2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #39059

Take responsibility to understand engineering (TRUE): A qualitative investigation of student's engineering self-efficacy as a result of participation in a multi-stakeholder program

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WIP: Taking Responsibility to Understand Engineering (TRUE): A qualitative investigation of students' engineering self-efficacy as a result of participation in a multi-stakeholder capstone program

Abstract

The recent Boyer 2030 commission report on undergraduate education at U.S. research universities emphasized "World Readiness," referring to "a vision of undergraduate education that includes and goes beyond the essential goal of near-term workforce readiness to empower students for citizenship, life, and work throughout their lifetimes" [1, p.22]. In order to optimize student learning and success towards "world readiness," we must empower students to become agents of change in their own spaces, including being able to effectively self-regulate their own learning and take responsibility to understand and apply engineering. In 2015, the Electrical Engineering Department at a University of South Florida (USF) university in the U.S. initiated the Taking Responsibility to Understand Engineering (TRUE) initiative as part of a department cultural transformation program.

The TRUE initiative was one of multiple elements in the transformation, and within the initiative, the implementation of TRUE projects was a key programmatic activity. TRUE projects bring together students, faculty, industry, and community to engage in doing real-world problem-solving during the 4-year undergraduate program. Students take responsibility to self-regulate, learn, and apply engineering to real-world problems. While similar models of real-world engagement (e.g., EPICS) exist, they are either limited to a specific category of stakeholders, such as industry or community, or a particular program, such as capstone design. The TRUE projects allow learners across the four-year engineering curriculum to participate while holistically building the skills required for the projects via specialized courses, outreach programs, and mentorship.

Implementation of the TRUE initiative over the past seven years provides an opportunity to qualitatively understand the development of students' engineering self-efficacy as a result of their participation. Self-efficacy measures students' beliefs in their ability to achieve tasks [2]. In this study, it serves as a construct to understand TRUE projects utility in preparing "world-ready" engineers, since students who believe in their own capabilities also tend to engage in their work for their own mastery and find their work valuable and interesting [3]. Therefore, we ask: *What are the students' perceived engineering self-efficacy beliefs as a result of participating in Take Responsibility to Understand Engineering (TRUE) projects?*

We conducted semi-structured interviews with three students to gather data on their experiences in TRUE projects. Using thematic analysis, we apply deductive coding to identify themes that answer the research question. Results from this study provide insights into the efficacy of department-level reform initiatives in addressing the demand to prepare engineers ready to grapple with complex global problems and effectively seek nuanced understandings in 2030 and beyond.

New model for a holistic capstone experience

A decade ago, the Electrical Engineering Department at University of South Florida (USF) had one faculty member advising approximately 80% of the capstone projects. Initial internal evaluation of the capstone design courses and projects showed a disconnect between the two semesters of the capstone design as well as project management and assessment challenges. In 2012, through a significant departmental-level reform, approximately 40% of the entire department's full-time faculty got involved in capstone design. In the same year, a new curriculum development framework was designed by the electrical engineering department curriculum committee using the perspective of complexity [4]. The reform also integrated curricular changes with content on professional competencies such as project management, communication, and teamwork. Additionally, an adjunct professor from local industry was hired to teach the capstone Design I course. While evaluation reports showed progress after the reform in areas such as team management, communication, interdisciplinarity following a system engineering process, some critical issues remained. These issues were pertinent to the nature and quality of the projects the students were completing. For example, projects such as "car headlight control" by a student team were seen as too simple, while another project, "painter robot," lacked dynamism and relevance to the real world. The cross-cutting issue that was identified was attributed to the nature of project selection, which was the majority of the time done by the student teams themselves. Two key criteria that supported in the evaluation of nature and quality of projects was the perspective of complexity and the systems engineering model discussed earlier. Based on these two models, the projects were deemed lacking quality if it failed to demonstrate multiple stages of the design process and lacked advancement in complexity towards arriving at the final design solution.

Therefore, in 2015, a different model was piloted. In this new model, under the Taking Responsibility to Understand Engineering (TRUE) initiative, industrial partners were invited to participate to be part of the TRUE-Partner Network with their commitment to contribute to the professional formation of Electrical Engineers students. Florida Power & Light (FPL) identified the first TRUE project carried out during the Fall 2016 – Spring 2017. During the Fall 2018-Spring 2019, a problem was identified using industry consultation, and a design competition was initiated. Three capstone teams participated in the design competition to produce different products following System Engineering (SE) methodologies for the same "engineering design challenge": to address the automation of ground maintenance service in large solar farms. Evaluation post-completion of the design competition revealed increased satisfaction amongst students, faculty, and industry partners. Following this, the TRUE model was adopted as part of the capstone design.

In the summer of 2020, only two types of capstone projects were encouraged: (a) TRUE projects and (b) Student-initiated projects that were reviewed and approved by a faculty committee through a proposal system. By Spring 2023 (as of the writing of this work-in-progress paper), all capstone design projects in the department of EE have been converted to fit the TRUE project model, which means all capstone projects are real-world projects with industry/community sponsors/partnerships. While this significant shift has been driven by anecdotal experiences shared by various stakeholders and the general evaluation assessments, an evidence-based research study is yet to be conducted to investigate student experiences systematically. Therefore, we initiated a long-term study to qualitatively analyze students' experiences using the construct of engineering self-efficacy by asking: *What are the students' perceived engineering self-efficacy beliefs as a result of participating in Take Responsibility to Understand Engineering (TRUE) projects?* We present our ongoing efforts in this long-term study as a work-in-progress to highlight initial findings from a small sample size (3 interviews) to gather critical review and feedback from the field of engineering education.

We begin by reviewing relevant literature on capstone design programs in the USA, various program evaluations and related scholarly research performed over the years, and critical gaps identified from research. Further, we expand on the construct of self-efficacy as the basis of our conceptual framework. We will follow that with our research design, preliminary findings, discussion, and next steps.

Industry involvement in capstone design

In 1994, 2005, and 2015, three large-scale nationwide surveys of capstone courses were conducted. The most recent survey in 2015 showed that in three decades, the number of industry-sourced capstone projects has increased by 21% [5]. The trends also showed an increase in the two-semester adaptation of capstone instead of one-semester. The survey results highlighted that finding suitable projects was an ongoing task that remained tedious across many institutions' capstone design programs. Later in 2019, in a book chapter written by the authors using the 2015 survey results, they provided additional strategies as recommendations for institutions. One of the key recommendations was to foster industry involvement in capstone design courses through three specific actions: (1) inviting industry representatives as guest speakers; (2) Industry representatives as project sponsors and technical advisors; and (3) forming industrial advisory board members and curriculum advisors [6].

Industry-sponsored capstone design courses with industry representatives playing a critical role in the design and evaluation of projects have shown to be successful. Dutson et al. [7] reviewed the literature on engineering design in capstone courses. They found that a liaison engineer from the industry embedded in the capstone was critical to determining the success of the projects. The liaison engineer's participation was noted to have made the "students feel responsible and accountable to an industrial customer" (p. 22), an essential learning outcome for engineering practice. An industry-sponsored mechanical engineering capstone design program at Purdue University-Fort Wayne demonstrated quality, practical, and real-world projects [8] with an active role taken by industry representatives during the design and evaluation of the projects.

Goldberg et al. [9] highlighted the industry involvement via guest lectures. Industry representatives can provide a focused, real-world perspective on topics, reinforcing the professional formation of engineers and associated engineering practice. The authors also highlighted common topics addressed by industry guest speakers in their program, including "project management, patents, teamwork, globalization, risk management, personal and professional liability, and software validation." (p. 7). The higher representation of professional competencies-related topics can be associated with the significance of those skills in the industrial workforce, which are often left out or integrated unequally into the academic curriculum.

Studies have denoted the expectations from the industry, which wants graduates to demonstrate professional abilities and adequate skills ready to tackle complex real-world challenges [10]. Shurin et al., [11] as a result of a literature review, summarized specific capabilities that were required of engineers by the industry. The list included: (1) multidisciplinary abilities; (2) the ability to optimally develop a product; (3) optimal utilization of resources; (4) identifying needs; (5) creativity and Innovativeness; (6) wide perspective; and (7) ability to manage projects. While these capabilities must be developed throughout the entire duration of the undergraduate degree through a well-aligned curriculum and co-curricular activities, many programs rely heavily on capstone design as the main program for these skills' development.

In their final (capstone) year, engineering students are at the crossroads between formal education and engineering practice. Across the extant literature briefly summarized here, we see that engineering industry expects recent graduates to be world-ready, equipped for multiple professional, technical, and cross-cutting skills. As Trevelyan [12] notes, world-readiness for engineers is often perceived as a social/technical dualism, but in practice, engineers are asked to integrate across a host of interrelated social demands. This transition to authentic engineering work asks for authentic learning to transition world-ready engineers, but misaligned industry versus university experiences and understandings may result from a clear disconnect in final-year experiences and the realities of engineering work outside of the academe [13]. A more porous industry/academe border could be realized through experiences like the TRUE projects, whose larger department context we describe here.

Organized revolution in the context of the study

The USF electrical engineering department's organized cultural transformation program was officially funded by the National Science Foundation's Revolutionizing Engineering Departments (RED) program in 2020. However, the activities and efforts towards the revolution began as early as 2015, with the transformation activities specifically noted as recommendations by Howe and Goldberg. Though this article focuses on the TRUE capstone program, we briefly mention the department's key activities and overall philosophy of transformation to situate the research and the findings holistically. The department's efforts towards the transformation are motivated by the need to develop students as "integral engineers" [14] who will possess and demonstrate nine distinguishing qualities. They are (i) competent, (ii) confident, (iii) creative, (iv) innovative, (v) entrepreneurial, (vi) ethical, (vii) self-learner, (viii) team players, and (ix) socially aware.

Professional Formation of Engineers (PFE) 1-3 courses

The PFE 1-3 courses are one credit-hour courses in the program's second semester each year. The major topics covered under each PFE course are presented below.

- PFE 1 – Principles of Lean Launch Pad, literature searches, oral communication skills, technical reporting, teamwork, generating spec reports, social and ethical responsibility
- PFE 2 – Project and time management, patent searches, data visualization, building a business case, workplace communication skills, proposal writing
- PFE 3 – Trouble-shooting, reverse engineering, test plans and validation, design reviews/design tradeoffs, technical reporting, regulations, and standards

The students in all three PFE courses will have the opportunity to be part of the TRUE projects, concurrently serving various roles as part of the team and applying the learning from PFE immediately in real-world design projects.

TRUE Lecture Series (TLS)

TLS aims to create a meaningful and direct link between students of all classes (first-years to seniors) with professional engineers in an interactive setting. The guest lecturers from the industry are invited to present and discuss various topics that include technical and non-technical competencies with students.

TRUE Projects

The TRUE projects are the main experiential learning activity that student teams engage in during the time of their PFE courses and later as their main capstone design project. The projects are scoped via the Track-Focused Advisory Boards (TFABs) set up by each technical track within the department (e.g., Wireless, Power, Controls, Communications) as a collaboration between the faculty, industry, and students. The network of industry sponsors for the capstone projects each year is called TRUE Partners, and their participation takes several forms:

a.) TRUE partners facilitate student capstone projects relevant to their organizations' needs, which can be completed in two semesters (Design I and Design II).

b.) True partners also participate in the TLS, providing critical learning inputs of interest to each organization and is a critical demand amongst the students.

Example TRUE projects:

1.) Autonomous Drone for Power Line Inspections sponsored by the State power utility company - Students designed a solution to the problem of inspection of power lines at high elevations without using human presence. Students designed an autonomous drone with thermal and visual cameras to solve the problem with a short-term return on investment.

2.) Autonomous Food Delivery System sponsored by a local food service company to address the growing demand for delivery services. The completely automated, GPS-based delivery systems face restricted movement capabilities in indoor environments. Physical interfaces like doorways and elevators limit the ability to shift between indoor and outdoor environments. To address this challenge, the students designed a smart robotic arm as a subsystem to interface with a pre-existing autonomous food delivery robot prototype. The addition of a smart arm will be able to surpass these challenges by providing a means to grab and turn door handles and push elevator buttons.

These three activities - PFE courses, TLS, and TRUE Projects - are designed to provide students with a holistic, integrated experience to develop them as "integral engineers." In this study, we investigate the role of these activities in building their self-efficacy, which as a construct, overlaps with the various qualities of integral engineers, such as confidence and self-learning.

Engineering Self-Efficacy as a conceptual framework

Self-efficacy, the set of beliefs individuals hold about their own capabilities, has been argued to demonstrate how they function and succeed in a specific domain [2]. High self-efficacy leads to greater academic persistence and achievement [15]. Therefore, self-efficacy has become a key construct amongst researchers in studying the predictors of an individual's future accomplishments. In engineering, self-efficacy has gained traction in the last decade as a predictor of student success [16], as a design construct for understanding students' prior beliefs, and effectively contextualizing teaching strategies [17], and as a variable to understand the differences in students development and performance based on specific demographics such as gender [18].

Engineering self-efficacy refers to students' perception of their ability to apply engineering knowledge and skills in a specific context. Researchers have measured self-efficacy within engineering in various ways. Mamaril et al. [19] noted that self-efficacy measurements in engineering could be grouped into three categories: general academic self-efficacy measures (beliefs in their abilities to perform academically), domain-general self-efficacy measures (general confidence to function successfully in specific domains), and self-efficacy measures for specific engineering tasks or skills. Studying these various measures of self-efficacy, Mamaril et al. identified limitations to these measures in terms of wording in certain scales that increased ambiguity around perceived beliefs and specific misconstrued measures that could be interpreted as personal traits instead of efficacy. Therefore, they created a new measure of engineering self-efficacy for use with undergraduate students. By studying 728 undergraduate students across 30 engineering courses in multiple universities across the U.S., they demonstrated reliability and validity to the self-efficacy measures they developed. The self-efficacy scale, modified and adapted from the other measures, comprises two scales:

1.) General Engineering Self-Efficacy Scale - Designed to assess the student's perceived capability to master content in their engineering coursework (p. 372)
2.) Engineering Skills Self-Efficacy Scale - To assess students' self-efficacy for performing specific engineering skills such as experiments, tinkering, and design

We realized that both of these scales provide a general understanding of self-efficacy to the broadly and traditionally identified engineering elements. However, they do not sufficiently include professional skills and competencies such as teamwork, leadership, project management, and communication as engineering components. This lack of representation of skills repeatedly noted and highlighted by researchers and industry representatives as critical to the professional formation of engineers results in challenges in effectively measuring engineering self-efficacy.

Additionally, self-efficacy is often measured using quantitative methods using Likert scale questions, leaving a significant gap in knowledge generation of what students think and how they describe their self-efficacy by associating it with their lived experiences [20]. Hutchison et al. [21] examined the self-efficacy beliefs of first-year engineering students using a mixed-method approach. The instruments used were the self-efficacy surveys and qualitative questions that asked students to list and rank factors they felt influenced these beliefs. A limitation of this approach is that it lacked the methodological depth to clarify why students felt these factors influenced their beliefs.

How to study engineering self-efficacy qualitatively?

Qualitative studies investigating self-efficacy show that an alternative is adapting qualitative interview questions from quantitative surveys and questionnaires. Zeldin & Pajares [22] used this procedure to gather data to conduct a case study of STEM women. Interview questions were framed based on questions from questionnaires that were made into open-ended questions in a semi-structured interview protocol. We adopt this method by using Mamaril et al.'s engineering self-efficacy scale to design the interview protocol. To fit the context of the TRUE projects, we changed the sub-scale of experimental self-efficacy to Project self-efficacy with questions centered on projects rather than experiments. We also added professional skills self-efficacy to identify students' experiences with teamwork, leadership, communication, and interpersonal skills. Participants were initially asked to describe their experiences in the TRUE projects using the developed semi-structured interview protocol. Following their response, prompts relating to one of the self-efficacy measures (General Engineering, Design, Project, Tinkering, and Professional skills) were used.

Data Sources

A total of four participants were identified for the semi-structured interview. The four students were purposively selected based on connections with individual faculty in the department. Since this study is at the initial stages of proof-of-concept, we decided to identify students who maintain relationships or are well-known to the faculty even after a few years of graduation. These students are assumed to be willing to participate in the interview and provide rich and meaningful data. At the time of submission of this draft, only three participants were interviewed. The fourth interview had to be rescheduled due to logistical and scheduling constraints and will be added in the next submission draft.

The three participants interviewed were unknown to each other, which provided diversity in terms of the year of their engagement with the TRUE program and the type of projects they completed.

1.) The first participant, a woman who graduated in 2021, is currently a graduate student in the same department at the university. She had participated in TRUE projects since the start of her junior year and had participated in both PFE courses and TLS. She had also completed the Qualification Plans as part of the PFE courses. Her TRUE project, however, was a different version compared to the majority as they were designing for an IEEE competition instead of an industry client.
2.) The second participant, a man who graduated in 2019, is currently a graduate student pursuing project management and business analysis at another university. At the time of the interview, he had started his job with a large, multinational industry corporate. Before graduate school, he had worked for a year for another large, multinational aerospace industry as a system engineer and for another aerospace company as a design engineer for a year. He had not taken part in the PFE courses and in TLS. His TRUE project was industry-sponsored.
3.) The third participant, a man who graduated in 2019, currently works as a systems engineer for a multinational, large conglomerate. He completed graduate school right after his undergraduate and began working for the company in January 2021. He had taken part in the PFE courses and completed the Qualification plans but had not taken part in any of the TLS at that time. His TRUE project was also industry-sponsored.

The interviews lasted about 50-60 mins on average for each interview and were recorded upon receiving consent from the participants. The recordings were then transcribed using a third-party transcription provider. The first author reviewed the transcriptions and made edits as necessary.

Data Analysis

The first author coded the transcribed data using deductive coding. Nvivo, a qualitative data analysis tool, was used for the coding. The deductive coding was done using the coding framework presented below in Table 1. The framework consists of main codes referring to the different engineering self-efficacy notions adapted from Mamaril et al. Each main code was also coded to one or more sub-codes. The sub-codes are derived from Albert Bandura's four primary sources of self-efficacy as described in his social cognitive theory [23]. The first, mastery or enactive experience, refers to a person's direct experience of mastery or failure. The second, vicarious experience, refers to observing another individual's success or failure, fostering self-efficacy beliefs. The third, social persuasion, arises from the evaluative appraisals of others, and the fourth, physiological and affective states, refers to the feelings, moods, and arousal resulting from engaging in an activity.

Statements were first read and coded with a main code. The same statement was then re-read and coded to one or more sub-codes.

TABLE 1
Sample excerpts and associated codes

Few sample excerpts coded	Main code	Sub-code
"here's some industry ways of doing things. It's expected that you try these…… Now, if it wasn't an industry project, I do think it probably wouldn't have been taken as seriously and it wouldn't have been as useful of a learning lesson."	General Engineering Self-Efficacy (Academic learning)	Mastery Experience
"it was a little bit stressful not having a guideline in the terms of companies might be like, listen, this is what you need to reach, here's the materials, and then you guys do however you think with all this stuff."		Physiological and Affective States
"I mean, right now anybody comes up to me at work and they say, "I have this problem, can you solve it?" My answer's always yes…. And that comes from the work I did at USF because there, I knew I was able to figure things out. And so that just builds that confidence."	Design Engineering Self-Efficacy	Mastery Experience
"we 3D printed all the parts. And so using software to make it, I was like, 'Okay, well, this is what literally engineers do they have jobs and where they're creating and fabricating the robot itself, and we're using software to do that.'"	Tinkering Engineering Self-Efficacy	Mastery Experience
"Management isn't just telling people what to do, it's about understanding where people are coming from and then looking just at the logic of what people present, and then working as a team together deciding….. So it taught me that sense… how to be a good teammate. It taught me how to lead."	Project Engineering Self-Efficacy	Mastery Experience
We had somebody on our team that was actually working in an engineering company, but he came back to school, so he was working at the same time. He was like, "Ugh, if it could only be this easy." I'm like, "Oh my God, for me, this is so hard. He's like, "No, no, no. You don't know." This is a very small glimpse sense of how the career, lifestyle will be like. And so it gives you a, it's exciting, but it also is like, "You get a glimpse of it." And it's like, "Okay, this is how it will be eventually if I do take it to a career with group work."	Professional Engineering Self-Efficacy	Vicarious Experience

After the initial coding, the statements within each code were analyzed and grouped into common trends. These trends were then later merged to form assertions.

Findings

In this section, we present preliminary results from the ongoing analysis of investigating the students' perceived engineering self-efficacy beliefs as a result of their participation in TRUE projects. We present and discuss one key assertion for each self-efficacy category adapted from the Mamaril et al. scale by coding it for the sources of self-efficacy explained by Bandura.

Engineering Skills Self-Efficacy

First, we categorize and group the engineering skills self-efficacy together, which is consistent with Bandura's guidelines [24] assessing students' beliefs in their capabilities of four engineering skill sets that are identified as important to all engineers: design, tinkering, project management, and professional skills.

Design Self-Efficacy

Assertion - Guided, independent, self-regulated learning and problem-solving lead to engineering identity development.

References to design self-efficacy beliefs made by the participants were all from the source of enactive, individual experiences they had during their engagement in the TRUE projects. In line with the philosophy of the TRUE projects to promote independent, self-regulated learning, the participants revealed experiences that strengthened their beliefs.

Participant 3's comment about engaging in project-based, experiential learning matching his learning style set him on the path of self-exploration and iteration through strategies for problem-solving, an essential skillset discussed in the literature of engineering design as a distinguishing quality for informed design [25].

> So I'm the type of student, when I was in school…I always loved the project-based classes….. But project-based, especially with a lot of the professors at USF, they kind of say….they give you the basic information and you have to figure it all out on your own. And basically doing that or doing these projects under PROFESSOR-NAME, it was all of, "This is what the company wants, you guys just have to figure it out….. So for me, I was first, you do the thing, you Google. So I was googling for answers and then I quickly found out nobody really has a solution for this…….I started digging into data sheets and eventually I found a solution within data sheets…….And without doing that project, I don't think I ever would've learned that of how to dig into a problem. (Participant 3, 1/27/23)

Such experiences have built up this participant's confidence levels to translate similar approaches to iterating and problem-solving currently in his workplace.

> ….right now anybody comes up to me at work and they say, "I have this problem, can you solve it?" My answer's always yes. And that comes from the work I did at USF. And so that just builds that confidence. (Participant 3, 1/27/23)

Similarly, participant 1 expressed that the independent aspect of learning and exploration helped him to develop a sense of being an engineer. This experience mainly manifested in her experience as the transition from a student to a professional identity.

> And that whole process of going out on my own and finding what it is that I need, how to do it, and then putting it all together, I feel like it was the whole experience of being an engineer. **I felt like I was an engineer versus an engineering student.** [emphasis added] I was actually doing applications of it and understanding what an engineer actually does with the documentation and also with the fabrication of it. So I think the whole experience was not only truly understanding what engineers do, but also feeling like one. (Participant 1, 1/24/23)

Tinkering Self-Efficacy

Assertion - Using tools and technical knowledge for troubleshooting and exploring new areas

Tinkering self-efficacy beliefs are associated with an individual's beliefs to apply technical knowledge and work with tools to build, fix, assemble, and disassemble things [19]. Researchers noted tinkering skills as critical in engineering practice [26]. The students in TRUE projects are positioned favorably with a demand to learn new technical tools (both hardware and software) to meet the needs of the industry customer, which would otherwise not be acquired. Students choosing their own projects tend to avoid learning new tools or skill sets and situate projects with the knowledge that is familiar to them [27].

Participant 3 explained that his capstone design team took advantage of the project structure's independence to be innovative in their projects. The result from this applied learning, a new technical concept outside of the participant's area of expertise, resulted in a stronger tinkering belief. Further, the ability to do it on his own without the intervention of a faculty member strengthened his belief.

> One of the things we wanted to do was we wanted to control our base model of the robot with an Xbox controller just for development reasons... And, well, I've never worked with Bluetooth, interfacing with Bluetooth. I've never worked with any sort of controls to that degree outside of the math we would do in a class. And so I was like, "Oh, I want to do this." So I spent a week trying to figure out how to interface this Xbox controller with this Raspberry Pi . And it was miserable because apparently there was some bugs in the devices themselves. **And I figured it out. And one, that's a major confidence boost that you have the ability to do this. But another thing is you learn how to figure these things out, not having a professor to tell you what to do.** (Participant 3, 1/27/23)

Similarly, participant 1 mentioned a case of learning a new software tool for their project that initially they considered as a difficult task to do, but, when accomplished, boosted her tinkering self-efficacy.

> And coming to knowing the software itself and being like, "Oh my God, we know this. And some people couldn't even tell us this." It was a good feeling. W**e were able to overcome something that we really didn't think we could do.** (Participant 1, 1/24/23)

From another perspective, Participant 2 explained cases of failure and challenges experienced during the TRUE project actually allowed him to relate it to the current engineering practice (and real-world failures) he experiences. As a result of going through these challenges, he felt better prepared to tackle similar challenges in his job.

> So one of the problems I remember was when we were initially thinking that testing would take about two weeks to do, it took us a month and a half to actually complete testing. And so we finished everything, but the drone kept on crashing. We did plan, that's another risk that we did record, but we didn't anticipate it to be crashing and then not connecting well to the RF controller, the flight plan was also off. **And now I see this is also how it works in the engineering world too, is that testing always takes longer. There's always something that's going to go wrong during testing.** And so based off of just engineering skills, we're able to troubleshoot and find out the problem. (Participant 2, 1/24/23)

All of these experiences expressed by participants 1, 2, and 3, were possible as a result of their engagement in TRUE projects that set up the platform for them to access new learning opportunities. TRUE projects have also played a key role in engaging learners to convert performance avoidance into mastery, as noted by participant 1.

Project Self-Efficacy

Contemporary industrial and workforce requirements show project management as an essential skill needed for engineers to be relevant and competitive in the 21st century [28]. Project management is a skill that is best learned experientially [29] and a key learning outcome of TRUE projects.

Assertion - Planning, an important skill acquired by engaging in TRUE projects

Participant 2, when prompted to explain his choice of participating in a TRUE project, noted the requirements and guidance from the industry helped him scope and plan better for the project. In particular, participant 2 had already done a similar project on his own during his years before the capstone and found that the lack of objective didn’t let him proceed further.

> It's better that I did work with INDUSTRY-NAME Company because it gave me that experience. So for example, they told us that we had an end date of April, 2019 to present this thing at a conference, and the requirements that they had was it needs to go from point A to point B, it needs to be able to start up autonomously, and it needs to be able to land autonomously. It needs to have some sort of connection, some sort of RF communication to a remote, which is accessible to the engineer, the flight engineer. And then those were the requirements.
>
> **So when I made that prototype, I had no idea, there was no point in, I was just making it just for fun.** There was no requirements, there was no objective. And so INDUSTRY-NAME, by having them to telling me that they need autonomous, they need all these requirements, I was able to address and plan out the scope and then also organize it in these

> documents and then present it in a professional manner to the company. This was really my first leadership position. They actually prepared me to be a manager today. (Participant 2, 1/24/23)

Similarly, participant 3 explained his realization of the importance of planning from the time of his engagement in the capstone to his current role in the industry.

> Another thing, and this goes back to the Capstone, is the planning stage. I think especially now that, **now that I work in the industry, I see the value of planning well in advance.** When you're just doing a homework assignment, you just do whatever. It's a problem that can be solved in let's say 10 hours. You don't need to plan much. But on larger systems, if you plan poorly, you're going to mess up big time. So I would say that's a big hurdle is learning how to plan correctly. (Participant 3, 1/27/23)

The guidelines and requirements given by the industry are repeatedly noted as a key element supporting the planning abilities. In the case of participant 1, who engaged in a semi-TRUE project of designing solutions for an IEEE design competition, felt that the industry-led projects offered a better opportunity to manage projects effectively. With her experience to design for a competition, social persuasion by the faculty and peers was essential in building her beliefs in her capabilities in scoping and managing the projects.

> When we were worried, our advisor and other faculty said "You guys should be able to meet this." A**nd it does push you because it's like, okay, this is something I've never thought I could do, but it's also reasonable, you guys have probably set it up for us that it could be reasonable for us**….. So I feel like having a set of projects for us and just letting us choose is a better way to do it… I like with TRUE projects, I feel like it's a little bit more easier because you give some clear guidelines. (Participant 1, 1/24/23)

Professional Skills Self-Efficacy

Assertion - Communication, Leadership, and Collaboration - Key professional skills gained. Across the myriad professional competencies identified in the literature as critical for engineering, the participants in this study highlighted three specific skills from their TRUE program experiences.

In participant 1's case, communication, particularly through different media, was noted as a major learning. The design competition for which her team was designing required them to deliver in-person presentations in addition to a video and a website to communicate their project to a wider audience. This requirement enabled the participant to acquire communication skills that she otherwise wouldn't have had the reason to learn.

> …I think it did help me overall, the practice of doing a huge presentation that was 20 minutes long, doing a video, doing a website, getting the steps that you should have before you do a presentation. But **it set me up for having better confidence overall within my knowledge.**

> **And then also speaking wise and documentation too.** Of course, that's a big thing again. (Participant 1, 1/24/23)

For participant 2, the TRUE project allowed him to hone his leadership skills while also learning to resolve conflict and collaborate with team members effectively. He noted his experience of conflict resolution with a team member has been a standard reference in his job interviews to demonstrate his professional competencies.

> So I was the lead for this project …. So I was able to organize, one person would be working on the battery, one person would be working on the microcontroller, and another on the motors. And so, I was able to not only get my work done working on the communication side, but also integrate all, everyone else, and then be able to provide status too. So it taught me leadership skills too, and how to work with everyone's statuses and then provide that to INDUSTRY-NAME.
>
> **I use a story about this Capstone in almost all of my interviews because it teaches me so much about, for one, troubles that happen in the work environment, especially as a leadership role.** For example, I talked about how I battled with one team member about the design. We had a huge argument and it almost got to a personal level, but to calm his nerves, we were able to meet at a later day when everyone's calm, present all the ideas, and then after that, then we could decide as a group logically how we're going to go about approaching this. So it taught me on that sense of working with people on a personal level. (Participant 2, 1/24/23)

General Engineering Self-Efficacy

General engineering self-efficacy denotes the student's belief in their capabilities to perform well in their engineering program. Our study considers General engineering self-efficacy as the belief to master and practice engineering within the TRUE program. Therefore, we prompted participants specifically on their experiences with the Professional Formation of Engineering courses, Qualification plans, and the True Lecture Series participation. While multiple assertions have emerged, we present one at the time of this draft, as we continue to refine our findings, particularly in this category.

Assertion - PFE courses help complement TRUE experiences if set up sequentially.

Participant 3 took all three PFE courses before starting his engagement in the TRUE capstone project and noted that the courses complemented TRUE projects by offering knowledge and skills that he could apply. PFE courses in particular offered experiences to enact professional engineer roles through topics around professional competencies that are excluded from other courses.

> It was great. I mean, I did PFE one, two, and three, and it was really nice. I think we also interviewed people who were successful in their fields. We did some projects ourselves as a

> class, we undertook a potential large project. And also I got to connect with students that I didn't really get to connect through classes.
>
> The PFE I think was my junior year. So I like to think of it as Capstone, for example, it introduced you to how to work on a project from start to finish. PFE, I would say compliments that in terms of it teaches you how to be a professional engineer, not just the guy that does the math problem, but also the guy that talks with other people and gets the project. We even did things like, you do your five year planning, we did stuff like that in PFE, which nobody else at USF taught us that. (Participant 3, 1/27/23)

Participant 1 took part in PFE courses concurrently as she was engaged in TRUE projects and noted that it wasn't as effective when both experiences were happening together. She also noted that there weren't any explicit expectations and clarity on the philosophy of PFE courses to set up the skills required for TRUE projects.

> ..I don't think it has a huge correlation, but it would obviously help somebody who our engineering minds are so chaotic already. It could organize it a little bit with PFE and help like, "Okay, this is something that we have even from the past that we've learned. Okay, maybe we should apply it here." If I was to take PFE-1, PFE-2, PFE-3, and then design course, it probably would've helped if it was semester back to back. But I don't think it was that bad that I didn't. That's the only thing. I would've never put them two together, honestly, because I will admit like PFE is something that we kind of didn't correlate with a lot of our coursework. And I'm speaking for a lot of students because it was a one credit course that nobody really looked forward to on a Friday afternoon. But I did appreciate the work that was into it and seeing how it could apply to real life. (Participant 1, 1/24/23)

The PFE courses currently present a clear opportunity to support self-efficacy growth in learners if they are set up as a sequential learning program leading to the TRUE projects and explicit linkages in the course context are integrated.

Discussion and Conclusion

The TRUE initiative aims to change how individuals in academic institutions (students and faculty members), industry, and broader engineering systems can relate and work together. The core concept of Taking Responsibility is derived from the grassroot idea that students' formation as professionals is not exclusive of any individual in particular but rather is shared and distributed [30]. An organized cultural transformation toward achieving this goal is currently ongoing in the electrical engineering department of USF with TRUE as a model for capstone design projects. In this study, we have investigated the perceived self-efficacy beliefs of learners who participated in the TRUE projects. Self-efficacy beliefs were chosen as the construct, assuming that it provides a critical perspective towards student experiences and development post-graduation and in their current engineering practice. The preliminary findings demonstrate two key outcomes from this study.

One, the findings serve as a proof-of-concept towards meeting the research goal of generating evidence to systematically understand the role of TRUE projects in developing integral engineers. Students' experiences across all the categories of engineering self-efficacy discussed under findings demonstrate mastery in multiple qualities defined under integral engineers, such as competence, confidence, innovativeness, self-learning, and team player. The results highlight specific areas within TRUE projects, such as the presence of industry representation and space provided for self-learning, contributing effectively towards self-efficacy growth. The results also present evidence for additional efforts needed to align the PFE courses thoughtfully and TLS with TRUE projects to multiply the impacts.

Two, the findings add valuable knowledge to literature evaluating students' self-efficacy beliefs as a result of engagement in capstone programs. We concur with the existing literature around the benefits of industry involvement in engineering capstone programs [5] and align ourselves with the trend of being among the growing number of institutions that thoughtfully engage industry involvement [10] through multiple activities. Participants in our study referenced the TRUE project experiences as removing the boundaries that traditionally exist between industry and academe, while preparing students for holistic development. For example, Participant 3 in the study noted that his experience in the TRUE projects had prepared him for his current role to excel and also be seen as a leader within the organization.

> Believe it or not, it actually translated again to my current position. I mean, there was times at work now where we have some problem and we need more engineers. And since I'm the one familiar with the program, which it is so many parallels between what I did at USF and what I do at work now, it's crazy to me because none of it is on purpose, it just happens to happen. But even the INDUSTRY-NAME, there was these programs, there was a problem and we needed more engineers. But then we also bring in the higher-level engineers and I have to lead them, which, to me, that was the weirdest thing ever. You got these senior guys and I'm telling them what to do. So having that experience with the project and team at USF, that was definitely helpful. (Participant 3, 1/27/23)

As a work-in-progress study, we cannot yet provide concrete conclusions and recommendations for similar programs. We also recognize that purposive sampling is also a limitation to broadly understanding the student experiences of diverse learners. The convenience sampling method therefore introduces significant limitation to the transferability of the results so far. We acknowledge that the findings of the experiences contributing to engineering self-efficacy might not necessarily be exclusive to the TRUE projects and as the few students who continue to maintain their relationship with the faculty and the university we assume that these experiences are not representative of the entire student community in capstone design courses. Therefore, as a next step, we intend to release a call for interview participation using the alumni network of the department and conduct interviews until we have met the criteria of sample saturation. Additionally, we will be interviewing faculty, and industry partners too to understand their perspectives on student learning and engagement. Following this additional data collection, we aim to synthesize results for both internal and external audiences.

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