Paper ID #16489

Developing an Entrepreneurial Mindset in Engineers: An Application of the Three C's (Creativity, Curiosity, and Connections) in a Collaborative Summer Mega-Course

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Abstract
In order to develop intra- and entrepreneurs, it is important to encourage a student's curiosity and skill in creating value and forging connections. We (a cross campus collaborative team of three professors from humanities, science, and engineering) developed an integrated mega-course that incorporates three separate fields that encompass a number of themes. These themes include teaching innovation, developing an entrepreneurial mindset, and creating solutions for developing economies. The program focuses on engaging students with our quickly changing world and its needs, bringing them out of the academic bubble to ignite their curiosity as they investigate the Grand Challenges proposed by the National Academy of Engineering (NAE). Students from various majors work together in teams using their creativity to design a solution that solves the stakeholders' needs. Students are motivated to produce a high quality design not only through the intrinsic motivation of meeting stakeholders' needs, but also by the requirement of holding a press-conference with local media, who will need to be convinced of both the need for and the value of the students' design.

Background: About our Program
The program investigates the Grand Challenges proposed by the National Academy of Engineering (NAE)[1] in a multidisciplinary course providing credit in Communication, Physics, and Mechanical Engineering. The NAE Grand Challenges are broad, important concepts for engineers to accomplish in this century for the betterment of humankind, and provide our students with a large number of topics to consider for their project. We provide the students with a broad goal shown in Table 1 and allow them to brainstorm ideas to pursue. Our students break into groups to make initial prototypes (column 3 of table 1) of a product they would like to pursue for the summer. The students then assess the various prototypes as a group advocating for both their design and another groups' design. This competitive process ends with the class voting as a whole on which project will go forward. We then assign a project lead from among the students to carry the elected prototype through to completion.

The program the students take is close to a fulltime term in hours required and credit, resulting in what might be called a single mega-course, at least in terms of scope—however, we keep the number of students enrolled small, from 10-15 participants, so that all can ultimately work on a single project. This program allows the unique opportunity for science and engineering students from different majors and backgrounds to pull together in a single design, build, and test scenario; for instance, students taking the course range from civil engineering to physics majors.

Table 1. Student assigned goal, students initial concepts, and final design for three years.

Year	Goal assigned from Grand challenge	Initial concepts	Final design
1	Help Kenya	Mosquito chaser Fuel from algae Solar backpack with LED Solar powered engine Slow sand filter Water pasteurizer	Slow sand filter with solar trough pasteurizer
2	Help Haiti	Greenhouse fish aquaponics Cellphone battery charger Plastic bricks for housing Water purification and storage	Melting plastic for reuse as construction material
3	Provide easily manufacturable prototype for Haiti client	Solar oven Solar trough Composting latrine	Solar trough to create shingles from plastic

The Summer Grand Challenge Program was initially developed in summer 2012 and was taught for three consecutive years in the Summer from 2013-2015. It is an immersive ten-week program in which undergraduate students design and build an inexpensive and locally manufacturable system for underdeveloped countries. After an intensive problem definition phase, students determine the target location and needs of the local customer, which influences the final product's functionality. Students earn twelve credit hours (four credit hours of science, four credit hours of engineering, and four credit hours of technical writing and communications) for the program, generating revenue through tuition—thus the program is self-funding.

Introduction: Developing an Entrepreneurial Mindset

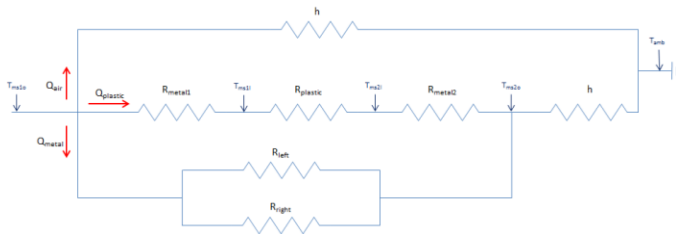
Various authors have studied the skills an entrepreneur possesses that allow them to become successful[2,3]. These have been found to include curiosity, an ability to see connections, and recognition of the possibility to add value[4]. We propose to engage a student's curiosity, build connections between courses and real engineering, and help the students recognize the value in their classes and their own work. Curiosity as a trait has been studied and contemplated by many in an effort to employ curiosity to learning.[5] In fact some have divided the concept of curiosity into separate compartments including an "entrepreneurial curiosity".[6] Research has also suggested that curiosity can help learning within an appropriate level of arousal.[7] Too much arousal causes anxiety, not enough arousal causes lack of interest. We aim to keep the students "interested" hopefully without straying into the significant anxiety range.

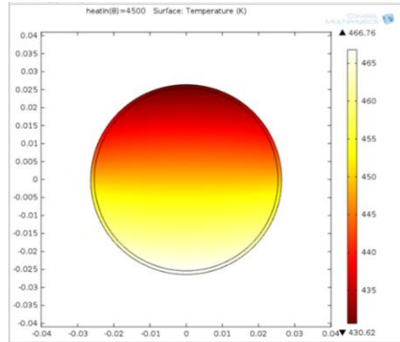
Students' curiosity

We start the course by giving the students a geographical location most know nothing about and task them with trying to find out more information that they think is relevant to identifying a problem. To help students learn to see opportunities, we have them investigate the "Grand Challenges" proposed by the National Academy of Engineering (NAE) as a possible starting point. By providing the students with simply a region and the NAE website, the students become engaged with our quickly changing world (especially due to natural disasters) and its needs, bringing them out of the academic bubble of a US-based institution. When performing their research, rather than providing students specific questions that they have to answer, we have the students answer questions they think are relevant such as who, what, when, where, and why. This allows for the students to remain engaged and not become overwhelmed by the final task. For instance during the first course offering we started by having the students research Kenya. They decided that it was important to ask questions such as what is the average income, who are the local tribes, where do they live, what beliefs do they have, what is the local geography, what issues are they having, when did these issues begin and why? The students felt all of these pieces of information were necessary in order to better understand the true challenges the region is facing. By allowing the students to determine what is important to know, they become more curious about the region rather than simply researching set questions. They can go in directions that their research takes them, and they start to figure out what exactly they need to know. In this way the students identify problems in a given community rather than selecting solutions that hopefully fit a problem that might not even exist. This process provides flexibility and buy-in from the students in the selection of problems that they are interested in tackling.

In addition the students' curiosity was piqued when starting to develop concepts for their design. For example each year, the students quickly recognized the need to better understand heat transfer in order to determine size dimensions of their system. We were then able to provide the students a quick lecture on heat transfer that was relevant and just-in-time such that they had a much higher stakes and interest in learning the material than in a traditional course. Also, the problem is more complex than those typically solved in the engineering textbooks. They had to understand what assumptions they should make and were making in order to assess the accuracy of their calculations. Students started trying to change assumptions and exploring parameters of the design to see how that would affect the results indicating an arousal of their curiosity. For instance, what if they changed the pipe's diameter, the material used, the reflectivity, or added insulation? Figure 1 shows an insert from the students' daily online logbook (which they were required to keep as part of their project documentation) that shows their curiosity in changing these parameters.

Furthermore, unlike typical problems solved in textbooks, these challenges require understanding the constraints of dynamic contexts including the current marketplace. For instance, even though a certain material was readily available in the U.S., the students had to determine the availability and cost in the region of interest. Also they had to consider portability of that item to the jobsite. These are some aspects that are typically overlooked and not discussed in textbook problems. This also helped to stress that sometimes the best "technical design" is not the best solution for a certain client. Thus, curiosity is central to the design process encouraged in this program.





Members of the team went on to modify this model so that we could account for different things, such as different materials and insulation.

Today we added insulation to the COMSOL model to get a more even distribution of heat through out the pipe. We then created time graphs in COMSOL. We then did the same thing for the pipe with air instead of plastic inside it. The new model can be seen below.

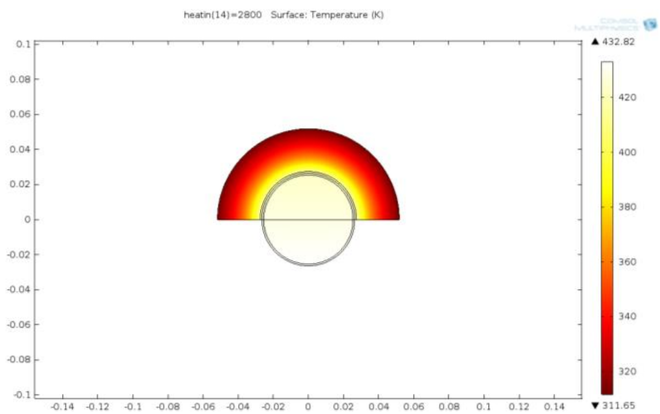


Figure 1: Insert from the students' logbook that shows the equivalent circuit for the heat transfer in their device along with two computer models that shows the temperature at various locations on the device, one with and one without insulation. The students generated a number of these models on their own without prompting for their own curiosity.

Forging connections

The program is unique in that it is co-taught by three professors from different fields—in this case, physics, engineering, and humanities—with the goal of providing multidisciplinary experiential learning opportunities for students. Students with various majors are forced to work together and make connections between theories taught in the classroom and real-world design applications—improving their understanding. Connections among the disciplines drawn from in this program can be seen in Figure 2. These connections are forged and experienced by both the faculty teaching the program and the students in it.

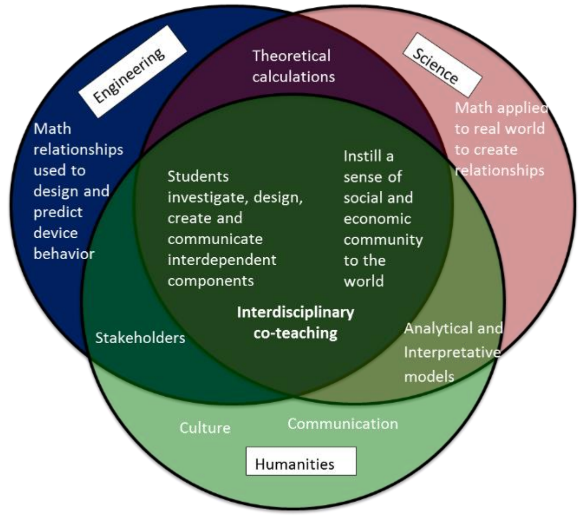


Figure 2. This Venn diagram indicates the connections among the different subject areas within the course and the expertise area of the faculty.

For instance, in science the goal of creating models is to predict the world around us. Communication models rely on being able to predict human behaviors and responses. However, there is an overlap in that both fields are using analytical and interpretative models that predict behavior. These models are then used by an engineer to predict device and user behavior. As an example of how models are generated and used to inform design decision, the students decided to plot the temperature of the device as a function of time and model it theoretically. Figure 3 shows that both the prototype and the theoretical model agree, thus showing connection between the physical world and theory. The students then used this information to determine the time duration required for melting the plastic and how much material could be produced per day. This then connects the theory back to the stakeholder as amount of material produced per day affects their daily income.

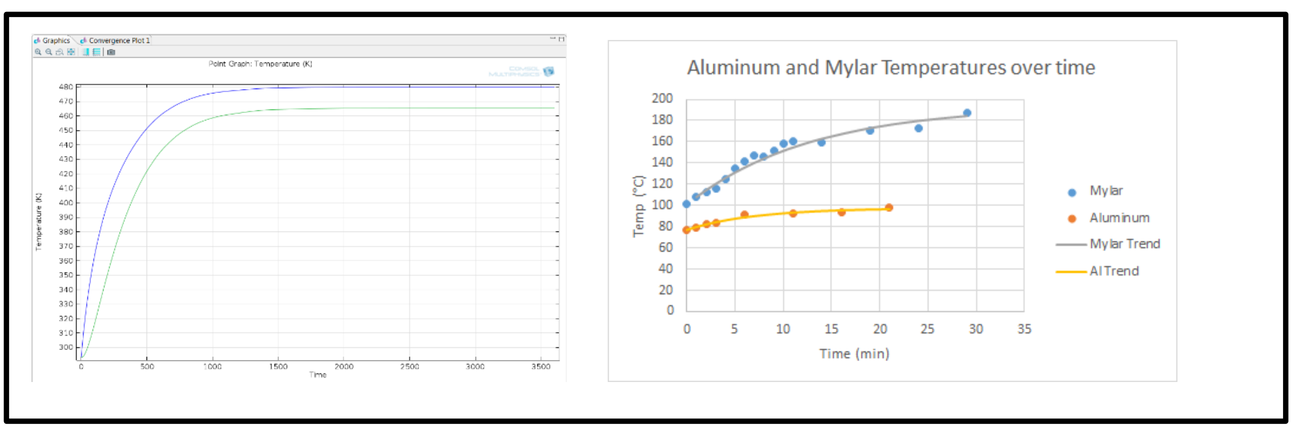


Figure 3: (a) Theoretical calculations generated and (b) experimental results. Note that these were generated in a logbook and thus not intended for final publication. The axes are different scales on both the x and the y-axes.

Interconnections are forged not only from similar subject matter but also from co-teaching as instructors build off of each other's lectures. As one instructor would provide instruction for a certain set of subject matter, the other instructors could reinforce this subject with examples in their own discipline of similar/connected topics. For example, when the technical communication professor discussed rhetorical situations and analyzing the audience, the engineering instructor would provide examples from her experience in the workforce and preparing different presentations for their project (managerial) lead vs. their functional (technical) lead. This helped stress the importance of rhetorical analysis in the workplace rather than solely an academic exercise. In addition, the longer classroom time with no partitioned segments for science, writing, and design highlights how these activities are intertwined and cannot be performed in a void. By teaching three components at the same time, we are inherently creating connections among our subject matter. For instance, all assignments were graded not only for their technical content and scientific principle but also for their ability to communicate results effectively. By grading in this manner (sometimes sitting in view of the students), it helped the students see the interconnections between these subject areas.

Creating and recognizing value

Our students first pursue the knowledge to develop innovative solutions that we expect will create extraordinary value and improve the quality of life of people in the given region, especially because we have real clients vested in the final product. After writing an IEEE article the previous year, we were contacted by a group from Clemson's Engineers for Developing Countries (CEDC), who currently have interns that live and work in Haiti for at least one semester and would be interested in implementing the final design. Not only has this group been interested, but over the last three years we have had several different clients reach out to our students about their designs and ask about using their idea to make different products besides roofing. For instance, recently a student from another university contacted our students to see if their method of repurposing plastic could be used to create crutches. Thus, this further demonstrates how the students' work that was developed during the class provides value beyond a single client and even after the course is over. In addition, the students can also see how communicating their results can provide value to the scientific community as well as the importance of clearly communicating your ideas and results.

In order for students to develop the knowledge necessary to understand issues in a certain country, students research stakeholders, challenges, cultural context, and scientific principles. They can then leverage that knowledge to develop models that express the stakeholder needs and optimize their design such that the features included provide the most value. We have students study trade-off spaces and create decision matrices to see what features are more highly valued. To ensure that the students accurately captured these value-added features, they were in regular contact with their clients involved in CEDC. An example of how creating value was demonstrated by the students is their change in the design. Initially the students developed a modular type heating system that required numerous people to move and operate the device. The students decided that this modular device, although easier to manufacture, would not benefit the final client nearly as much as it would if one person could operate the device without any assistance. Thus, the student decided to create a more integral design. The two different designs are shown in Figure 4.

(a) (b)

Figure 4: (a) Original modular design developed by the students and (b) improved design that can be moved and aligned by a single operator.

Not only does the product that they produce provide value, but also the students start to see value in past courses that they took and future courses that they will take. For instance, the small amount of heat transfer that was covered in the class demonstrates why it is important to take the more advanced heat transfer course and why the theoretical content covered is invaluable because they already saw the application for this content.

Additional motivation for producing a high quality design is provided by the requirement of holding a press-conference with local media, who will need to be convinced of both the need for and the value of the students' design. Besides being featured on the school's website and on the local news, the students also were interviewed via a radio station hosted in Washington, D.C. The knowledge that their project will be made public helps instill the mindset that final failure is not an option. Throughout the course the students experiment, design, fail, and ultimately succeed in the development of their own design. In addition to providing value in terms of a functioning product, the course also provides value to the school—value that we seek to increase in future developments of this program.

Assessment of the course in regards to creativity, creating value, and connections

The numbers in each class of students were relatively small making numerical analysis difficult, with questionable statistical value; however, below is some anecdotal evidence for assessment of curiosity, connections, and creating value.

Curiosity
Our intention is to utilize the curiosity students start with in order to complete their design Evidence of the increase in student's curiosity can be seen through the following avenues:

-Creating comsol models other than those required by the course

-Development of another solar collector outside of the course to see if they could further improve last year's design

-Performing tensile tests and bending test without being told and learning how to analyze the data

Connections

Several students after taking the course stated that it helped them in future analysis classes as it provide the reasoning why performing theoretical calculations are important.

Most of the evidence for connections created is in the form of student comments:

> "It has broadened my understanding of science and engineering and I am learning very useful information about the world around me."
> "I'm enjoying myself quite thoroughly due to the interesting class combination."
> "The aspect of this class that I have enjoyed the most is the co-teaching. The combined knowledge that the three of you share will help us students excel outside of academia."
> "The best thing is everything we learned matches each other like gears. This experience is not easy to have during a normal school year."

Creating Value

The student's recognized the value created through the development of this device. If the students didn't see the value they were creating, they would have been less willing to stay late (sometimes until midnight) to keep working on the project. One team member also requested that he continue working on this device for his senior design course as he wanted to further develop the device so that it could eventually be implemented in Haiti. In addition, the value created was also recognized by groups other than our students. For instance, they were invited to write an article in IEEE Potentials magazine and was also contacted by other student groups at different universities to find out more information.

Conclusion

In summary, the development of this Summer Grand Challenge Program provides an excellent opportunity for students to develop an entrepreneurial mindset through manufacturing a prototype that is targeted towards a developing country. The students learned valuable lessons in writing, modeling, and design, and their crossover to other disciplines. The material the students encountered affected curiosity through their actions, demonstrated by the students' exploration of multiple versions of their project design, and numerous heat transfer models. The manner in which the course is taught provides opportunities to ignite the students' curiosity, forge connections between courses and design, and provide value to their clients and the scientific community.

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