Work In Progress: Incorporation of the Entrepreneurial Mindset into the Introduction to Engineering Course

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Abstract

This Work In Progress paper will describe changes made to the first year Introduction to Engineering course at Arizona State University in order to promote the entrepreneurial mindset. The changes were made to the team-based hands-on design projects to involve customers using three different approaches including fictional customers, real world customers but no direct student-customer interactions, and real world customers with direct student-customer interactions. Preliminary assessment shows that all three approaches are effective at raising students' customer awareness, though the third approach which involves real world customer and provides opportunities for students to engage with customers throughout the design process has been found to be the most effective approach for instilling the entrepreneurial mindset.

Introduction

Technical skillset alone is not sufficient for engineering students to address the societal challenges. According to the 2015 National Academy of Engineering (NAE)'s report *Educate to Innovate*[1], the development of critical thinking skills as well as an innovative and entrepreneurial mindset is equally important. In order to meet the needs of the global economy, besides emphasizing technical skills, engineering curriculum should incorporate content and activities that promote the entrepreneurial mindset and the best time to start this is during the freshman year. This, however, is not the same as teaching entrepreneurship or preparing entrepreneurs. According to Kriewall and Mekemson[2], "an entrepreneurial minded engineer (i.e., an engineer instilled with the entrepreneurial mindset) places product benefits before design features and leverages technology to fill unmet customer needs". Skills associated with the entrepreneurial mindset include: effective communication (verbal, written, graphical), teamwork, ethics and ethical decision-making, customer awareness, persistence, creativity, innovation, time management, critical thinking, global awareness, self-directed research, life-long learning, learning through failure, tolerance for ambiguity, and estimation[3]. In order to prepare more engineering students with such skills, the Kern Family Foundation has established the Kern Entrepreneurial Education Network (KEEN), a network of institutions that are committed to changing their pedagogy to develop entrepreneurial mindset in undergraduate engineers, that is built on the principle of "the Three C's"[4]: Curiosity - demonstrate constant curiosity about our changing world & explore a contrarian view of accepted solutions; Connections - integrate information from many sources to gain insight & assess and manage risk; Creating Value - identify unexpected opportunities to create extraordinary value & persist through and learn from failure.

While many Introduction to Engineering courses have developed the best practice of adopting project based learning, often times the role of a customer in the design process is not modelled. Gerhart, et al. emphasize that without a customer, project based learning activities often devolve into solutions that students think are the best from their perspective alone rather than considering the needs and motivations of others[5]. In order to teach the entrepreneurial mindset, customers must be integrated, in some way, into the class. However, the way in which customers are integrated into projects varies widely in literature. There are three main approaches which have been identified as viable ways of incorporating customers into a project: 1) creating a fictional setting with fictional stakeholders[5,6], 2) incorporating a real-world setting, but without direct interaction with real clients (ex. designing something for a third world population)[7,8], 3) designing a product for a real client[9-11]. There are also other projects that involve students creating solutions to problems that they face[12], but these were not considered since they often rely heavily on the students' own perception of the problem. While each of these approaches has their advantages and disadvantages, there has not been a direct comparison between these methods as to how well students are able to apply the entrepreneurial mindset in these different scenarios.

This paper will discuss three approaches of using team based hands-on design projects to incorporate the three C's in the first year Introduction to Engineering courses at Arizona State University, one of the institutions in the network. One of the projects involves fictional customers, acted by the teaching team, and a fictional scenario. The second one is based on a real world problem and a real world location that most students are not familiar with, and students do not have easy access to the customers, therefore, they rely on extensive online research. The third one offers opportunities for students to interact with real world customers throughout the design process. This paper will compare these three different approaches and discuss observations of early outcomes, in the form of excerpts from students' take-home critique of a flawed design process and project reports. Specifically, these excerpts will be used to evaluate whether the type of interactions with "customers" influences how a student demonstrates the three C's in their project. It should be noted that this study only focuses on students' customer awareness in each of these scenarios and there are other aspects of the entrepreneurial mindset that were not considered. Future work will be recommended that may address some of the limitations of this study.

Description

Fictional Clients and Problem

Getting real-world clients and real-world problems is sometimes difficult. It requires identifying a context that students have access to and problems that are tractable to first year students. A simple way of mitigating these problems is to create a fictional setting and introducing a problem that students can solve within that environment. In order to incorporate customers, the instructional staff can role-play as customers for the project.

For this particular implementation of this approach, a fictional town was "created" and an overarching problem was given to them based on the "needs" of this city. The problem given to the students in this case was that this city was experiencing a population increase and is in need of additional power to account for the increased demand this population increase has caused. This would model the case where a request for bids was solicited from the city and the student teams would operate as competing teams of engineering companies seeking to win the contract. Students were also "introduced" to four fictional stakeholders through brief descriptions of who they are and how their interests might be relevant to the problem. Students were required to interact with these stakeholders via a discussion board on the learning management system (Blackboard) where they could ask questions of the stakeholders in order to help them identify criteria and requirements for their design (they were required to identify which of the stakeholders they were addressing in their question). Instructional faculty would then respond to the questions in the personas of the person that were addressed in the student questions. These stakeholder personas were intentionally chosen to represent a diverse and sometime competing set of opinions that may be present in a real-world city. The stakeholders for this project include the mayor, city engineer, president of the HOA, and the president of an environmental activist group known as SRGT. Students could ask anything they thought was relevant to these stakeholders and the instructional staff (one faculty member, one graduate teaching assistant and one undergraduate teaching assistant) utilized real-life information from "similar" cities to help answer questions about population numbers, current power production, etc. but preferences of stakeholders were determined based on what the instructional staff thought the specific stakeholder might answer. The TA's were given basic instructions about the concerns and personas of the stakeholders at the beginning of the semester and if there was any doubt about how to answer a particular question, the faculty member was consulted on how to respond. Students would then build a small-scale working prototype of the design that would solve this problem.

The advantage of this approach is that the problem can be scoped by the professor so that it is tractable in the time-frame and information is consistently given to all of the teams. It also makes assessment and planning easier. This makes scaling this kind of project much easier when dealing with many sections of the course. The disadvantage of this approach is that work does have to be done on the part of the instructors to provide enough detail of the fictional environment to make the scenario "believable" to the students. Since the instructors were role-playing as the stakeholders, it is especially hard for both the students and the instructional staff to make sure to not mix in the interests of the "stakeholders" and the professor (trying to please the professor giving the grade rather than thinking of their success being tied to meeting the needs of their stakeholders).

Real Clients and Problem

Another approach is to provide students with a real world problem and real customers. However, often times, it is difficult to connect students with the customers that they are serving, especially when there is a large student population and scaling is of interest. Therefore, in this approach, the problem was carefully selected so that even though direct customer interactions are difficult to achieve, students are still able to obtain large amounts of information about the problem and customers through online research. The geographic location for the problem was also carefully chosen to provide a social and cultural context that most students are not familiar with. This way, students cannot simply consider their own needs or use their own experiences and criteria when developing a design solution and they are forced to determine and examine the needs and wants of others. The project used for this approach was a clean water project for Haiti. Students were only provided with the fact that Haiti is known for its water crisis and were asked to help provide access to clean water for families in rural areas along the north and west coastline of Haiti.

The advantage of this approach is that the problem is a real world problem. Students are able to gather information relatively easily to help them define the problem. For example, information such as the average income of Haitians, the recommended minimum quantity of water needed per person per day, how Haitians currently get access to water, etc. is readily available online. In addition, there are various opportunities and many different solution paths students could identify. This approach takes the burden of providing information such as customer personas off the instructor. It also makes scaling this kind of project easier when dealing with many sections of the course. The disadvantage of this approach is that students' research approaches are very limited. They are not able to immerse themselves in the context and therefore they may not empathize more deeply with the Haitians who need access to clean water; and they cannot deeply engage with or learn from the customers to gain a richer understanding of their needs and motivations. Another disadvantage is that students cannot directly test their design prototypes in the real world context or incorporate direct customer feedback for design iterations. It requires the instructor to create a simulated environment for project testing and demonstration. The amount of information available could also overwhelm first year students and they could find it challenging to process and synthesize all the information collected.

Real Clients and Problem with Direct Student-Client Interactions

The best situation is where students get a chance to interact with real customers to solve a real problem. In this paper, the project that was used for this case was a STEM education project. A class from Arizona State University partnered with a 5th grade math class from a nearby school to solve the problem of students learning difficult math or science concepts at the 5th/6th grade level. The problem statement given to the students mostly came from statistics that stated that the majority of students in Arizona failed the standardized tests in math and that nationwide there is a shortage of students going into STEM fields. They then had the opportunity to meet with the “clients” to clarify the kinds of concepts that students struggled with as well as their perceptions of math and science. The students were also able to ask about their current classroom environment and the teacher of the partner class also provided her perception of the problems she experienced in her classroom. The students were asked to create a design that would help solve this problem while taking into account the insights gained through their interactions with their “customers”. Opportunities to get feedback from the customers were provided throughout the semester.

The advantages of this approach are that the students can create a personal connection with those who would actually use a product that they are developing. There are many opportunities to identify opportunities in this open-ended project and there are multiple stakeholders that the students must identify and address the needs of (parents, students, teachers, etc.). The disadvantages are that this kind of collaboration is very time consuming and resource intensive. It is very hard to find these kinds of projects that involve real customers and are still able to be solved by first-year students in one 15-week semester. It is also very hard to assess the projects since there are so many different directions that could be taken. It requires the students to work hard in finding an aspect of the problem that they can actually address and sometimes students can get overwhelmed by the open-endedness of the project. This problem is particularly difficult for first-year students who may not have been exposed to open-ended projects before, especially ones involving real customers.

Preliminary Assessment

The three different approaches described earlier were implemented in different sections of the Introduction to Engineering classes at Arizona State University taught by the authors during the Fall 2016 semester. Two sections (of approximately 40 students) completed the project with fictional customers in a fictional environment (approach 1), three sections (of approximately 30 students) completed the project with a real-world scenario but no direct customer interaction (approach 2), and one section (of approximately 30 students) completed a project involving real-world clients (approach 3).

To evaluate how students have demonstrated the three C’s, multiple evaluation techniques have been used. First, a take-home critique of a Gantt chart describing a flawed design process was analyzed. This same analysis was used by Zhu and Mertz[13] and Saterbak[14] to assess student understanding of the engineering design process. However, in this analysis, these critiques were evaluated based on the percentage of students who mentioned customers in their critique and the level of depth of discussions about customers’ role in the design process. The different approaches were compared using this analysis as a preliminary indicator of whether students could identify the importance of customer interaction in the design process (which directly relates to the entrepreneurial mindset).

To assess how well students have demonstrated the three C's, final design reports were also reviewed. For curiosity, number of citations; whether or not the teams have conducted research beyond what was required; and/or obtained/incorporated customer feedback directly or in an analogous situation have been evaluated and compared. Discussions about how external research has helped with establishing design criteria and/or influenced design decisions have been used as evidence for connections. Indicators of creating value include discussions about how the design was unique in the market; and/or how the design's features specifically addressed each customer need. For each of the three Cs, percentages of teams that have included the evidence discussed above were compared between different approaches. Student excerpts which demonstrate typical ways that each of the three C's are addressed will also be included as a way of telling a story of how students are incorporating the entrepreneurial mindset into their projects. This combination of qualitative and quantitative analysis was used together to strengthen the findings through triangulation[15,16].

Preliminary Results and Discussions

For this study, the response rates (percentages of students who have made a take-home critique of the flawed design process submission and a final report submission, and gave the authors consent to use their submissions for this research study) for the three different approaches are 37.7%, 77.4%, and 48.4%, respectively.

Figure 1 below shows the percentages of students who have mentioned customers in their critique of the flawed design process. It can be seen that there are little differences between the first two approaches, suggesting that these two approaches have had very similar impact on students' understanding of the importance of customers in the design process. On the other hand, the third approach has been more effective (about 19% higher compared to the other two approaches) which is expected since students had opportunities to interact with customers throughout the design process. This result suggests that if scalability is not a concern, the best approach to incorporate the entrepreneurial mindset is to utilize real world problems with real world clients. However, if scalability is of interest, the first approach is as effective yet it offers more flexibility in terms of project topic selection compared to the second approach.

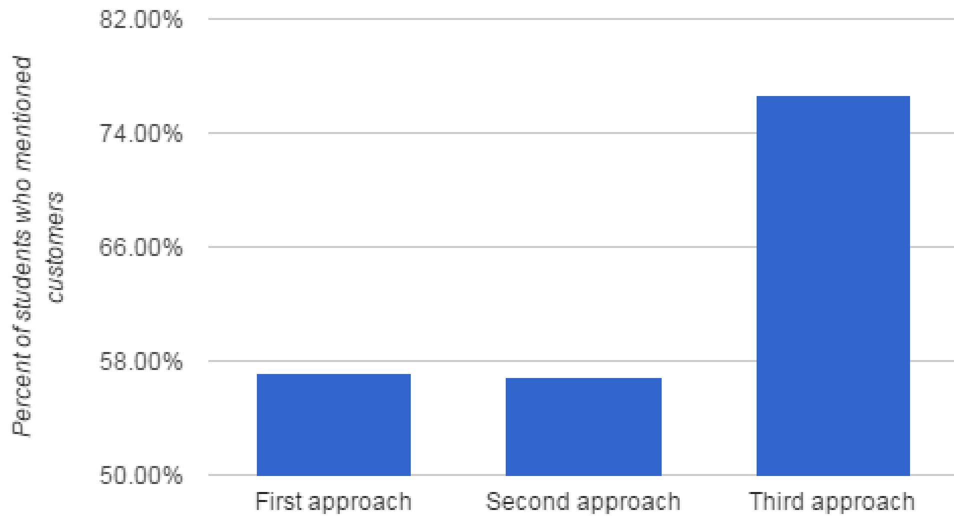

Figure 1. Comparison of percentages of students who mentioned customers in their critique of a flawed design process

To evaluate the level of depth of students' understanding of the importance of customers in the design process, a score of 1 or 2 has been assigned to each student who has mentioned customers in their critique. If the student simply mentioned customers without providing any explanations or discussions about their role in the process, a score of 1 is assigned, otherwise a score of 2 is assigned. For example, if a student only mentioned "*Teams must know what the client wants*", a score of 1 is given because the student did not demonstrate a deep understanding of why client interaction is important. On the other hand, examples of excerpts for a score of 2 include

"*The first step in the engineering design process is to figure out what the customer's needs are. This can be done through researching the problem, interviewing people on the problem, or, the best way is to talk to the customer and figure out what they need.*"

and

"*During this time the concept must be selected to fit the best need of the customer. This is essential in the design process, as you want to ensure that you are following the interests of the stakeholder. It is necessary to understand the interests of the stakeholder and apply them to the design. This is the ultimate goal of the project and should be top priority.*"

Mean scores and standard deviations have been calculated and compared and the results are shown in Table 1. It has been found that the majority of students who have mentioned customers really understood why customers are important and what roles they must play throughout the design process, because the mean scores are all above 1.5 (out of 2) for the three approaches. The results for all three approaches are very similar, indicating that the three approaches are equally effective.

Table 1. Comparison of mean scores and standard deviations showing level of depth of understanding the importance of customers

	Mean Score	Standard Deviation
First approach	1.64	0.49
Second approach	1.78	0.42
Third approach	1.58	0.51

The number of citations used in students' final reports is an easy way to quantitatively measure how much background research students performed during the problem definition phase of the design process. It must be noted that there are weaknesses to this approach. For example, students may have not cited all sources used in their reports and the extent to which the sources were used to help students understand the problem or to help them justify design decisions was not taken into account. However, it does provide insights into the level of curiosity displayed by students. The number of citations varied from 0 to 12 and on average the numbers of citations are similar across the three approaches (see Figure 2). It should be noted that most teams have included more sources and researched information in their design notebooks, however, they either did not include all of them in their final reports or did not directly use all the information in developing their designs. In the future, it would be helpful to further evaluate the types of information students have identified as needed for them to successfully solve the design problem and researched throughout the design process, using various sources for evidence including student design notebooks, proposal presentations/documents, in addition to the final reports.

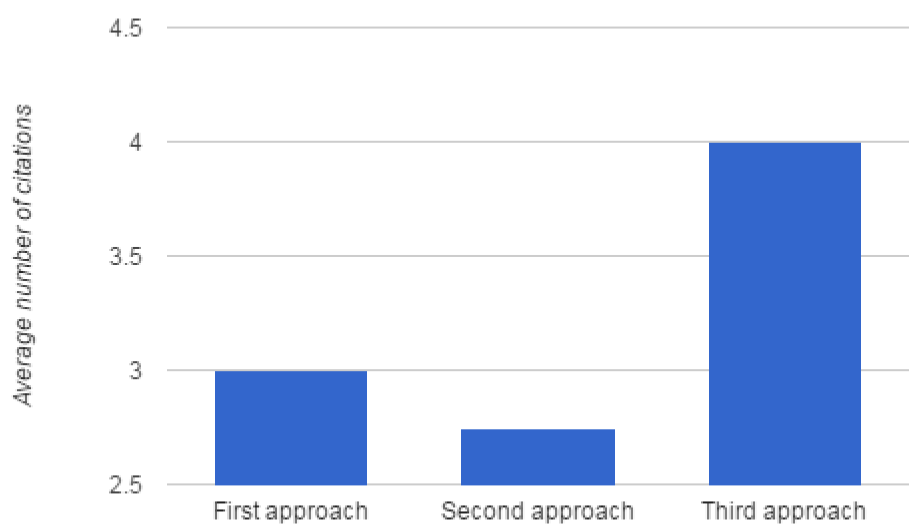

Figure 2. Comparison of average number of citations in the final design reports

In addition to evaluating the number of citations, percentages of teams that have included and discussed background research that was actually useful and substantial; and/or discussed how they have involved customers in the testing phase of the design process and incorporated their feedback in their designs; therefore demonstrating curiosity, were also compared. Close to 90% of teams for the second and third approaches have demonstrated curiosity whereas the result is 67% for the first approach (see Figure 3).

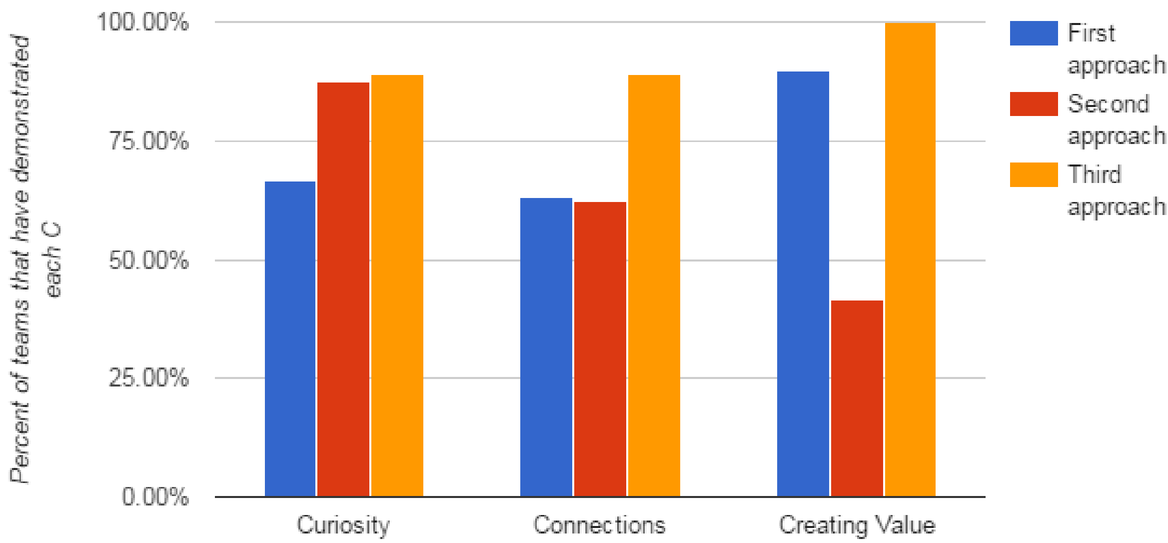

Figure 3. Comparison of percentages of teams that have demonstrated each of the three C's

The first approach is a little weaker in this area because instead of conducting research, when students had questions or needed information about the problem, they referred to the fictional customers (acted by the teaching team). Not many students were able to research analogous settings to help them formulate the problem for the fictional setting. For the second approach, since direct interaction with the customers was challenging, the only way for students to gather useful background information about the problem was to perform online research. For example, one team mentioned that

"Research was done before the project in order to understand what the customers are going through and what the customers want out of the filters. The research done consisted of background of health in Haiti due to the impure water sources, information on how Haitians get their water and how far the walks are to the water sources. Who are the ones getting the water for the families in Haiti and what is used to hold the water that is found."

In addition, some teams chose to collect feedback from their classmates, friends, and/or strangers about certain aspects of their designs, which was a good approach due to the lack of access to real clients. For example, some teams had reviewed the average amount of time it took different potential users to figure out how to use their design and evaluated average ‘customer’ ratings on the design criterion ‘ease of use’.

For the third approach, students demonstrated curiosity more because they needed to conduct research and benchmark existing products on the markets and determine why these products fail to fulfil their customer’s specific needs. Below is an example excerpt from the final design report:

“Similar products exist on the market that integrate math practice into board games; however, most of these products fail to implement a cohesive real-world theme to keep students engaged. One such example is the Math Star Word Problem game, which uses a theme of space travel [citation]. This theme does not, however, extend to the math problems themselves, so the theme is therefore disrupted at regular intervals; in addition, this approach does not provide the students with any real-world applications for math.”

For connections, the impact of the first two approaches is very similar as the percentages of teams connecting background research to the development of their designs are about the same (~63% - see Figure 3). The third approach is better in this regard since close of 90% of teams have demonstrated connections. The different ways that students have demonstrated connections include how background research has led to the establishment of their design criteria; how similar systems and other products from benchmarking have inspired their designs; and how researched information has led to certain design decisions. For example, one team has made low cost the most important design criterion based on the fact they have researched that on average their customers only make $2.00 a day and another team has justified their decision of a rain collection system based on the amount of rainfall in the area for the second approach:

“With research showing that the average Haitian family makes an income of around $2.00 a day, it was a priority to make the design cost effective. Surely it would be easier to make one quality device that would last much longer, however, it would be much more difficult for Haitians to buy it at a higher price point.”

“Since one of the big selling points of the design was that it was a rain catcher, the team had to be sure that it rained enough have water to filter. Pictured below in Fig. 1 is the amount of rainfall for the whole year in the Port-de-Paix region is about 1317 mm (52 in). This amount of water is what led the team to design a rain collection system.”

Another example is how one team has connected an automotive application to the hydroelectric power generation system they were designing:

"The group based the design off of the Garrett Turbocharger. The group saw the spiral styled blades in an elongated tube, which influenced the overall design process and laid out the basis of what the design would look like (Garrett Turbocharger)."

For creating value, out of the three approaches, the second one has been the weakest since the least amount of teams have demonstrated creating value, as can be seen in Figure 3. This is probably due to the fact that for this approach it was very challenging for students to narrow down to a specific customer and they were not able to better connect with their customers personally due to lack of interactions. One mitigation strategy of this might be to require students to create ideal customer profiles and focus on a specific family rather than a large geographic region and a general population. It was clear from student comments from the real-client project that specific pieces of information gained from their customer interactions influenced how they decided to create value for their clients (the same was true for the fictional clients project, but to a lesser extent.). For instance,

"In order to obtain information about what the design had to accomplish it was especially important for the team to speak to the stakeholders, both the students and teachers who would need to eventually implement it into the classroom. As such before brainstorming solutions we made sure to come up with a list of questions (see Appendix 6 for Student Interview Question List) that would see what the kids struggled with and would be excited to use in school. Their commentary helped to define our criteria, and as we came up with designs we were in constant communication with our stakeholders."

To summarize, a larger percent of students demonstrated customer awareness in the third approach, though the level of customer awareness demonstrated is very similar for all three approaches. Out of the three C's, the third approach has a slightly greater impact on connections and creating value, while each of the first two approaches is found to be the weakest out of the three approaches in areas of curiosity, and creating value, respectively. The first two approaches had very similar impact on connections, and the last two approaches performed equally well for curiosity.

Future Work

While some insights can be gained from this study, the limited sample size and evaluation techniques do need further refinement. Specifically, a more detailed examination of the final reports and prototypes produced by the students may lead to a much richer evaluation of how the three C's were actually implemented by the students. Further work on assessment tools which assess students' ability to demonstrate the three C's, specifically for Curiosity and Connections are also needed as these are difficult to reliably assess.

Prior to the curriculum changes made in order to incorporate the entrepreneurial mindset, students' understanding of the engineering design process was found to be weak in areas such as "needs assessment/establishing design criteria" and "design context review" when students critiqued a Gantt chart that describes a 14-week schedule of a design project which has many flaws[13]. More specifically, many students who mentioned the "needs assessment/establishing design criteria" step did not mention client/customer or the role they play in developing criteria[13]. The assessment of student work could, in the future, include reviewing the responses to the Gantt chart critique to see if there are any improvements in these areas. There are also opportunities to review design notebook entries and personal reflections from the course in order to better understand how students perceive and apply the three C's as they relate to this course.

Another area of future work is assessing how the inclusion of customers in the project has impacted other skills associated with the entrepreneurial mindset, for example, engineering ethics and ethical decision making, persistence, creativity, self-directed research, etc.

Conclusions

This paper presented a comparison between different methods of incorporating customers into a semester-long first-year engineering project. These different methods reflect modifications made to the course in order to promote the adoption of the entrepreneurial mindset as evidenced by increased customer awareness when going through the design process. Three different methods were compared (fictional setting and clients, real setting but no student-client interaction, and real setting with real clients). While this work-in-progress study is limited in scope, it was observed that increased customer awareness occurred in all three scenarios, but having students actually engage with real clients had a greater impact than if they were not able to talk with real clients. There was not a noticeable difference between the projects with a real setting versus a fictional setting. This is especially important when trying to account for scalability since a fictional environment may be easier to incorporate on a larger scale (although either of these approaches is scalable).

In the future, it will be important to identify ways to bring more of the real-client experience into the other structures. This will involve identifying what it is about those customer experiences (and students' perceptions about the customer) that promote increased customer awareness and mimicking them with fictional clients. Work also needs to be done to find an efficient and effective way of evaluating the three C's in light of the larger body of entrepreneurial mindset literature. This paper takes a fairly simple approach to the analysis, but more insight may be obtained through deeper analysis of the final reports and personal reflections in the course.

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