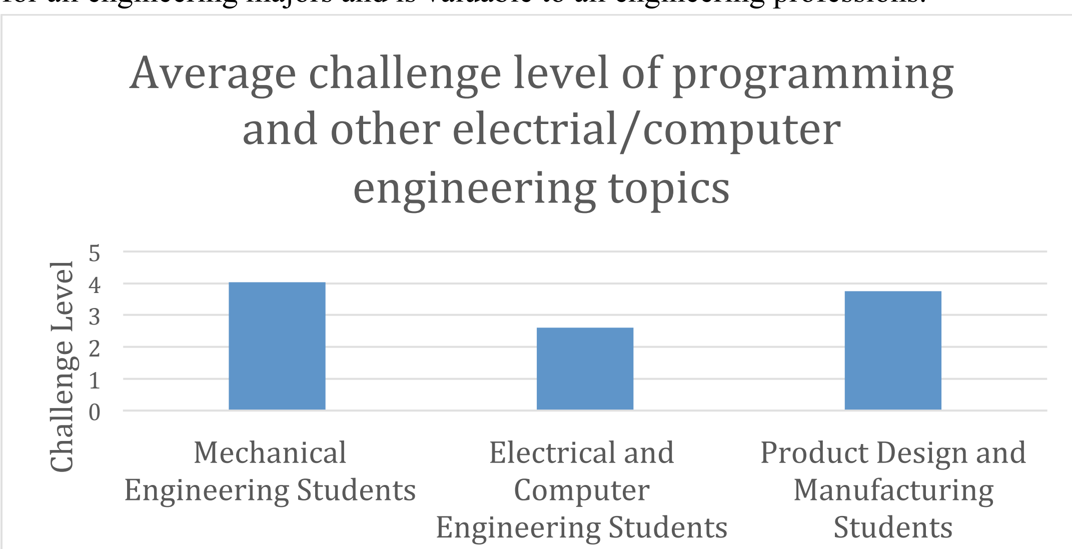

Figure 3: Survey results of engineering student responses to the question, "How challenging is computer programming and other similar electrical/computer engineering topics?"

When asked about difficulty of learning programming and other electrical and computer engineering topics, the results were similar, as seen in Figure 3. Electrical and computer engineering students felt that computer programming and similar topics were neutral in their difficulty rating with a 2.6, where 5 is extremely difficult and 1 is easy. Mechanical and PDM engineers felt that these topics were difficult, rating them at 4.04 and 3.75 respectively.

As a result of this perceived difficulty and lack of importance, mechanical engineering students tend to put less effort into learning computer programming and other electrical/computer engineering topics. The decrease in effort yields a lower performance from those students in the class. It should be possible to improve the performance of students if either the topic is easier to learn through innovative approaches or by increasing the perceived value of the topic, increasing the amount of effort students are willing to commit.

Faculty Observations and Motivation

In addition to what students have said in a survey, the all the faculty teaching these classes, observed the trend. This may not be common at other institutions, but it seems to be true here. Mechanical engineering students tend to repeat the programming course, and electrical and computer engineering students find little value in the CAD/CAM course, which is verified in the comment section of exit surveys of graduating seniors. It was these observations, combined with a high attrition rate among first-year students, which prompted faculty to revamp the freshman year. The first step was to replace the two engineering courses previously taught EGR101 (CAD/CAM and graphical communications) and EGR261 (Structured C Programming) and replace them with a course sequence called Introduction to Engineering Design (EGR106/107). The courses being replaced were skill courses; they were designed to teach the students a skill without much else.

The part that was clearly lacking was a context for the students to understand why they were learning what they were learning. These were courses that are taken by all incoming engineering students. Without a doubt, the depth of knowledge of CAD and C Programming needed for students varies based on their major, but they should all have a basic introductory understanding of these topics. Mechanical engineers will need to be able to write programs to run simulations and do design work, and electrical engineers may need to design a printed circuit board (PCB) and communicate with other engineers that are designing enclosures for their electronic designs. The motivation for the students to learn the material is clear, and they are topics, which can be taught prior to students completing Calculus and Physics. However, students were not getting a true sense of what engineering is. They were learning valuable skills, but C Programming does not provide an overview of electrical engineering any more than CAD does so for mechanical engineering.

New Courses

Given that the skills still needed to be learned by engineering students, and that courses in the curriculum expected students to have those skills, they needed to be incorporated in to EGR106/107. The lists of topics for the old courses are shown in Table 1.

Table 1: Topics taught in preexisting courses.

EGR 101 Topics	EGR 261 Topics
Design Process	Variables and data types
2D sketching	Expressions and operators
Lettering	Formatted I/O
Isometric Sketching	Writing and calling functions
Orthographic Sketching	Logic operators
Sectioning	Program flow control
Dimensioning and Tolerancing	Numeric arrays
Tolerance Analysis	Pointers and strings
Assembly Drawings and Bill of Materials	Modular programming
Geometric Dimensioning and Tolerancing	Program documentation
Solid Modeling	Program testing, debugging, and validation
Computer Aided Manufacturing	Variables and data types

The new courses incorporated all of the topics taught in EGR101 and EGR261, but rather than being taught in separate courses, the topics were taught side-by-side. The other major difference was the incorporation of Project Based Learning (PBL), which has been well documented in publication and are showing up in books on teaching STEM.[2,3] At the end of both courses, a multidisciplinary project was added were the students are teamed up in groups. There have been a few variations, but the current projects at the end of EGR106 and EGR107 are the Robot Olympics and King of the Hill Competitions. The Robot Olympics is made up of a variety of contests that require different approaches. All robots must be designed and build using CAD/CAM knowledge in the course. The robot is to be completely autonomous and use an Arduino to read in sensors and command motors. This allows students to see how these skills come together as well as allow the students to go through the design process. The King of the Hill Competition is more difficult, since it requires more than one type of sensor and the programming needs to be more complicated since the goal of the competition is to push another robot out of the arena, and their robots need to be prepared for the variety of strategies employed by the other teams.

In the current version of the Robot Olympics, there are five different events: Line Follower, Lane Follower, Rhythmic Gymnastics, Hill Climb, and Tug-of-War. The only sensor needed for these events is a reflectance (line sensor) and the programming is relatively simple. The first three competitions (Line Follower, Lane Follower, and Rhythmic Gymnastics) test robot designs the robots more on the electrical/computer engineering side, since their chances are greatly affected by how they incorporate sensors and their control method. The last two Hill Climb and Tug-of-War test the mechanical design of the robot, since success has more to do with the center of gravity of the robot and method of propulsion. Despite the obvious bias in the events, none of them can be done without a multidisciplinary approach. Figure 4 shows a robot that was built for the Robot Olympics. Figures 5 & 6 show robots competing in the Lane and Line Following events respectively.

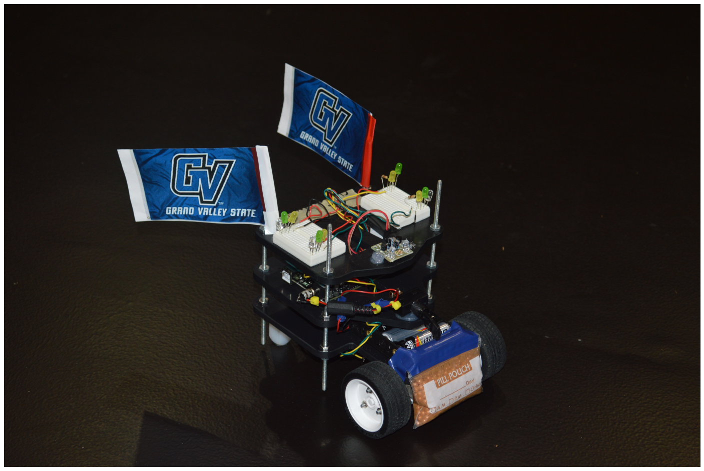

Figure 4: Robot made for the Robot Olympics

Figure 5: Robots Competing in the Lane Follower Event

Figure 6: Robot competing in the Line-Follower Event

The King of the Hill competition begins were the other competition left off. The students are required to follow a line into an arena and seek out their opponent and push them out of the arena. Figure 4 shows a depiction of the arena. This challenge is a great way to show multidisciplinary engineering. The robots need to process sensor data from line sensors to detect the path and the boundary of the arena and interface with distance sensors to detect and localize their opponent. The robots need to also be designed to withstand impact with the other robots and maintain good traction with the ground and have enough propulsion to push the other robot out of the arena. The robot cannot be built from kits and needs to be designed and fabricated in our freshman design lab, which is equipped with CNC mills, soldering equipment, drill presses, band saws, sanding station, and more.

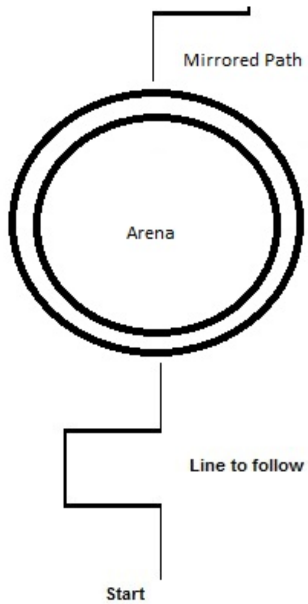

Figure 7: King of the Hill Arena

With these projects, it is clear that we are doing something similar to what is being done in maker spaces. Our freshman design lab even fits the definition of a maker space. At present, these projects make use of topics taught in the course, but they do not go all the way.

Proposed Maker Approach

To improve student motivation to learn a topic, it needs to be perceived as having value to them. The best way to change someone's perception of something is through experience. In traditional coursework, students are taught a topic and then taught the application, as with our current end of semester projects. If this is flipped, the students will see the application and understand why they need to learn the topic. This is how the Maker Concept works. In the Maker Concept people decide that they want to build something, without the knowledge needed to accomplish the task. They then proceed to seek the knowledge necessary. Everything that they learn is perceived to have value and they retain the knowledge gained from the experience.

The positive impact of Maker Spaces has been well documented, but they depend on people to seek out the Maker Space.[4,5,6,7,8,9,10,11,12,13] There is seldom structure to learning that occurs in Maker Spaces. Part of the novelty is the freedom it gives to those who are using them. People in Maker Spaces choose what they want to build and what they want to learn as a result. This self-guided discovery is very appealing to the hobbyist, and could have value to engineering students. At present, maker spaces have been made available to engineering students, but it is difficult to integrate the maker concept into engineering curriculum.

At present, students in our curriculum are taught computer programming and CAD/CAM as part of a freshman engineering design sequence. The topics are first taught and then students are required to take part in a final group project, which requires them to use knowledge from multiple disciplines. The students are required to design and build a custom robot to participate in the Robot Olympics and King of the Hill competitions. To help the students develop their robots, there are many topics taught in addition to programming and CAD/CAM, such as motors, sensors, and gears. Prior to the project, the students do not perceive the value in learning all of the topics, and they seem to have nothing in common.

Table 2: Topics for Maker Class

Optional Topics for Maker Class
Soldering
DC Motors
Stepper Motors
AC Motors
Gears (Ratios, Torque, and more)
Servo Motors
Distance Sensors
Motion Sensors
Digital Multimeter (Voltage, Resistance, and Current)
Battery Sizing and Power Consumption

In a future offering of this course, a pilot is planned that will introduce the project at the beginning and have a variety of topics available to the students to request. Half of the classes will be preplanned and dictated by course objectives; however, for the other half of the classes, the students will choose topics that are covered in greater detail in later classes and are only present to improve performance by first-year students on their project. A list of potential "Maker" topics can be seen in Table 2. This is to be done instead of having a strict course schedule with all topics planned out. The students in the class will be able to vote and request the topics that they believe to be the most important to learn next. In essence, the students will be learning as they would in a maker space. They are in the process of building a device and they will realize that they need to learn more about a topic to make their robot work properly and compete in the Robot Olympics.

Discussion

This paper lays out the motivation to pilot a Maker Concept in a freshman course. Maker spaces are being added to engineering colleges as well as local communities. Modeling an engineering class around this concept has its challenges due to its unstructured nature; however, student motivation to learn a topic is linked to perceived value. This method is similar to project based learning methods, but it removes some of the structure in the course to allow the students to discover the topics that they need to learn to complete their projects. The hope is that students will gain an understanding of the value of breadth in engineering fundamentals as they decide which topics are more important to them and their project during the semester.

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