Paper ID #22875

Entrepreneurial Mindset (EML) Modules for Chemical Engineering Courses

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Abstract

Traditional chemical engineering curriculum focus on the math, science and engineering fundamentals culminating in a senior year process design course. These courses are excellent preparation for most chemical engineering jobs, but they typically omit very practical skills such as curiosity, connections and creating value. The lack of these fundamentals of the entrepreneurial mindset puts chemical engineers at a disadvantage in today's workplace. The faculty at Villanova University have made the effort to focus on EML (entrepreneurial minded learning) by creating modules that can be implemented in already existing courses. These modules all vary in time, scale, and application, but have the same goal: to introduce chemical engineers to the entrepreneurial mindset.

This paper will review in depth three different modules created and presented to students. The projects vary from elective courses (intro to biotechnology and polymer science) to required courses (heat transfer operations and process design). The projects included an attempt to explore a contrarian viewpoint by evaluating "bad" plastics, design of a shower without electricity and the design of a heat exchanger for commercial scale brewery. The projects were all evaluated using student surveys and post implementation reflection by the faculty. The authors believe these same modules can be implemented in similar classes at other institutions with equal success.

Background

The National Academy of Engineers has established a list of Grand Challenges for engineers which include several topics that will require novel designs based on chemical engineering expertise, such as engineering better medicines, providing access to clean water, providing energy from fusion, managing the nitrogen cycle, preventing nuclear terror, and developing carbon sequestration technologies [1]. These grand challenges present the opportunity for chemical engineers to show their curiosity and creativity in determining new processes and design solutions. The need for these innovative, entrepreneurial engineers is obvious, and the universities are recognizing the need to incorporate these skills into their curriculum [2] [3] [4, 5].

Villanova University has recognized the value of entrepreneurship in engineering education and has therefore partnered with the Kern Entrepreneurial Engineering Network (KEEN) to creative entrepreneurial minded (EM) engineers. KEEN has established a skillset necessary to be a successful entrepreneurially minded engineer. This skill set allows engineers to use their technical competency to always be searching for the best solution that creates the most value for the customer. The skillset is divided into three main categories, known as the three "C"s- Curiosity, Connections, and Creating Value [1]. The establishment of curiosity and creativity in an engineering student is essential in developing "outside of the box" ideas to solve these grand challenges, but is often undervalued in current engineering education [6]. The connections skillset focuses on drawing connections between technical skills learned in the classroom and real world engineering problems. The connections can also occur between different disciplines in engineering to create a novel solution to a problem. The final category is creating value to the customer with your design. While students are taught to calculate the cost of their product, they are often not taught to look at the product in a more holistic view to incorporate customer feedback, societal impacts, or even the value of their design compared to others on the market [7]. While engineering students can benefit from some of these concepts, the development of an entire business plan for every design is not the goal of establishing an entrepreneurially minded (EM) engineer. The use of a set of canvases developed by Strategyzer has been beneficial in many engineering classes to introduce students to the concepts of value proposition and an abbreviated business model (via the business canvas) [8].

Despite the effort of many engineering schools, as summarized recently by the National Academy of Engineers [1], to update their curricula to include EM concepts in their students, many of the projects are focused on mechanical [9], electrical and civil engineering disciplines [10, 11]. A search of the Journal of Engineering Entrepreneurship shows very little on chemical engineering, as does a look at the ASEE Chemical Engineering division and American Institute of Chemical Engineers (AIChe) conference programs. The discipline of chemical engineering evolved from the need for improved safety in hazardous processes [12], and has traditionally focused on designs that met the needs of product quality, safety and environmental regulations (as reflected in the ABET criterion [12]). This strong culture of safety, while necessary, has often prevented chemical engineers from being truly innovative in their designs. Throughout the KEEN Network, and even at Villanova University there is strong incorporation of EML into the curriculum for departments other than Chemical Engineering [9, 11].

The authors believe that chemical engineering students must develop not only the technical skillset but also the entrepreneurial mindset necessary to address the grand challenges proposed by the NAE. The authors believe, that Chemical Engineering departments must make an effort to incorporate more EML into their curricula in order to develop engineers ready for these and future challenges society will face.

Methodology

The faculty that helped to develop and implement these modules all participated in an entrepreneurial minded learning workshop (the Villanova Deep Dive), sponsored by the Kern Family Foundation's KEEN Institutional grant. The goal was to introduce faculty to EM concepts, and help them to develop methods to include these essential skills (curiosity, connections, creating value) into their courses. The resulting modules were developed to try to reach as many students as possible by spreading them through different years and courses in the curriculum. Each module varied in the amount of in class vs out of class time, and no one module tried to include all of the major concepts. Each project focused on one or two main concepts allowing the students to understand that specific set of skills in an example relevant to the course material. The goal was to not make it feel as though "irrelevant" material was being "shoved into" the course, but rather use EM concepts to excite and engage the students.

Several modules have been developed to hit the curriculum in as many places as possible, however, only a few have been implemented thus far, and are presented in detail here (indicated [1-

[3] in Table 1). A few more have been developed but not yet implemented and assessed (*in Table 1).

Table 1. Villanova University's plan for modules on EML in ChE curriculum Modules are designed to target either curiosity, connections, or creating value. The modules are mapped over the four years of the curriculum in order to promote a sense of importance for the students.

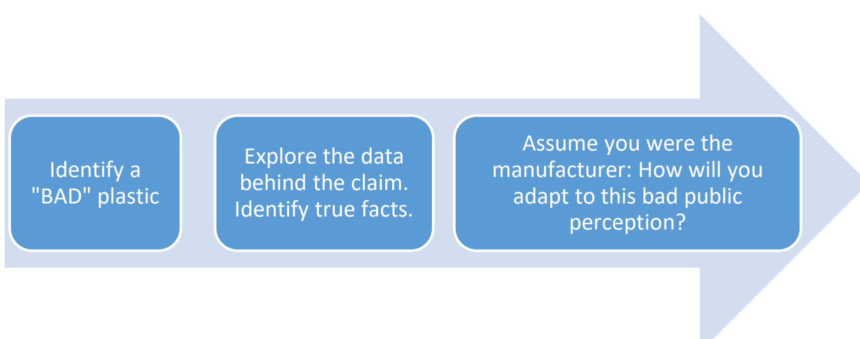
	CURISOSITY	CONNECTIONS	CREATING VALUE
FRESHMAN YEAR	Introduction to CHE*		
SOPHOMORE YEAR		Fluid Mechanics*	
JUNIOR YEAR		Heat Transfer Operations[3,4]	
SENIOR YEAR			Unit Operations Lab2*
ELECTIVES	Polymer Science[1]		Intro to Biotech*

Module Results and Discussion

The following section will outline each module, its implementation, and the results (via instructor feedback and student survey results).

Module 1: Plastics: Exploring a contrarian view; the good, the bad, the potential

This module was developed specifically for a junior/senior level chemical engineering elective on Polymer Science and Engineering. It can be broadly applied to any course with polymers in it, or even as a starting point for a module on any topic area in engineering that has a "negative" perception by the public (GMOs, chemicals in skincare, etc.). The goal of this project was to get students to explore a contrarian view to a presented idea, and back up their opinion with scientific data.



Module 1 Overview: Plastics: Exploring a contrarian view

The project starts by having the students "Google" the words "bad plastic" in class one day. The students find this somewhat hilarious, and shocking, how many "hits" those words retrieve. After 10-15 minutes of perusing these pages, the students are to divide into teams and choose a topic of interest to them. By the end of the class period, they are to present their findings to the rest of the class on this bad plastic, including their web references. This leads to an excellent point of discussion on valid scientific references (e.g. badplastics.com is probably not one of them), since all groups presented data from websites and not peer reviewed literature. The next assignment is for them to delve deeper into the "bad plastic" and find out the truth behind the claim (e.g. BPA in your water bottle causes cancer!). Most students are surprised to find, many of these claims are based on no facts, or a misinterpretation of the real scientific data [1]. The final assignment is to take their findings and use it as an opportunity. The students must develop either a marketing strategy to fight the "negative perception" of their plastic, or design with a new plastic (or additive) to replace the "bad" one.

The module is spread throughout the semester, so that students are given multiple opportunities to present their ideas and get feedback from the instructor, and classmates. The final projects varied between marketing campaigns (some students with business minors really enjoyed that focus), and new product designs. Student groups were told to pick a particular product to focus on if that was the case instead of a type of plastic in general. For example, rather than just focus on BPA in polycarbonate, focus on BPA in polycarbonate used for baby bottles. Some of the students projects presented in the course are listed in Table 2 from the first attempt at this project.

Table 2. Student project ideas for finding opportunity in "bad" plastics

Examples of student projects from the first attempt
Pro BPA social media campaign
Alternative for Styrofoam cups using an edible mushroom based polymer
Infographic on the safety of phthalate containing plastics
New plastic processing for toys (so no chance of lead exposure)
New plastic composite for insulation for homes
Alternative plastic for disposable water bottles (easily degradable and recyclable)

The final projects were all presented well, and researched thoroughly, but creative thought in the designs, and technical feasibility were somewhat lacking. The author decided to increase the time spent in class on this project in order to achieve better results. The second time through this project, the addition of in class feedback on student progress was incorporated several times. In order to spark creativity in the project ideas, the assignment was initially introduced using a JIGSAW. The JIGSAW was one four different "bad plastics". The teams then came back together and debated which "bad plastic" had the greatest potential for improvement in their opinion. This was followed up one week later with a quick presentation to their peers on a proposed improvement for their bad plastic. Feedback was given, and the students then had to complete a customer survey to gain even more feedback on the potential value of their idea. This was then turned into a value proposition canvas [2]. A "Gallery Walk" style peer review of the value proposition canvas, as well as the business canvas were beneficial in the students being more detailed in their final canvases [2]. Prior to each "gallery walk" the students were given examples of what each canvas would look like completed for a sample product. This evaluation of their peers' work allowed them better insight into what the different categories represented, as well as provided ideas for revenue, or potential pitfalls they may not have foreseen.

Feedback from the students on the project the second time showed that they increased their understanding of the EML content through the project. A survey of the students showed that 20% were previously familiar with EM concepts from the Entrepreneurship minor prior to the Polymers class. While 26 of the 28 students had previously done one of the other EML modules in the Heat Transfer class, unless they were in the Entrepreneurship minor, they did not recognize that they had been introduced to these concepts prior to this project. The authors now realize there is value in being more explicit with students in the goals of their projects. The overall project designs in this second attempt of the class showed an increase in overall technical feasibility, as well as an increase in detail in their business canvas. Projects included ideas such as the use of a biodegradable plant based Styrofoam alternative, a method for recycling Styrofoam, a campus wide recycling program targeted at the dorms, and a BPA free liner for paper coffee cups. The student feedback, taken via a post project survey indicates the project allowed students to draw connections with their class work and a real world engineering problem.

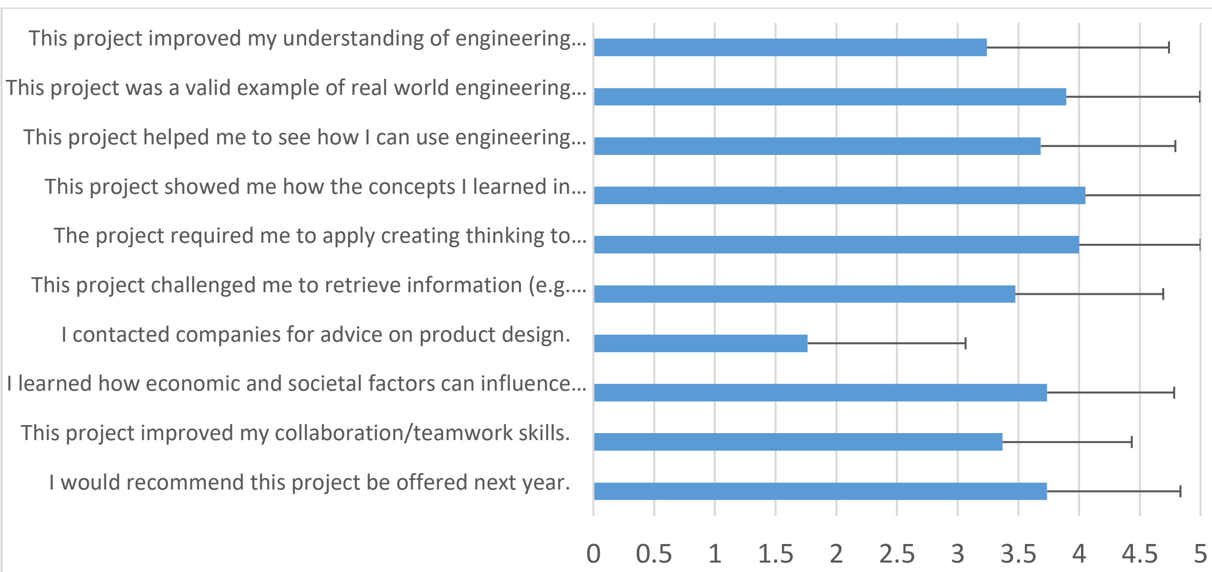


Figure 1. Student survey results for Bad Plastics Module. The student survey was completed after the completion of the Polymer Science course, for n=20. The students were asked to rank each question from 1 (strongly disagree) to 5 (strongly agree). Results indicate the students did find the project a useful experience and were able to apply their engineering skills to a real-world problem.

Module 2: Brewing Technology: Integrating information from multiple sources

Modules 2 and 3 took place in a junior level required course on Heat Transfer Operations. The students had a larger group design project (2 Brewing), and a shorter in class assignment (3 solar shower). Both projects were developed initially to get students to see the application of the material learned in this course in different, more “exciting” applications.

The brewing technology project was designed to get students to learn to integrate their own research, as well as that from lecture material and the textbook, into a more open design than a traditional “problem” assigned in class on heat exchangers. The main goal of the project is to design a heat exchanger to chill the boiled mash (known as wort) from 100 ^{0}C to 10^{0}C in order to pitch the yeast to start fermentation. The requirements were it had to be within an hour, and handle a 350 gallon tank of wort. The heat exchanger needed to be food grade, and easily sterilized. The students were taught the necessary engineering skills for the design in class, and were also taken on a tour of a local brewery (process scale, not micro-brew, Figure 2), to learn from the process engineer all the aspects of the brewing process. They were given the chance to ask questions and should have left with a good understanding of the process.

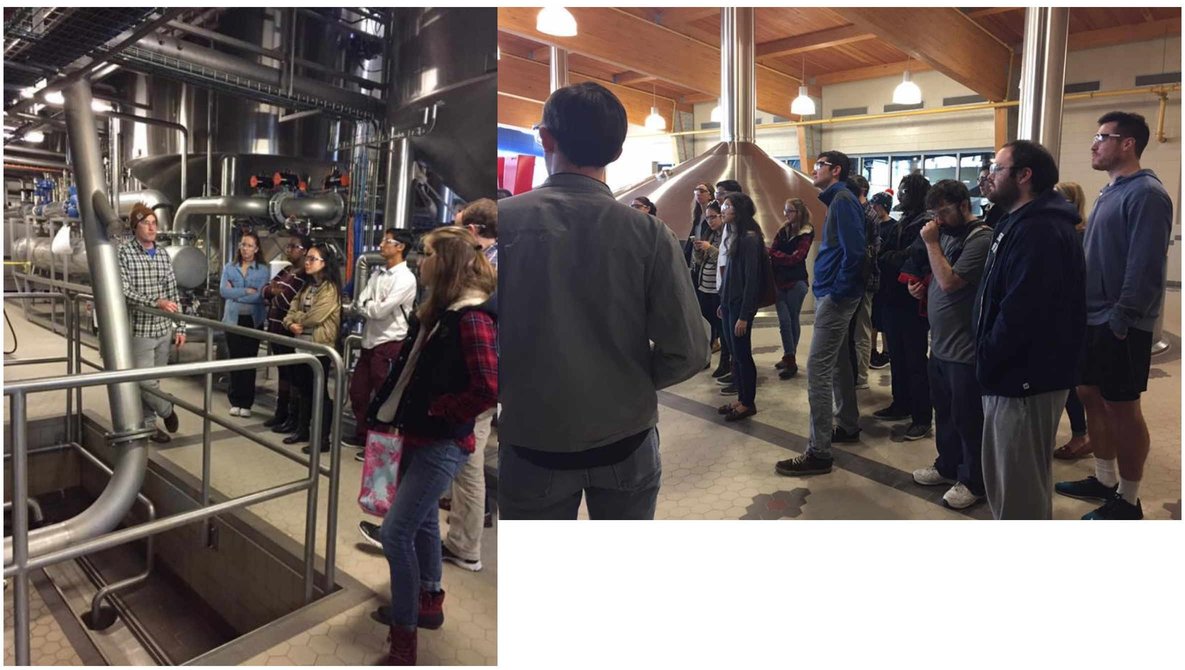


Figure 2. Students tour a local brewery to learn about the brewing process.

Students were then asked to create their design, and “pitch” it to the class and instructor, to prove theirs was the best design for a brewery. Having had a chance to “meet” their customer at the local brewery, designs this year as compared to previous years without the tour, were greatly improved. Students gave designs of reasonable sizes, materials, and sterilization techniques that were technically feasible. Per the student survey in Figure 3, the students still lack the confidence to directly contact companies without assistance to gather information. Overall, most thought the project was beneficial, and did improve their understanding of how the concepts learned in heat transfer related to real world problems.

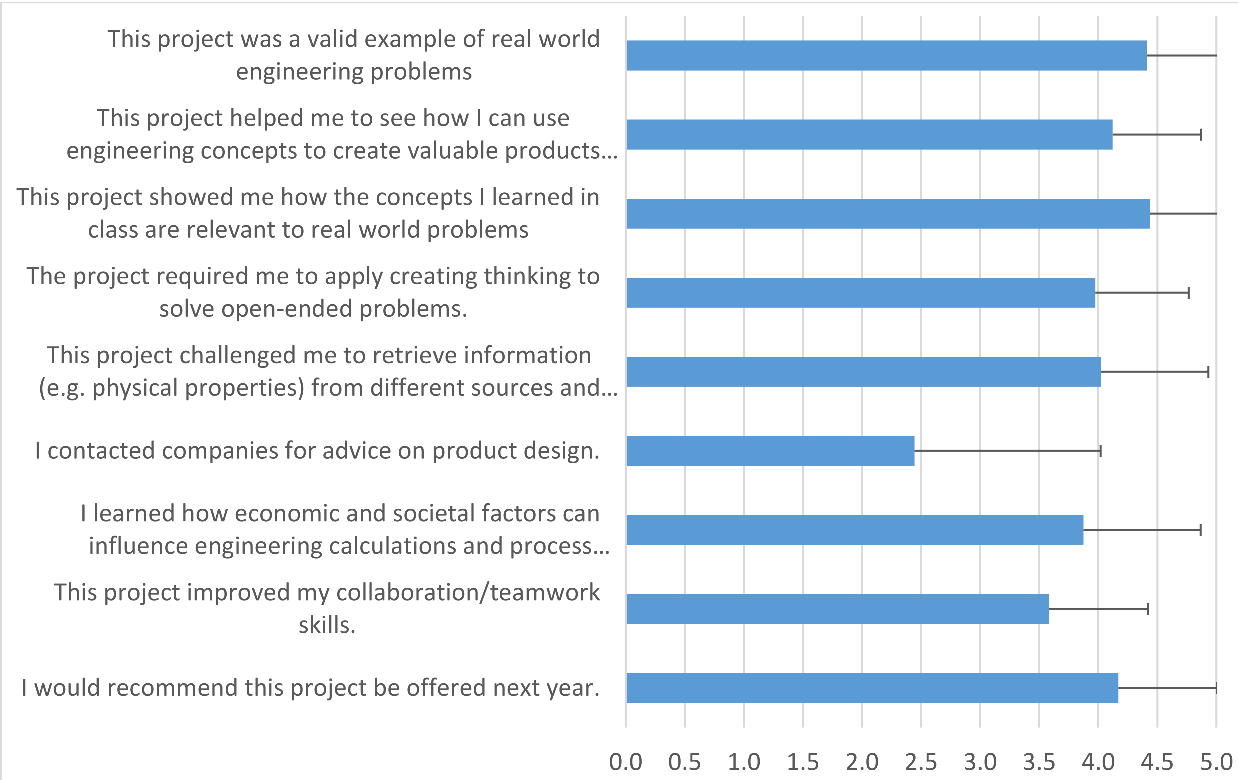
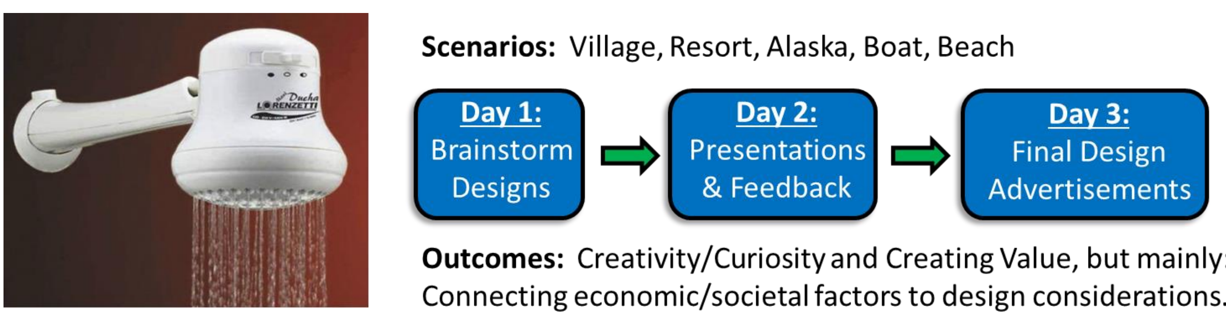


Figure 3. Student survey results for the Brewing Technology Module. Students (n=50) answered the questions above about the brewery design project with 1 being strongly disagree, and 5 being strongly agree. The error bars indicate the standard deviation.

Module 3: Solar Showers: Seeking connections to solve an unmet need

The second module given in heat transfer was a shorter design of a solar shower head for various locations. Each location presented a different set of challenges based on resources available, and was assigned randomly by the instructor. The first day the students were given the assignment and allowed to brainstorm ideas. They next came back with short presentations of their ideas to get feedback from the class. Their final designs were presented at the end of the week, and were to be an advertisement for their product.



Overview of Module 3: Solar Shower: Seeking connections to solve an unmet need

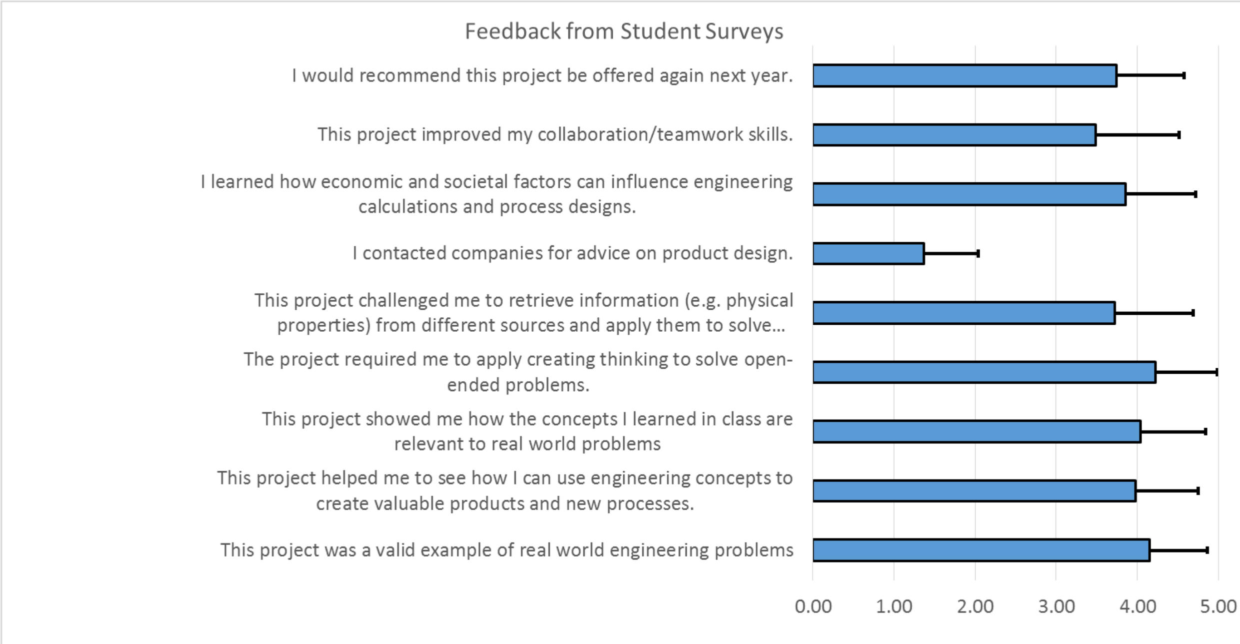


Figure 4. The student survey results for the solar shower project. After completion of the module (N= 74) students completed the survey based on the scale 1 (strongly disagree) to 5 (strongly agree). The students overall found the project to achieve the goals the instructor was hoping (minus contacting companies for advice).

The same survey was given to the student as for module 2 (Figure 4). Interestingly, the students did even worse at contacting companies for advice, or information on their design. Cost estimates were often based on supplies available by Amazon. The authors believe that we may have overlooked a key educational component in not teaching them how to source and price engineering materials and equipment by assuming they knew how to do that. This will be incorporated in future iterations of this module (and probably others). The survey results, along with the instructor's evaluation, show that the students did learn from the project, and saw how the concepts of solar radiation learned in the course could translate into valuable product designs.

Conclusion

Although still relatively preliminary student data has been collected, feedback from the instructors (authors), indicates the students are engaged in these EML modules. The results of the student survey post module showed, in all three cases, that the students saw the connection with the real world problem presented and their coursework. The students saw the value in seeking additional information, as well as teamwork, however they were not inclined to contact companies directly for information. The authors feel this is a point of emphasis that will need to be included in future offerings of these modules. The authors also note, that after development of this survey, it did not sufficiently address the ability of the projects to address the creating value and curiosity of projects. While the instructors judgement of improvement on these categories is valuable, a more detailed rubric on these categories, as well as improved student survey will be incorporated in future offerings as well.

The modules were not as difficult to integrate into the course material as first perceived by the authors. The use of these modules, in the instructors' assessment of exams year to year, did reinforce course content and students maintained their technical competency (based upon course final grades) from previous offerings without the project. This was important to the authors, as some of these projects were a large portion of class time to implement. The university standardized course evaluations indicated that students enjoyed the projects, and the course value overall more than previous offerings.

Although the modules presented are specific to their courses, the instructors believe these concepts can easily be applied to many topics (for example, the heat transfer projects could be switched to mass transfer applications, or bad plastics could be switched to alternative energy for value creation). Our belief is that sharing these modules will provide a starting point for other instructors to be able to incorporate EML concepts into Chemical Engineering Courses.

Acknowledgements

The authors would like to acknowledge the Kern Family Foundation KEEN program for funding of the Villanova College of Engineering, which allowed the opportunity for them to learn about EML and develop these modules for implementation.

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