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Using Authentic Project-Based Learning in a First-Year Lab to Elevate Students' Perceptions of Engineering*

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Evidence suggests that some undergraduate engineering students drop out after their first year because they do not understand the nuances of the profession. Recommendations to alleviate this challenge include developing first-year experiences that provide more authentic contexts and emphasize the social benefits of engineering. The current study investigated a first-year undergraduate engineering lab module that used project-based learning and authentic customer interactions. Eighty-four students created unique prototypes for customers while recording personal reflections about their experiences. These reflections were analyzed using inductive qualitative methodology to determine how this experience affected students' perceptions of the field of engineering. Researchers discovered that the central phenomenon characterizing the experience for students was related to a growing awareness of the field of engineering and whether it was a viable career path. The characteristic of the module that most affected students' perceptions was its authenticity. Students' abilities to work in teams and successfully use problem-solving skills were also important factors that affected students' perceptions of the module. After the module, students felt they gained many 21st century skills including collaboration, communication, creativity, and confidence. Furthermore, the experience helped students discern if engineering was a career they wanted to pursue. Although there have been numerous studies about project-based learning and its effects on students' attitudes about academic material, this study provides insights into how a first-year experience can affect students' perceptions of the field of engineering as well as students' identities with the profession.

Keywords: engineering identity; 21st century skills; project-based learning; grounded theory; first-year engineering courses

1. Introduction

Retaining students in engineering disciplines has been a challenge for many years [1, 2]. Although reasons for retention challenges are wide-ranging, some reports and studies suggest early courses in the major are key factors that determine if students stay in the discipline. For example, the "sink or swim" mentality that pervades many early undergraduate engineering courses may drive potential majors out of the field [1]. In addition, some evidence indicates dropout rates can be attributed to students taking first-year courses in engineering but never really understanding what the profession is all about [2].

Efforts to improve early undergraduate engineering experiences have been ongoing for decades. As many students are not exposed to authentic engineering contexts in grade school, a student's first exposure to the field is often in an undergraduate engineering course [3]. In some cases, a student's only impressions about the field could come from that introductory experience [2]. As a result, developing early experiences that accurately portray the field are important. When these experiences are personally meaningful, research suggests students are more likely to identify with the profession [4]. On the contrary, when undergraduates do not have opportunities to engage in authentic practices and develop a proper understanding of the engineering field, their likelihood of dropping out increases [2].

In light of the current needs in the field, it is paramount that engineering programs develop attractive first-year experiences that provide students with an authentic view of the field. When successful, these experiences have the capacity to attract diverse candidates to the field, retain these

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students, and equip them with a diverse skill set. In effect, these early-learning experiences can become the "main entrance door" to the engineering profession [2]. In the current study, researchers investigated a first-year undergraduate engineering lab module that used project-based learning, real customers, and a team approach to facilitate students using the design process to create a product to meet the customers' needs. The purpose of this study was to use qualitative methods to determine how this first-year experience affected students' perceptions of the engineering field. The findings from this study provide critical information for course developers as they create and refine early engineering experiences that attempt to improve students' understanding of the engineering field and their potential place in it.

2. Background

Literature suggests that many factors contribute to making early experiences more compatible to real-world engineering contexts. Some of these factors include emphasizing 21st century skill development, using ill-structured problems, highlighting the societal value of engineering, and incorporating project-based learning (PBL). First, 21st century skills include cognitive (e.g., critical thinking), interpersonal (e.g., complex communication, teamwork), and intrapersonal (e.g., self-regulation, adaptability) skills that are needed in the workplace [5]. Incoming undergraduates might have an accurate impression that modern engineers need to be competent in math and physics, but fewer may be aware of the vast array of 21st century skills that are necessary for success. These include communication, as up to 55–60% of an engineer's day is spent connecting with others in collaborative settings [6]. Early undergraduate experiences become more authentic when students have opportunities to use their technical skills in combination with emerging 21st century skills like teamwork, complex communication, and nonroutine problem-solving.

Second, authenticity of early experiences can be improved using ill-structured problems. According to Dringenberg and Purzer [7], ill-structured problems: (a) do not provide all the relevant information, (b) do not have an established method for finding a solution, (c) do not have a single correct solution, and (d) cannot be solved with certainty. As such, these experiences more closely mimic the challenges faced by engineers. Ill-structured problem-solving also meshes well with 21st century skill development. In order to solve problems in the field, engineers must adapt to dynamic conditions as they work closely with others to pool their interdisciplinary knowledge and exercise their creativity to find a solution. When exposed to ill-structured problems in early coursework, students experience authentic scenarios that require synthesis of knowledge and leveraging of creativity to design solutions.

A third factor to consider in early experiences is a societal connection. The authors of *Educating the Engineer of 2020* [1] suggested developing undergraduate courses that take a "servant-to-society" approach emphasizing how engineering can improve society. According to these authors, such an approach more accurately depicts a career in engineering. Some research suggests that these societal experiences have positive effects. For example, a PBL engineering elective class at Rice University, USA, had students work in small groups to design and build a product tailored to a customer's needs. Students improved in writing and editing technical documents, as well as in designing and prototyping skills. Furthermore, students who participated were more likely to stay in the field [8]. Experiences like these facilitate students' understandings of the profession, provide opportunities for students to identity with the profession, and help them see how they could benefit society through the profession.

The PBL approach is a fourth factor that can make an early experience more authentic. PBL has been used since the 1960s to increase authenticity of problem-solving in classrooms. Originally developed for use in medical schools, the pedagogical approach is now common in a variety of classroom contexts. In engineering contexts, Saterbak [9] found that students in a PBL class reported positive increases in relevant skills. In addition, Cropley [10] discovered that creatively motivating students (by things like PBL) offered a means to revitalize engineering programs and reach underrepresented students. PBL has become a pedagogical strategy allowing students to apply their learning, be innovative, and foster the skills craved by future employers. When offered to first-year students, these experiences may help with retention as students are given the flexibility to use their creativity [2]. When done properly, PBL emphasizes both the technical and 21st century skills required in engineering jobs [11]. Moreover, PBL can create a more authentic learning environment for students as they apply engineering principles and develop the critical thinking skills necessary to solve ill-structured problems [12].

Incorporating these factors, as well as others, can help transform an early engineering course into an engaging experience that creates interest for the field and potentially helps students visualize what a career in engineering might be like. The current study was designed to determine if and how an early engineering experience that incorporated many of the previously-mentioned factors affected students perceptions of the engineering field. The study focused on a PBL-based laboratory module (see Appendix A) that was embedded into a first-year engineering course at a liberal arts college in the Midwest region, USA, with an ABET-certified engineering program. As work on this module occurred throughout an entire semester and was mixed with more traditional laboratory content, it was considered an interwoven experience using a classification system for categorizing research experiences [13]. Throughout the semester, students were introduced to the basic principles and various disciplines of engineering in tandem with traditional laboratory investigations that familiarized students with force, equilibrium, concepts of stress and strain, Ohm's Law, and Kirchhoff's Voltage and Current Laws. Furthermore, the new module integrated teamwork, a real-world design project, and a customer from the local community who had a genuine need.

One challenge associated with offering a first-year engineering experience of this sort is the limited experience and expertise that students have at the early stages of their academic careers [14]. In this module, instructors required students to only submit prototypes of their products (see Appendix B). While this reduced costs and eased some of the tensions associated with developing a final product, module developers hoped the real customer connection would add complexity. In addition, course designers wanted the customer component to illustrate how professionals deal with varied challenges while working with diverse people to create divergent solutions.

Furthermore, this module created teams of three to four students who collaborated throughout the project. On a related note, the module emphasized team-based grading with few individual assignments. Instructors in the course continued emphasizing fundamental engineering concepts, but the module was scaffolded to guide students through the design process from start to finish. Early in the course, instructors used worksheets and class discussions to move students from basic concepts to understanding customer requirements. Instructors then helped students generate engineering specifications, brainstorm initial ideas, conduct functional analyses, and evaluate concepts. From that point, the focus moved to prototype building, testing, modifying, validating, and concluded with students presenting the prototype to the customer. Module assignments tracked students' progress and modifications of the design as new information and specifications were clarified through research and testing.

In the current study, researchers investigated the first two years of module implementation. Each year, a new customer was selected from the community. Instructors screened possible customers using the general criterion of the customer having an engaging need that could be satisfied by multiple products. Furthermore, these products had to be simplistic enough to be prototyped by first-year engineering students. Once selected, the customers met face-to-face with students at the beginning of the module in order to create a personalized connection and hopefully generate enthusiasm for the project.

In the first year, the customer's name was Elise (pseudonym). She was a charismatic woman with severe physical limitations due to cerebral palsy. She shared her love of watching American football games with her friends on the television, and she challenged students to design a product that would allow her to enjoy snacks (e.g., popcorn, chips, etc.) during these games without help from others. During the initial meeting, Elise provided specifications of the device including dispensing amount, her physical limitations that would affect control capabilities, and mounting criteria for her wheelchair. From these customer requirements, student groups worked through the design process and tried to meet as many needs as possible with their prototypes.

In the second year, the needs of a customer named Nathan (pseudonym) provided the context for the module. Nathan was an elderly man with poor grip strength due to inclusion-body myositis. He challenged students to create a device that would allow him to put on socks more efficiently and with less difficulty. In students' initial meetings with Nathan, his physical capabilities and desires for the product were clarified so engineering specifications could be determined and suitable solutions to the problem could be investigated.

Although reform efforts in engineering education have been ongoing for many years, current research still shows that STEM courses use more lecture and less student-centered practices than other disciplines [15]. Additionally, studies report that many institutions across the world continue using traditional teaching methods in their introductory STEM courses [16]. The module investigated in this study, although not novel in its approach, served as an appropriate context for determining how factors like ill-focused problems and use of authentic customers affected students' perceptions of the engineering field. In this study, the research question of interest was how (and why, if applicable) does participation in a first-year engineering design project impact students' perceptions of the field of engineering?

3. Methods

Recent articles in the engineering education literature discuss the merits of qualitative research and its distinctions from quantitative approaches (e.g., [17]). Although it is accurate to say the field of engineering education typically favors quantitative approaches [17], the current study utilized qualitative methods because the authors agree with Borrego, Douglas, and Amelink [18] that research focus should drive methodology, not personal methodological preferences. The research question in this study favored qualitative methodology as it was open-ended and centered on students' impressions of their experiences. Furthermore, written student reflections that were collected after students completed the courses served as the data source.

Grounded theory methodology [19, 20] was specifically chosen as the qualitative approach for two reasons. First, researchers wanted to analyze the data from an inductive perspective. Deductive qualitative coding requires researchers to force data into preconceived categories. Therefore, a deductive approach would be detrimental to the goal of learning students' perspectives based on their own experiences. Second, grounded theory methodology allowed researchers to go beyond descriptive narratives and explain the *whys* and *hows* behind students' experiences [19]. The conceptual model constructed from grounded theory helped explain *why* students characterized their experiences in the module the way that they did and *how* these ideas connected to each other. In sum, grounded theory methodology fit the needs of the research. Moreover, other recent studies have successfully used this technique in engineering education contexts (e.g., [21]).

3.1 Participants

The sample for this study included 84 students who were enrolled in the first-year engineering course over a two-year period (32 students in Year 1, 52 students in Year 2). From these students, 9 collaborative design teams were formed in Year 1, and 14 teams were created in Year 2. Data from years 1 and 2 were analyzed concurrently.

3.2 Data Collection

Each of the 23 design teams created a unique prototype and turned in portfolios with worksheets and lab assignments documenting their progress (see Appendix C). In addition, members of each team turned in personal reflections about their experiences. The reflection from each student served as the data for this study. The reflections were semi-structured in the sense that they were open-ended prompts inviting students to share details about their personal experiences during the module. Students were prompted to reflect on: (a) what it meant to participate in a design project, (b) what they learned from the module that was over and above the material from the traditional labs and lecture components, and (c) how they might apply what they learned from the module in the future. After completing the prototypes, each student had two weeks to finish their reflection, and they were graded on completion (i.e., no grade for content, length, etc.). All 84 students in the courses turned in a written reflection.

3.3 Data Analysis

All reflections from years 1 and 2 were coded together using grounded theory per Strauss and Corbin [20]. Raw reflections were entered into the qualitative software program, NVivo. Analysis consisted of open, axial, and selective coding. Open coding began as researchers read the reflections and extracted the main concepts on a line-by-line basis. After fracturing the data into pieces (i.e., open coding), researchers proceeded to axial and selective coding which included identification of categories and their subsequent properties and dimensions. Determining properties and dimensions involves "putting the data back together" [20] by discovering relationships between categories. For example, two initial categories that were defined included *Authenticity* and *Customer*. As researchers used the NVivo program to review where these two categories were coded and the contexts in which they appeared, they determined that *Customer* was a property of *Authenticity*. Properties, as defined by Corbin and Strauss [19], are the characteristics of a category that define and give specificity to it. In this data set, when students talked about the customer, they often did so in context of how working for the customer increased the real-world application (i.e., authenticity) of the experience. This process of determining properties and relationships continued with all identified categories.

3.4 Analytical Rigor and Positionality

Throughout all of the coding processes, researchers used constant comparison [22, 23] to continually relate new data to previously analyzed data in order to make higher-level connections between concepts and to inductively create a comprehensive conceptual model (Fig. 1). During this process, categories and definitions were modified and subsequently verified as researchers reviewed the transcripts and considered quotes that both supported and refuted the categories. Furthermore, categories were discussed frequently by the team as multiple coders debated to agreement on final operational

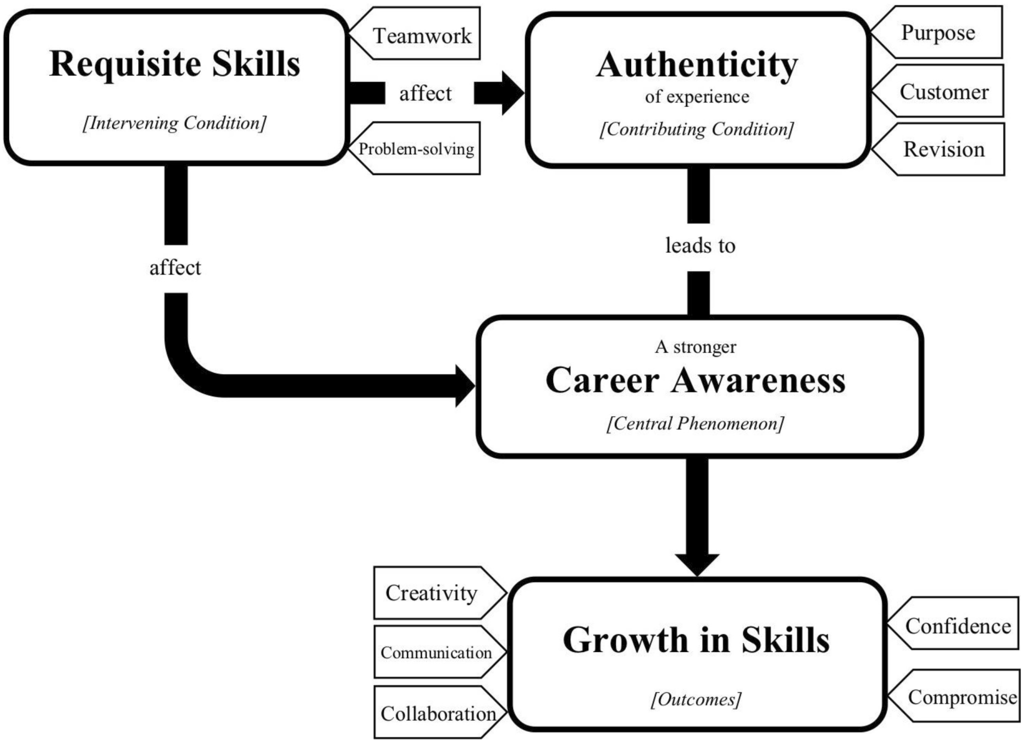

Fig. 1. The inductive conceptual model developed during this study to explain students' experiences during the engineering module. (Based on Strauss and Corbin's paradigm model).

definitions. The inclusion of multiple coders and the use of collaborative debate is one technique used to maintain trustworthiness in qualitative studies. This technique is called investigator triangulation [24]. In addition to constant comparison and investigator triangulation, the team used other strategies to maintain analytical rigor. For example, the team used low inference descriptors (i.e., direct quotes), reflexivity (i.e., openly admitting biases and how they might affect interpretations), and peer review (e.g., presenting and defending conclusions to parties not directly involved in the project) as per Johnson [24].

The research team consisted of two professors (first and fourth authors), two undergraduate students (second and fifth authors), and a staff member (third author) from the institute at which the module was implemented. The first author has many years of experience in K-12 and higher education as an instructor, administrator, and researcher. His research background is in student motivation and innovative STEM education. It is also worth noting that he was a member of the biology and education departments (not from the engineering department) and had no interactions with students involved in the module. The student researchers had never taken any engineering courses or knew any of the engineering professors. They, along with the staff member (who was also not affiliated with the engineering department), were trained in qualitative methodology by the first author before this study began. Finally, the other faculty member was from the physics department and was involved in research design and investigating background information related to this study. She has a background in discipline-based research and course-based research experiences, and she has been instrumental in getting many of these kinds of initiatives started at the institution.

4. Findings

Table 1 provides a summary of the categories and their properties as derived in this study. It is important to note that Table 1 does not represent the full spectrum of categories from the analysis. Instead, Table 1 contains the most common and important categories based on analysis of all students' reflections as a whole. Researchers took these salient categories and organized them into more abstract groupings. The abstract groupings, referred to as the paradigm model by Strauss and Corbin [20], included the *central phenomenon, contributing (or causal) conditions, intervening conditions*, and *outcomes*. These groupings were used to classify the categories and visually represent their relationships with each other. The first step in establishing the paradigm model was identifying the central phenomenon or "big idea" from the data set.

Table 1. Categories, operational definitions, properties (as applicable), and exemplary quotes derived from inductive coding. The number in parenthesis refers to the total number of references by participants that were related to that specific category or property

Categories	Properties	Exemplary Quotes
Career Awareness (132) – Students' insights about engineers, the field of engineering, or their potential futures as related to engineering		"[The module] showed me also that I am interested in becoming an engineer in the future." (Group 1 student; hereafter designated as G1) "[The module] opened up my eyes to the possibility of everything that I can do with an engineering degree." (G13) "The design project also showed me that there was a lot more to take into account when attempting to design something than one would initially think, giving me a greater respect for the field as a whole." (G20) "I found that this project helped to show me that the engineers do not match the stereotype of being awkward, unsocial people. . . This project provided me with a real-life example of engineers in a social context." (G1)
Authenticity – Real-world feel of module activities as expressed by students	a. **Purpose** (126) – references to feelings of helpfulness and/or fulfillment as a result of working on the module.	"I loved participating within a group to help someone with a particular problem by designing a machine to help them." (G15)
	b. **Customer** (75) – references to the relationship of the customer to real-world context.	"[The module] gave me the opportunity to learn more of how engineering works in real-world problems. It taught me how to apply what I know to serve a customer by engineering their needs." (G21)
	c. **Revision** (52) – references to the iterative nature of the design process as a real-world experience.	"The engineering process is very long and tedious at points. . . Every time we thought we had a good idea, we would find something wrong or it wouldn't work the way we wanted it to, and it was back to the drawing board. But...you start to think harder about a solution. . ." (G12)
Growth in Skills – skills that students felt had increased as a result of participating in the module	a. **Creativity** (i.e., divergent thinking) (71) – references to thinking outside the box, critical thinking, creative solutions, etc.	"I learned a lot about how to think outside of the box." (G20)
	b. **Communication** (66) – references to presenting ideas, group discussions, and listening to team or customer.	"I also learned how to present my ideas to people in a clear and concise manner." (G5)
	c. **Collaboration** (61) – references to working together, synthesizing ideas, etc.	"I also learned how to work in a group better by understanding how the other members in the group are thinking." (G19)
	d. **Confidence** (41) – references to increasing confidence in skills; confirmation of choices; increasing comfort with engineering terms and concepts.	"Because of the structure of this project, I am more confident in my ability to solve problems, meet specifications, and collaborate with others." (G1)
	e. **Compromise** (18) – references to compromise, negotiation	"The experience of working on the group design project showed that at times, there is a definite need for compromise within a group setting because not everyone is going to agree on how things should be done 100% of the time." (G20)
Requisite Skills – skills that participants identified as necessary for successful navigation of the module	a. **Teamwork** (92) – references about the importance of working together.	Facilitating: "As a group, we had to collaborate on our work. . .I loved the challenge. . ." (G15) Constraining: "Different people had different strengths, which sometimes made it difficult to put all these strengths together into a single design." (G19)
	b. Open-ended **Problem-solving** (51) – references to the need for skills to solve ill-structured problems.	Facilitating: "Any problem can be solved if you just think critically, artistically, and analytically." (G22) Constraining: "In order to produce a device that does such a simple task, one would not think it to be difficult. This project, of course, was here to prove me otherwise." (G21)

4.1 Career Awareness

Researchers identified the central phenomenon as *Career Awareness* as many students expressed strong views about a growing sense of awareness about engineers, the engineering field, and their potential place in it. The central phenomenon, as well as the other parts of the model, are illustrated in Fig. 1. The arrangement is based on the paradigm model and was developed to show the relationships between the categories and their properties. Although course designers certainly hoped students would be drawn to the field of engineering as a result of this module, it was overwhelming to see how strongly students expressed feelings about their futures based on this one experience (132 total references made by 84 students; Table 1).

4.2 Conditions Contributing to and Detracting from Career Awareness

After identifying *Career Awareness* as the central phenomenon, researchers asked the question, "What was it about this experience that led students to become more aware of the field of engineering and consider their future in it?" Based on the data, the answer was the *Authenticity* of the module (Fig. 1). Using Strauss and Corbin's [20] paradigm model, *Authenticity* was determined to be a contributing condition as it led directly to the central phenomenon. As seen in Table 1, Authenticity was defined as the "real-world" feel of the module from students' perspectives. Students reported that the module gave them a way to apply their acquired knowledge. "[The module] differed from the [other parts of the] engineering class by forcing us to figure out what we were doing rather than just knowing how to solve problems and how to measure engineering specifications. It gave me a more practical grasp on engineering, on creating functional devices using knowledge we gain from physics" (G20). This experience was very different from traditional lab experiences: "Instead of completing the normal labs and lab reports, the [module] took the same knowledge that every lab student was taught, and applied it to real-life scenarios" (G8).

As researchers considered why students felt the module was authentic, three properties of Authenticity were derived from the data (Table 1). First, *Purpose* was identified as an important property of authenticity. Purpose was defined as feelings of helpfulness and/or fulfillment that students expressed as a result of working on the module. This category was related to the customer component as students realized how their work was serving a person. "The feeling of being able to make a difference, and knowing that I can make someone's life easier is a feeling that I have rarely felt in my life. Yet it is a fantastic feeling, and I love it" (G1). Although the customer was almost always mentioned by students when they discussed purpose, sometimes students referenced how things like customer feedback increased the authenticity of the module. So, *Customer* was designated as a second and distinct property of *Authenticity* (Fig. 1).

The *Customer* property was defined as references to the importance of the customer to the design process. Students found that the customer's original specifications and his or her feedback about their prototypes provided a real-world context because they had to make changes based on this feedback (as opposed to more traditional assessment feedback from an instructor). For example, students commented how initial "designing had to be around the parameters of [the customer's] constraints" (G21). As they met with the customer during the process, they saw "what didn't work for [the customer]" and "modified our design to reflect [the customer's] specific problems" (G20). Although surprised by the centrality of the customer to the process at the beginning of the module, students quickly realized how much the customer affected their thought process throughout the module and how much customers must affect engineering design in general.

The third property that was associated with authenticity was the *Revision* associated with completing the module. This experience was the first time in a school setting that many students had an expectation to authentically revise and resubmit their work. In fact, students were often amazed by the amount of revision required in engineering: "The main thing I learned about the engineering design process was how many times a group will revise and fix their idea is innumerable" (G13). However, this process helped students gain a better understanding of the engineering field and determine if the field was right for them.

In an effort to deepen the analysis, researchers considered if any categories could be serving as intervening conditions, defined by Strauss and Corbin [20] as factors that facilitate or constrain people's experiences. To find the intervening conditions, researchers investigated how the categories might explain why students sometimes responded differently to the module, and how these different reactions related to student's views of themselves and/or the field (i.e., their *Career Awareness*). *Requisite Skills*, or those skills that students identified as necessary for having an authentic experience, were designated as intervening conditions (Fig. 1). Although not cited as often as other categories (Table 1), students who mentioned these skills often linked them directly to their perceptions of the module and often to their perceptions of engineering. The two skills that comprised these *Requi-*

site Skills included Teamwork and open-ended *Problem-Solving* (Table 1). The data showed that some students felt more confident with these skills, and therefore developed a better feel for and understanding of engineering and how they might function as an engineer. In other cases, students expressed how they were deficient in one or both of these skills, and their view of the field and/or their potential place in the field was murky.

On the positive side, working in teams provided an opportunity for some students to showcase their more highly developed *Teamwork skills*. "I'm glad I was able to be a part of [the module], since one of my biggest strengths is being a team player" (G22). Students like this who functioned well in a team gained appreciation for why engineers often work in groups: "Engineering is group-oriented, and I now see why . . . I learned that my opinion is not the only one . . . it's more important that the best idea is brought up" (G14). Furthermore, students like this were more confident about their future in engineering: "Working on this group project . . . is going to be very useful in all aspects of my engineering career" (G18).

On the contrary, some students did not have the requisite background in teamwork and struggled from the beginning. One student shared how, "Throughout high school, most of us had the experience of working on a team. But, this was totally different" (G10). When students had little experience working with others, they struggled to clearly communicate ideas, lacked confidence to speak up when interacting with group members, and/or exercised poor time management and responsibility. These challenges directly affected their perceptions of the field and their potential future in it. One student lamented, "I am not a great group worker. . .my slowness, forgetfulness, and lack of participation makes me a nuisance to my partners" (G8). For this student, not being able to function effectively in a team made it difficult to ascertain if any part of the profession was for him/her.

The second property related to *Requisite Skills* was *Problem-solving*. This property was related to students' comfort level and skills when working with open-ended (i.e., ill-structured) problems. Once again, some students felt confident with this skill, while others did not. For example, some students embraced the open-endedness and felt freed by the experience: "I really enjoyed this project, because it wasn't a project with a predetermined outcome where everyone was going to get extremely similar results" (G1). These students were able to embrace the ambiguity and ultimately took ownership of the process: "We were given tools and prodded in the right direction, but the concept and design were really all our own doing" (G11).

For others, frustration set in because, "There was no set of instructions for us to follow. . .sometimes [things] didn't work" (G16). Some of these students never adjusted, and at the end of the module and course chose not to enroll in future engineering courses: "I am a simple person who prefers the most direct path, and when I come off of that path, I am pretty much lost... I am currently not enrolled in any future engineering classes" (G8).

4.3 Learning Outcomes

As students experienced the module, they commonly referenced a *Growth in Skills* including *Communication*, *Collaboration*, Creativity (i.e., divergent thinking), *Confidence*, and *Compromise* (Table 1). This growth, using Strauss and Corbin's [20] paradigm model, was considered to be an *Outcome* (Fig. 1). The relationship between these skills was complex and hard to tease apart in the qualitative analysis. However, it was clear from reflections that most students felt they had grown in one or more of these skills, and growth in one often led to growth in others. For example, one student shared how increased communication and compromise skills enhanced collaboration: "Ultimately, the two things that this project taught me in regard to being able to positively interact in a group project setting would be that both compromise and clear communication are key in making a group project successful" (G20). Another student linked his/her growth in communication with enhanced collaboration: "I learned the value in being able to articulate ideas well . . . The ability to present your ideas in multiple ways is very helpful, and it is much easier to work with people who possess that ability" (G19). Still others linked skills like compromise with stronger collaboration and ultimately the generation of better ideas: "Overall, I learned that my opinion is not the only right one. In the end it doesn't matter who comes up with the better idea, it's more important that the best idea is brought up" (G14). In sum, most students felt strongly that they experienced *Growth in Skills*, and that growth led to more positive attitudes about the module and the field.

Another important *Growth in Skills* area was *Creativity* (Table 1). *Creativity* in problem-solving was necessary as students had to think divergently to develop their prototypes. Student often felt as if they rose to the challenge and were able to harness their creativity: "We took the challenge of coming up with aesthetically appealing features as well as letting our creativity make an impact" (G13). Furthermore, students believed this experience would help them in the future: "In future engineering classes, I'll be able to apply out-of-the-box thinking to future designs" (G17); "I can use the critical thinking skills that I have learned in future engineering classes, as I will be given harder problems to solve and will have to think outside of the box'' (G3).

The final property associated with *Growth in Skills* was *Confidence* (Table 1). As one might expect, gains in all of the other skills led to greater confidence overall. For example, one student reported how s/he felt ''more confident in my ability to solve problems, meet specifications, and collaborate with others'' (G1). In other cases, being able to exercise creativity in problem-solving led to more confidence: ''Working on this design for Nathan has taught me that any problem could be solved if you just think critically, artistically, and analytically'' (G22). In all, the majority of students reported a growing sense of *Confidence* as a result of participating in this module.

4.4 Summary of Findings

As researchers inductively analyzed data and constructed the conceptual model using the paradigm model [20] (Fig. 1), it became clear that the biggest takeaway from the module for most students was a stronger sense of *Career Awareness*: ''[The module] really has given me a sense of what being an engineer is all about'' (G1). Students also indicated an increased awareness of how engineering might play a role in their future. ''Being a part of this design project showed me that I am in the field that I was meant to be in'' (G8); ''This project reminded me why I was excited about engineering'' (G9); ''I was thrilled to be working on a design project. . .It really made me excited for the major path I have chosen'' (G8). In fewer cases, students became aware that they disliked the field: ''I learned that I do not like to work with codes. . .something I did not know before I did this project'' (G19).

The *Authenticity* of the module, as characterized by its *Purpose*, the *Customer* connection, and its inclusion of *Revision*, was contributory to students understanding the field of engineering and their potential place in it. Moreover, *Requisite Skills* including Teamwork and open-ended *Problem-Solving* facilitated or constrained students' abilities to grasp the nuances of engineering and ascertain if they had a future in the field. Furthermore, students often reported learning outcomes related to a *Growth in Skills*, which included gains in 21st century skills like *Collaboration*, *Communication*, *Compromise*, *Creativity*, and *Confidence*. As students engaged in the module and developed skills relevant to the profession, most were able to gain a sense of what engineering was about and identify if it should be a part of their future or not. Student G7 summarized the experience well: ''I feel like this opportunity gave us a chance to see if we would truly like to do something like this for the rest of our lives. This is good to find out sooner rather than later.''

5. Discussion

As first-year experiences are critical to the retention of students in engineering [25], this study investigated how a first-year engineering module impacted students' perceptions of the field of engineering. Interestingly, the certitude with which some students commented about this module's impact on them was unexpected. One potential explanation for why students had strong feelings after participating in the module was that the experience helped them establish an engineering identity.

5.1 Building Engineering Identity

Three specific factors related to building engineering identity frame the current discussion on how this module affected students. First, students were treated like engineers during this module. The setup of the module and the activities that students engaged in were critical. Students are more likely to see themselves as engineers when they are able to make competent design decisions, work with others, and communicate accurately [25]. Students in this study were put in those situations: ''We were given tools and prodded in the right direction, but the concept and design were really all our own doing'' (G11). According to Godwin, Potvin, Hazari, and Lock [3], recognizing students as engineers is an important factor in influencing them to choose engineering as a career. Furthermore, these authors related how putting students in situations where they can show competence is important to persistence in the field. Although students in this study were somewhat uncomfortable with the expectations placed on them at the beginning of the module, they grew in confidence over time and ultimately took ownership of the process: ''Participating in a design project in . . . my freshman year in engineering was challenging at first, but resulted in an overall beneficial experience . . . I feel well-prepared for future engineering classes because of this design project experience'' (G2).

In addition to being treated like engineers, the second factor that helped students increase their career awareness in the field was the authenticity of the experience because of its customer connection and link to a purposeful solution. In fact, students who believe they can make a difference through engineering are more likely to initially choose and stick to an engineering path in college [3]. In this study, students wanted to do a good job to help a genuine customer: ''We were no longer working for the purpose of a grade, we were trying to make life easier for a person that we could see and talk to''

(G9). Svihla, Petrosino, and Diller [26] found that students who worked on ill-structured problems related to a customer had a much more authentic experience than students who worked on ill-structured problems related to written guidelines. Similarly, Kirn and Benson [4] discussed how presenting engineering as a way to help people and provide solutions to problems attracted students to the field and helped them build identity. These studies suggest that the customer and the purpose behind the module in the current study were critical factors that helped raise students' awareness about the field and build their identities as engineers.

A third factor explaining why students were more career aware after this module could be related to diversity. According to Passow and Passow [6], the term diversity has more than one application in engineering. In one sense, diversity describes the attributes of engineers as people (e.g., gender, race/ethnicity, background experiences, etc.). In another sense, diversity refers to the numerous skills that modern engineers need in order to work effectively. When students worked in teams during the module in the current study, perhaps they experienced both kinds of diversity. In other words, working in teams put students with people who were different from themselves and brought alternative ideas to the table: "It was amazing to see all the different ideas . . ." (G20). Furthermore, students in this study had to tap into a diverse bounty of knowledge and skills to solve the problem at hand: "We had to draw from the knowledge we had, the knowledge of others, and information from other sources" (G9). This notion is supported by Svihla, Petrosino, and Diller [26], who conveyed that working in teams typically leads to more creativity as various perspectives find their way into the final solution. Perhaps students in the current study benefitted from working with diverse people as well as being exposed to and using diverse skills. In doing so, they found fulfillment. This finding is consistent with research indicating diverse experiences can attract students to an engineering career [27].

5.2 Cautions to Consider

In spite of the overall positive response of students to the module, a few cautions should be heeded. First, past research reveals that undergraduates' plans for the future are easily swayed by single experiences [27]. So, although a positive early experience like this module may pull students toward the field, a negative experience later on can easily push them away. Second, for a small number of students in this study, learning more about real engineering complicated their feelings about the field and clouded or extinguished their vision of themselves as engineers. In some of these cases, students simply discovered they did not like engineering tasks: "I do not enjoy working out the small details of how [a design] will actually work" (G19). At other times, students perceived deficiencies in their own abilities: "I felt useless because my group was composed of people who solved problems differently than me" (G8). Either way, course developers should realize that regardless of how pedagogically sound early experiences may be, some students have skill sets more suited to other careers and others just do not have intrinsic interests in engineering [3]. Either way, these students are likely to choose another career path. Regardless, course developers should not be discouraged from improving early experiences as even students who successfully complete a major do not always commit to a career in engineering [27].

5.3 Practical Guidelines for Early Engineering Experiences

As one considers the conceptual model in Fig. 1, a few practical considerations for the development of early experiences emerge. First, in order to build engineering identity, early experiences should have an authentic context. In this study, the customer connection and the purpose behind the project in the module greatly affected students' perceptions of engineering and their potential place in it. "This project really helped to make me feel important in engineering. I feel like I have made a difference" (G1). Unlike experiences that are devoid of personal and social contexts, this module impressed students because of its personal connections to real people: "Meeting with Elise made the project seem so much more important and gave even more drive to create the best design for her" (G8); "Before this project, every other project in high school felt like they had no real purpose. Since our design could improve Nathan's life, there was an incentive to come up with an effective design" (G14). The customer and purpose behind the design module provided an authentic context that positively affected students.

Second, early experiences should provide opportunities for students to develop their 21st century skills [28]. In this study, students' abilities to work in teams and engage in open-ended problem-solving were particularly influential toward a positive experience (see *Requisite Skills* in Fig. 1). It is also encouraging to note that students in the current study felt they grew in many other critical areas (see *Growth in Skills* in Table 1 and Fig. 1). This is important because, as discussed by Strauss and Corbin [20], outcomes gained while engaging in an experience can enhance future, similar experiences. For example, some students who struggled with teamwork (i.e., *Requisite Skills*) in the early stages of this module were able to gain collaborative skills as a result of participating in the module. So, their future experiences may be more positive because of their gained skills. Some research exists to support this line of thought, as Dringenberg and Purzer [7] reported that students who initially struggled with ambiguous problems often acquired the requisite skills that helped them deal with ambiguity in the future. Modules like the one in this study provide a space where students can have authentic experiences in a socially-motivating context with opportunities to develop the requisite skills that help them make informed decisions about the future.

When students are able to engage in interesting and authentic contexts that help them see themselves as future engineers and provide opportunities for others to recognize them as engineers, they are more likely to identify as engineers and persist in the field [4]. So, although some argue that little has changed historically to move engineering education forward [29] and evidence of change in engineering education is hard to find [30], the findings from the current study compliment other research (e.g., [2]) that suggests authentic, customer-focused, early experiences can provide students with an authentic view of engineering and potentially help them visualize their place in it.

5.4 Limitations

This study reflects the experiences of students from one institute of higher learning. Although these findings can be considered when discussing module creation and/or revision at other institutions, the results should not be generalized on a grand scale. Also, even though responses to the reflection prompts that served as data for this study were not graded for content (only for completion), they were used by instructors as an assessment of participation. Therefore, it is possible that some students may have felt the need to answer these in the affirmative. In addition, the self-reported reflection data did not allow researchers to assess students' claims about increased 21st century skills.

6. Conclusion

This study investigated a first-year undergraduate engineering lab module that used project-based learning. As students participated in the module, they learned about the design process and worked with a customer to develop prototypes to meet needs within prescribed parameters. Students found the context to be authentic, and most students expressed a newfound awareness of the engineering field as a result of the experience. Evidence suggests these students developed an engineering identity and personally connected with the field. The most important factors that affected students' perceptions included students' abilities to work in teams and exercise problem-solving skills. After the module, students grew in confidence and in their abilities to collaborate and communicate. In sum, this study provides insights into how a first-year experience can affect students' perceptions of the field of engineering as well as students' identities with the profession. Future plans include developing measures to track growth in 21st century skills in these kinds of experiences. Also, efforts are underway to address questions about retention in the major, but it will take many more years to determine the potential impact this module had on retention in the engineering major at the institution involved in this study. Future research will also consider how early-experience modules affect student resilience when projects and engineering tasks get more challenging in later courses in the major.

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Appendix A: Purpose, Goals, and General Schedule of the First-Year PBL Module

Purpose

Provide a bioengineering-focused, basic design project to introduce students to the engineering design process. Project scaled to achieve proof of concept of their design within the one semester. Students are provided lab activities that scaffold both their learning of design concepts along with completion of design steps.

Learning Goals

- Understand the basic design process
- Engage in effective teamwork
- Understand interaction of mechanical and electrical components

Emphasize with students:

- Translating customer desire into engineering specifications
- Goal is proof of concept
- Teamwork is important
- Relates to concept of systems discussed in lecture

Design Definition

- Customer request
- Translate to engineering specs
- Brainstorm drawing of mechanical design
- Design selection
- Electrical study
- Electrical design
- Mechanical/electrical integration
- Prototyping
- Testing and redesign
- Final proof of concept
- Presentation
- Documentation

Year 1 Project
Snack holder to attach to a wheelchair.

- Use mechanical robot arm to move device in to place
- Use control adaptor for cell phone control (start/stop)
- Build snack holder to requested capacity
- Holder must have mechanical mechanism for refilling and moving in and out of feeding position

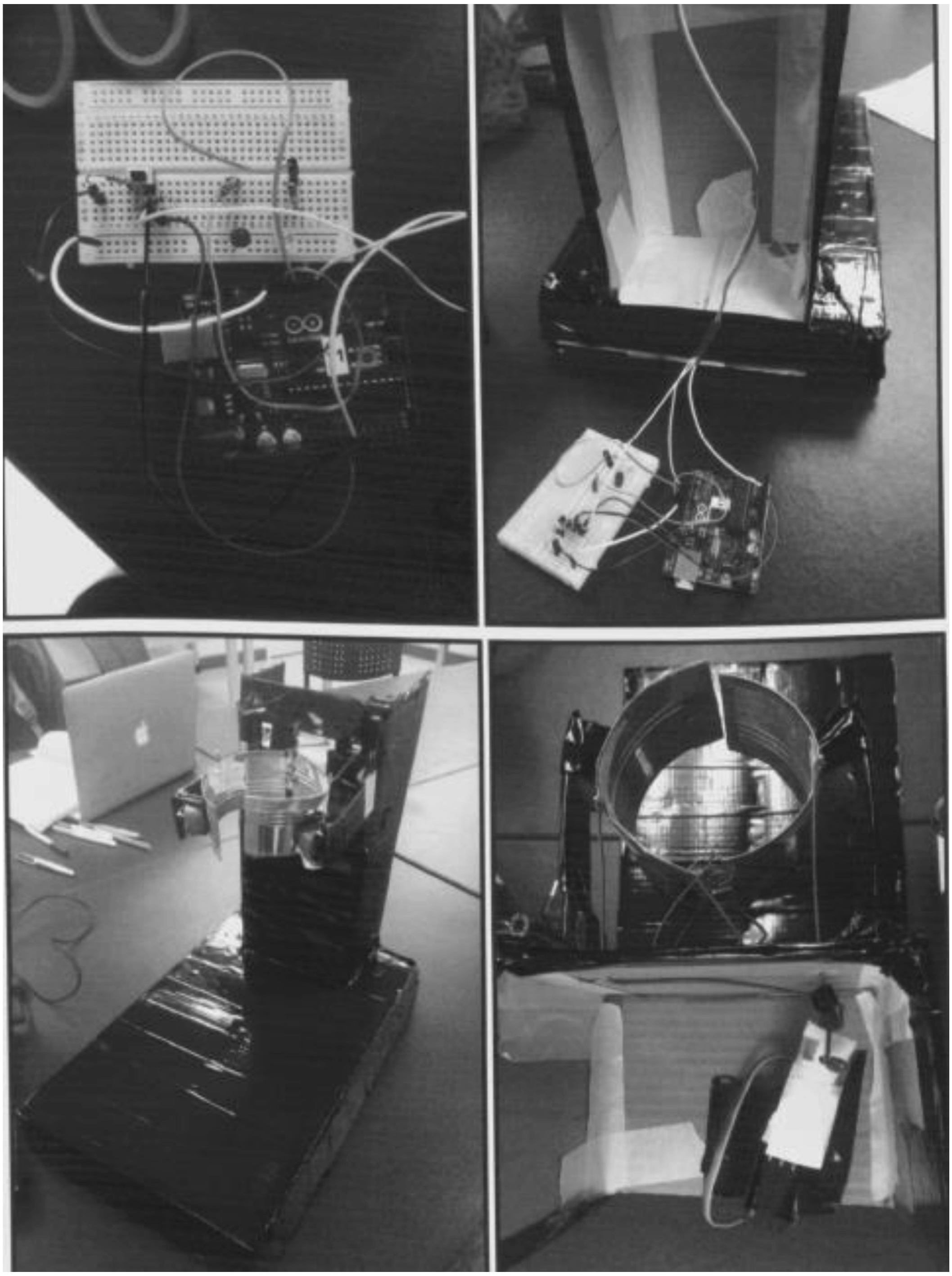
Year 2 Project
Device to help put a sock on

- Use mechanical robot arm
- Use control adaptor for cell phone control
- Build sock holder
- Required motion to put on sock must be shared between robot and mechanical components

Lab Session Schedule

Intro	Initial Intro Lab – Notebook Guidelines
Week 1	Customer Requirements
Week 2	Engineering Specs – part 1
Week 3	Concept Generation
Week 4	Engineering Specs – part 2
Week 5	Concept Build
Week 6	Functional Analysis
Week 7	Electronics/Controls – Test
Week 8	Prototype
Week 9	Redesign – retest
Week 10	Validation
Week 11	Presentation Preparation
Week 12	Final Presentations

Appendix B: Photographs of student prototype for the Year 2 project (sock assist)



Appendix C: Final Portfolio Guidelines and Assessment Rubric

Guidelines (for students)
Each team will prepare a portfolio with the documentation from their design work. The portfolio should include the following:

- Cover page
- Customer requirements
- Copy of each team members' initial drawing of design ideas (not the final! The ideas you had in the beginning weeks. Label as such. You may make a copy directly from your lab notebook.)
- Team members' Functional Analysis
- Design review notes
- Final Arduino sketch
- Final wiring diagram
- Final device scale drawing
- Picture of your final breadboard layout and prototype.
- Final reflection sheet (one from each team member)

Assessment Rubric for Portfolios	**1**	**2**	**3**	**4**
Engineering terminology used over 'layman's' terms (% of time correct terminology used in discussion questions).	~25%	~50%	~75%	~100%
Discussion of process references previous design steps.	No mention of design process.	Occasional mention of design process.	Significant mention of design process.	Significant mention of design process with connections made between the steps.
Progression of drawings reflect incorporation of customer comments and engineering specifications.	Drawings appear very similar.	Minor modifications made in drawings.	Obvious modifications seen in drawings.	Significant modifications seen in drawings.
Documents reflect increasing specificity of design with comments transitioning from qualitative to quantitative.	Comments remain qualitative.	Comments occasionally transition to quantitative.	Most references transition from qualitative to quantitative.	Coherent, logical progression from qualitative to quantitative.
Maintain focus on customer needs during design process.	Don't mention customer.	Occasionally mention customer.	Significant mention of customer.	Significant, appropriate mention of customer.
Design reflects understanding of interaction of mechanical and electrical design components.	Systems appear separate – rare mention of relationship in documents.	Systems loosely work together – occasional mention of relationship in documents.	Demonstrate understanding of relationship of two systems.	Design consideration given to optimize relationship between systems.