Pre-assessment of the Impact of Design Challenge Fabrication Modality on Engineering Self-Efficacy

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ABSTRACT

The introduction of project-based learning into university engineering programs has been shown to positively benefit students that prefer a hands-on experience and give future employers assurance that recent graduates have the tools to handle real-world problems as opposed to theoretical situations. Enhancing the engineering self-efficacy of students, recent graduates and seasoned engineers is made possible through the solution of complex, open-ended problems typically found in engineering design. A high engineering self-efficacy, in turn, positively reflects a person's perception of their complex problem-solving capacity which is critical throughout the design process. The decision to either work virtually with a team or onsite with group members nearby may also further influence self-efficacy and, ultimately, the designer's success. This raises the question explored in this study: Will a design challenge impact engineering self-efficacy equally for online and in-person participants? Two groups engaged in a design challenge to develop a mechanism meant for drone applications, where one group designed and tested their solution in-person, while the other group sent design plans to a third-party for fabrication and testing. Participants filled out a prototype engineering self-efficacy scale before and after the challenge, revealing a significant difference between these two modalities. The small sample size is noted as the cause for inaccuracies and surprising findings. Guidelines for methodology implementation in a larger scale study are included.

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GENERAL AUDIENCE ABSTRACT

In project-based learning courses, students work in groups to make a prototype or other solution to a stated problem, which are helpful for building student confidence in problem-solving, critical thinking and, especially, engineering skills. This confidence translates to believing that carrying out a specific task will lead to success with little-to-no feelings of fear or failure. This generally describes “self-efficacy,” and it can apply to any profession. Traditionally, hands-on projects are done in person, where an exchange of ideas is clear and any problems can be handled immediately. However, with schools closed due to the COVID-19 pandemic, these courses had to shift online, leading some to believe that students would not receive the same level and quality of engineering education. Online learning has been around for over 30 years and studies show that students learn just as much, if not more and better, online than sitting in a classroom. Can the same be said for taking part in an engineering project over the internet? Two groups designed a prototype drone attachment, where members of one group worked side-by-side to build and test their solution, while members of the other group worked online and sent files and assembly instructions to a third party. Each participant also filled out a questionnaire before and after the challenge to track their engineering self-efficacy. The limited data led to the conclusion that there is a noticeable difference between the two project completion methods, most likely caused by a low number of participants. The lessons learned from this study were used to create guidelines for a larger-scale study.

This thesis is dedicated to my parents:

I know. I'm surprised I wrote all this, too.

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Table of Contents

1. INTRODUCTION

1.1 Problem

Engineering education has largely evolved over the years to keep up with our everchanging world. The problems we face today, as well as the solutions that have been developed, were unthinkable just a decade ago. While a crucial first step is making sure that students are enrolling as engineering majors and that there is enough diversity of backgrounds and ideas, it would be for nothing if these students do not remain in the program, or worse, are not prepared professionally. One of the reasons students may feel dissatisfied enough to withdraw from an engineering program is the overly conceptual nature of some of its courses. The heavy focus on formulas and theory instead of practice and career preparedness often leads young would-be engineers to rethink their trajectory. To counter this drop in student engagement and retention, universities around the world introduced the concept of project-based learning as part of the curriculum, where students work in groups to source information and develop a deliverable that solves a loosely structured problem. The most well-known project-based course in engineering programs is the capstone course. Typically held during a student's senior year, this is the culmination of knowledge gained since freshman year applied towards a solution to either a self-defined challenge or one posed by a third party (advisor, course guidelines or corporate sponsor). Depending on the university or field of engineering (mechanical, aerospace, civil, etc.), there may be a similar course offered in the freshman or sophomore years, meant to be useful introductions to their field of choice for those who, up to that point, have not so much as even worked with tools. This lays the groundwork for future courses in the semesters to come.

There is data to support the notion that student retention and interest has increased once these courses were added to the curriculum [1]. While higher grades and positive survey responses may indicate academic success, it does not paint the whole picture. These students need to feel they are adequately prepared for a post-graduation career, which is the point of higher education in the first place. For that, the focus turns away from grades and towards the student's engineering self-efficacy, the perception that one is able to carry out engineering tasks successfully. First popularized by Bandura [2], self-efficacy is quantified using questionnaires with a 0 – 100 scale system. Respondents are given a list statements reflecting tasks or situations that they use to measure their perceived ability to complete by selecting a value from 0 to 100, where 0 signifies no confidence in their ability to complete the task and 100 showing total confidence. This allows for a more complete understanding of an individual's belief in their skills, as well as provides a benchmark for future growth. Self-efficacy scales exist for non-engineering professions for the same reason: to identify professional strengths, weaknesses, and areas for general improvement. Additionally, it can serve as a complimentary tool in assessing academic courses of any kind. This is why many universities utilize an end-of-semester course evaluation that employs some variation of a self-efficacy scale.

Traditionally, educators have been able to see the progress of their students throughout the semester due to the in-person nature of schooling. It was not until the 1980s that the technology was available to make higher education possible through the internet [3]. Students no longer needed to sit in a classroom to learn, and a university was no longer defined by geographical limitations [4]. This introduced a flexible learning experience and a more diverse student population. Some of these students go on to work in roles that require frequent online collaboration with global partners, thus distance learning is not just an academic tool, but an investment into future careers. It is important to note that distance learning differs from the flipped-classroom concept, where the former concerns course attendance and completion online, and the latter pertains to the viewing of previously uploaded lecture material in preparation for an in-classroom application and review of the content [5]. In either case, studies have been conducted to show that an online student gains a similar amount of education, support and success as the in-person counterpart [6] [7] [8]. With this lack of a detrimental impact to academic growth, it is suggested that students can feel comfortable knowing that they are not sacrificing their education in any way.

Research into each of these three facets of education – project-based learning, self-efficacy, and online education – has developed when looking at facets individually or two in tandem, but there still exists a research gap for all three working in sync. While the COVID-19 pandemic forced adoption, at least temporarily, of online education or distributed work, not every course could be translated to the web. For example, because it is difficult to teach hands-on material in a virtual setting, students of lab courses are believed to be the most affected. The benefit of attending a highly ranked engineering university in person is the access to quality machining tools, industry leading hardware and software, and notable faculty. Like any university, it also means working side-by-side with peers for group assignments. The impact that these historic times have had on academia will be studied for years to come, but it is clear that the mass adoption of online resources have come sooner than expected. What does this mean for engineering education in the future? Will this negatively affect students that cannot return to in-person instruction due to COVID-related restrictions, economic status, or medical conditions? Do recent and soon-to-be graduates feel they are on equal footing with pre-COVID graduates?

1.2 Purpose of Study

The purpose of this study is to determine if engineering self-efficacy can be influenced by the manner in which a design challenge is completed. The proposed online approach of progressing a solution from sketch to prototype would require the utilization of an outside source acting as a proxy to fabricate, assemble and assess performance. A certain level of trust in one’s capabilities to produce sound design plans is therefore essential. The benefit of in-person project completion is the opportunity to remedy any issues quickly and directly. For this very reason, a review of existing literature leads to the assumption that expectations of success and perceptions of anxiety are high and low, respectively, for hands-on work. As a result, each format engages specific aspects of engineering self-efficacy during the creation of a deliverable, with this thesis analyzing these observations and outlining the processes that were applied.

Due to the unpredictable nature of the pandemic, the scale of this study had to be minimized, as data was provided using a sample size of only four participants. However, this setback does not discredit the insight that this research has produced. In fact, it is proposed that the secondary purpose of this thesis is to demonstrate the methodology needed for a larger scale study when access to resources becomes available and restrictions are loosened. Guidelines for such a study, such as suggested number of participants, timeline, and design challenge options, are described in the “Future Work” section. By taking into account this data and the academic experiences of the COVID-19-induced pivot to online lectures, there may be a basis for universities to consider a future restructuring of the academic framework to make project-based learning courses as viable, as engaging, and as rewarding online as it is in-person. Engineering students that will have taken these courses would then be prepared for their careers and confident in their abilities regardless of the course modality selected.

2. LITERATURE REVIEW

2.1 Project-based learning

2.1.1 Background

For the last few decades, a key feature of engineering education, especially at the university level, has been the emphasis on hands-on activities. It gives these students the opportunity to set aside the pen and paper and put the theoretical knowledge gained from courses to the test. This arose from the goal of retaining as many engineering students as possible by listening to their concerns that the old approach did not prepare them for the workforce. There are many different variations of this format, called “project-based learning,” and, as a result, a plethora of studies have been conducted concerning its place among pedagogies of engineering education. Therefore, in an attempt to bring clarity, all relevant formats will be fully spelled out in this thesis.

Project-based learning is generally described to be a format that is centered on the student (“learner”) working collaboratively with peers in order to submit a deliverable that incorporates either the topics of that course or the knowledge gained thus far in their program [9] [10] [11] [12] [13] [14]. This method turns the instructor into a mentor, guiding students as they develop a prototype of their solution and receiving updates on their progress, usually in the form of reports or weekly meetings. Students become active leaners as they are, in most cases, given a loosely structured, open-ended problem for which they must accumulate information themselves.

Just as important as the project portion of “project-based learning” is its collaborative nature. Engineering is an inherently team-based profession, where ideas are shared and even improved by having rich discussions with colleagues, and the communication skills gained from these projects will prove crucial after graduation. In fact, many industry leaders praise the project-based learning format as it not only makes sure graduates have technical skills, but soft skills, such as communication, creativity, and leadership, as well [9] [14] [15]. In addition to the grade that comes from evaluating the deliverable, a portion comes from a regular assessment of the contribution of every group member, so that everyone is incentivized to perform the roles well.

While engineering programs are usually what comes to mind when someone explains project-based learning, it actually has its roots in another discipline: medicine [15]. Originating in McMaster University in the 1960s, the methodology was effective for the medical field due to the information-solution relationship [16]. Medical issues typically point to a single solution, and the information needed to find that solution can be easily researched. Engineering problems are open-ended, thus there may be many solutions, making evaluation less straightforward. The information needed to arrive at an engineering solution is obtained sequentially. For example, in order to build a rollercoaster, a mastery of physics is needed, which requires a grasp of calculus. A review of articles published between 1995 and 2015 with the keywords "project-based learning," "process-based learning," and "problem-based learning" revealed that the largest portion (28.6%) were medicine-related, while only 6.6% dealt with engineering [16].

As previously mentioned, project-based learning is not the only pedagogical approach studied, implemented, or proposed by researchers, as shown in Table 1. One such example that is similar in concept, but differs in execution, is problem-based learning. Since both formats can be abbreviated PBL and involve a goal of finding an answer, one can often be mistaken for the other. The main difference is that problem-based learning is more analytical and research-oriented, whereas project-based requires a deliverable after conducting said research, but as far as an engineering education is concerned, they are essentially the same [10] [12]. Typically, of the two approaches, cross-discipline collaboration is not a trait of problem-based learning [11].

Table 1: Learning pedagogies found in literature and accompanying descriptions

Learning Pedagogy	Description
Project-based learning	Self-directed, student-centered learning approach requiring submission of a deliverable that solves a stated problem, usually through group collaboration
Problem-based learning [10] [12]	Self-directed, research-oriented approach concerned with analysis of solutions as an end goal
Designettes [17]	Short but reoccurring design exercises prioritizing prototyping skills and regular integration of course and overall program content
Constructionism [18]	"Learning by doing" approach
Constructivism [18]	Approach where new information is framed using previous information or experiences
Think-Maps [19]	Visual approach of providing connections between pieces of information to illustrate thought processes and reasoning

University engineering programs have a few project-based learning courses, but it is rare for an entire program to be centered around the format, which is precisely the case with "designettes" [17]. This approach differs from project-based learning in that single design challenges are not drawn out for a semester. The goal is to "facilitate learning through short-term design experiences," and is more about building prototyping skills, rather than a polished final product. The Singapore University of Technology and Design (SUTD) has been incorporating and studying designettes since at least 2012, and there are four levels of the curriculum: 1D, where students occasionally engage in design activities throughout the course to better understand its content; 2D, where the scope of design activities is expanded to include content from the different courses in which the student is currently enrolled; 3D, a yearly revisit of designettes to retain information and expand the outcome, and; 4D, a collaboration between students and faculty, as well as volunteers from industry, to apply the collective knowledge and experience to the community in some way. Information is never forgotten, and design is always emphasized. A 2D level designette studied in this paper was titled "AutoMilk," an autonomous milk delivery mechanism that brought together students taking thermodynamics, biology and programming courses simultaneously. The professors worked together to include one design requirement each, which integrates material from two courses at a time. An ideal prototype could store milk properly and deliver a large volume quickly. Post-designette surveys showed an increase of 15% in perceived knowledge compared to pre-designette responses, and 10% in understanding cross discipline engineering problems, all after just one weeklong activity. Other designettes, such as an animal-inspired mechanism to use for rescues during natural disasters or an activity that relates music to electrical resistance, also showcased benefits of the format, but were used in community outreach events to inform the public about the SUTD curriculum, hence the data that was collected did not originate from enrolled students.

Active learning is synonymous with the phrase "learning-by-doing," a key characteristic of constructionism, a process of "constructing tangible objects" with the hope of facilitating learning [18]. It was introduced by Seymour Papert of MIT's former Learning Epistemology group in the 1980s and focused on studying how children mastered new concepts by providing an accommodating learning environment. For example, children naturally absorb information not by adult instruction or demonstration, but by recording everything they observe, especially what other children around them do. Project-based learning is derived from constructionism in this regard and is widely accepted now, but at the time of its introduction, that was not the case. The passive learning method had been around for so long that it was assumed that in order to improve a student's academic performance, all that was needed was a better professor, not a new system [18].

Constructionism, like "learning-by-doing", allows for a natural processing of information and lays the foundation for future concept mastery. To cement concept understanding, the idea of constructivism is discussed. Constructivism is about utilizing or relying on past experiences or knowledge to guide comprehension of new information [18]. Oxman (2003) created the practice of Think-Maps by combining this theory with concept mapping [19]. Existing information needs to be organized and readily available to create identifiable links between concepts. These links act as a rationale for any conclusions made, and as opportunities to strengthen understanding by replacing concepts or remapping links. Project-based learning courses, consequently, are a blended paradigm, taking the hands-on nature (students) and hands-off approach (instructors) of constructionism with the need to recall information built up over the duration of the undergraduate engineering program, as is found in constructivism.

The most recognizable project-based learning course in a university engineering curriculum is the capstone, a senior-level course taken prior to graduation that aims to prepare students for the workplace by replicating a typical professional project cycle, requiring they utilize knowledge from prior classes to solve a stated problem [12] [13]. A cornerstone course is similar in aim, but takes place earlier in the program, lacks industry involvement in most cases, and is supposed to increase student performance and retention in later engineering and project-based courses [15]. These problems are either provided by a faculty member or industry volunteer, or are invented by the student group themselves. In certain situations, capstones benefit not just the senior students with experience, but an industry sponsor looking for a quick prototype for their latest product or a professor that needs data for their research, thus problems are not as open-ended as others. An advisor is needed to guide progress, provide feedback and aid in evaluation. Capstones put a greater emphasis on the mentor role of the group advisor. Because these courses are the last before graduation, undergraduate engineering students look to the advisor for suggestions on networking, professional norms, career advice and even insight into future academic goals [13]. Pembridge and Paretti include that mentors should also coach, challenge, accept and confirm, counsel, and build rapport with their students. Direct instruction by advisors to students is not an element of capstone because students are directing their own research and sourcing their own information.

2.1.2 Impact of Prior Design Experience

Studies have shown that student performance in project-based learning courses may be influenced by prior design experience, either in how to utilize certain tools, access and organize information, and navigate different steps of the design process. Schubert, Jacobitz and Kim studied the impact of an engineering design course on a group of students with little-to-no design experience [20]. The *Introduction to Engineering Design* course at the University of San Diego is taken in the spring semester of the freshmen year and is meant to compliment the previous semester's *Introduction to Engineering* course. Students used a LEGO MINDSTORMS NXT system throughout the semester for different labs, and the assignment of interest during this study was to create a drag racing car. A questionnaire determining confidence to complete engineering tasks and basic engineering knowledge was filled out before and after the lab, while students simultaneously kept track of the order of design steps they took in a notebook. Students graded their confidence and knowledge level for each relevant question on a five-point Likert scale, and the researchers assigned values, also on the Likert scale, to students' responses to the knowledge-based questions. The results showed that 66% of the average student's gain in perception of knowledge for the semester came from just this one lab assignment, the first of seven in the semester, increasing from 2.48 to 3.33, reaching 3.78 by the end of the course. The researchers that graded the knowledge responses, however, noticed an increase of only 36% (a still significant gain) of the total change of the semester attributed to that drag racer lab. Improvements noted by both students and faculty were in relation to design iteration and solution evaluation. The student confidence average increased from 3.19 to 3.78, responsible for 58% of the course change in that metric. On that Likert scale, only 36.5% of students increased their knowledge by one point at semester's end, and 8.3% increased it by two. Analysis of the data seems to conclude that for freshmen engineering students with little-to-no design experience, a single exercise was sufficient in increasing perceived engineering confidence, as well as perceived and graded knowledge.

Williams, Lee, Gero and Paretti conducted a similar study, but compared students from two engineering majors to determine if the presence of design courses in a curriculum affected project completion behavior [21]. Mechanical Engineering and Engineering Mechanics sound similar and include many of the same topics in the undergraduate program. The main difference between the two is the presence of design-focused courses and elements that can be found pursuing a Mechanical Engineering degree. The sophomore students selected had limited professional or academic design experience, aside from a freshman course that provided some basics about the engineering design process, in which students from both groups were enrolled. Participants engaged in three design sessions (once each semester), verbalizing their thought processes and ideas and writing them down on a whiteboard as they reached a solution. The challenges were centered around assisting users with physical disabilities. In each of the three semesters, the control group, students from the Engineering Mechanics major, spent a short amount of time on function-related issues. This is the first instance where concurrent enrollment in a design course comes into play. The experimental group, Mechanical Engineering students, were enrolled in a design course during the first design session, and increased function-related discussions the first two design sessions, with a decrease in the third. It is possible that the even though no students from any group were concurrently enrolled in a design course during the second and third sessions, the course content was still fresh in the ME group's minds compared to the third session. The time spent defining the problem was longer in the control group than in the experimental group. The researchers then calculated a Problem-Solutions (P-S) Issues Index value, which quantifies design behavior. The P-S value increased each semester for the experimental group, a sign of "expert-like" design, whereas the control group did not have a consistent trend. The researchers believe that in a future study, regular enrollment in a design course each semester could further highlight these differences in design cognition between otherwise similar majors. Wells et al. also conducted an experiment where thought processes were verbalized and written on whiteboards, with high school students of varying design backgrounds instead of undergraduates [22]. However, no significant differences could be determined, with the supposition that the introductory Project Lead The Way (pre-engineering) courses did not focus enough on design thinking.

The hypothesis put forth by Chua was that students who had taken project-based learning courses would have the skills to perform well in future experiences [10]. 60 sophomore engineering students were broken up into two groups, those with and without design experience, to create a scalable prototype drying machine for agricultural purposes. Participants had taken heat transfer and fluid mechanics the previous semester, so a written test was distributed to compare grades before and after the exercise (drying fruit samples). Also filled out were questionnaires concerning opinions of project-based learning and individual and peer assessments. At least 46% of students with prior experience received at least a B in the knowledge test, while that number is only 30% for the novice group. None of the experienced students failed the test, while 6.7% of the novices did. Experienced student groups all developed prototypes that dried samples efficiently under 45 minutes, and received an average grade of 72%. Nearly every five-person team in the novice group had prototypes that took more than an hour to dry the fruit sample, resulting in average testing grade of 69%. By the end, 60% of experienced groups compared to 40% of novice groups earned at least a B for the design module.

The students who had previously taken courses like these viewed the learning experience favorably, as 86.7% reported it as wonderful, 93.3% mentioning improvement in self-directed learning, 76.7% preferred the method over passive learning, and only 40% reported trouble with group members. Those that were new to this method mainly had opposing views in all of the previously stated metrics: 40% enjoyed the experience, 53.3% had improved their self-directed learning, 80% prefer traditional learning methods, and 83.3% had group conflict. The latter may be due to differences in the goals of each member, as well as their abilities. The one metric that both groups seem to have common is feelings towards job preparedness: 80% for design-experienced students and 73.3% for the (now formerly) inexperienced group. It was not mentioned how the experienced students felt the first time they took a project-based learning course, but it looks as if Chua's hypothesis was correct during this study and will be correct the next time the design-inexperienced group participates in a similar exercise.

While prior studies contrasted the design cognition of students early on in their engineering degrees, a longer-term survey has not been discussed. Researchers at Deakin University in Geelong, Australia, surveyed seniors and freshmen of their engineering program to determine their attitudes over a design-based learning curriculum [9]. Only 14% of freshmen saw this curriculum format as a requirement for job preparedness, while another 58% felt that it only "possibly helps." Having gone through the program in question and about to graduate, 39% of the seniors that were surveyed felt it was necessary for job preparedness, and "possibly helps" was rated by 17%. A smaller difference in opinion (28% of freshmen and 39% of seniors) was achieved in believing that design-based learning does offer benefits in future job preparedness.

For 45% of freshmen and 61% of seniors, the best balance of project-based courses were half teams and half individual, lending the belief that just as valuable as collaborative efforts is the chance to complete a project individually. Researchers concluded that the overall view of the student is that courses that are project-focused, especially through teams, do well to prepare students for the modern workforce, which is why industry leaders champion this approach.

2.1.3 MUSIC Method of Studying Project-Based Learning

A review of the literature revealed a method of understanding student perceptions of engineering design course impact that has a substantial overlap with the goals of project-based learning. The MUSIC method was used by Jones et al. to evaluate student motivation in a capstone course [12]. The abbreviation stands for e**M**powerment, **U**sefulness, **S**uccess, situational and individual **I**nterest, and academic and personal **C**aring. Academic motivation is influenced by feelings of empowerment, and the self-directed nature of project-based learning gives students control over their work. Course content must also be useful to a student's professional or academic goals, and projects are a training ground for gaining useful skills. Motivation implies the student must feel they can succeed in a challenge, and working with group members of similar backgrounds eliminates feelings of inferiority. Projects of interest, especially those that are tied to a specific field of work, push students to learn as much as they can, and mentors can foster the growth and direction of that interest. Lastly, when an advisor or fellow group members show that they care about the student's academic goals, as well as provide support during personal issues, that student feels that the work they are doing matters and is compelled to keep going. Table 2 lists each MUSIC model component and the project-based learning trait that component most closely describes.

At the end of the capstone course, some students participated in qualitative interviews to describe factors of their academic motivation. 70% mention it was impacted by the type of project completed. A project that was selected by the student is more likely to result in higher interest and motivation, but one that was assigned to the group could negatively affect these aspects. 70% also liked having control over their project, timeline, abilities and learning, where 20% said that the scope of the project (applying concepts from previous courses) was a factor. Most students enjoyed the group dynamic in which they found themselves, even forming genuine

Table 2: MUSIC model components and corresponding project-based learning traits [12]

MUSIC Model Component	Project-Based Learning Trait Analogue
e**M**powerment	Learner-centered approach where students control their own progress
Usefulness	Self-directed learning where students must find information relevant to their project
Success	Students work alongside peers that are of a similar educational and experiential background, thus making success seem likely
Situational and Individual **I**nterest	Project topic may align with professional interests of the student, providing an opportunity for career preparedness
Academic and Personal **C**aring	Mentors offer educational and professional encouragement, while group members assist each other in order to succeed

friendships post-project, while 40% achieved academic success maintaining a business-only relationship with other members. Lastly, participants mentioned the influence of their advisors on their motivation. 40% believed their advisor worked to help them achieve success, and 30% described a hands-off approach from their mentor. The latter was comprised of anecdotes of uncertainty of this being the advisor's way of showing respect to his or her students (allowing them to grow as academic and professional individuals) or because that specific advisor had priorities other than the capstone. As is the case in other project-based courses, general attitudes towards the format were positive, and interview responses touched every letter of the MUSIC model. Motivation, however, was not deemed to be at a constant level throughout the semester, given influences by advisor priorities, project topic and group dynamic.

2.1.4 Hindrances to Project-Based Learning Implementation

With increased critical thinking, teamwork, self-directed learning, improved academic performance and overall sentiments of enhanced job preparedness, the benefits of project-based learning and all its forms are well documented. However, nearly every study dissecting the pedagogy notes the logistical issues and concerns from both students and faculty in centering a program around this format. For example, it usually requires more resources [10] [14]. Additional staff is needed to go around to each group in lower-level courses to get updates from students and spark discussion. Open air rooms with movable furniture add to the collaborative environment. While materials and faculty may incur additional costs, it would be a small price to pay in order to maintain a steady inventory of engineering talent [15]. Students inexperienced with this learning approach often mention the increased workload [10]. Time is spent outside of the classroom sourcing information, meeting with groups and building prototypes in addition to writing reports. There is also a concern that the format is unrealistic when compared to the day-to-day duties in industry, especially if a project topic is determined by a supervisor and not the students themselves [12]. Group members in industry would be comprised of varying backgrounds, giving entry-level engineers a point of reference for assistance. For the students who were not interested in engineering, these courses did not motivate them. The main concern heard from students is the drastic change from a passive learning approach to an active one [11] [23]. The responsibility of finding the correct information is on the learner, not an instructor, which can be frightening when students have been adjusted to taking notes during a lecture for the majority of their academic careers.

A suggestion put forward is to blend the two approaches, considering that Gao, Willmot and Demian determined no significant difference when the two are utilized [24]. In their study, three groups participating in a semester long design challenge kept track of the time they spent going to lectures, doing group or individual work towards the challenge and working under supervision. Each participant also filled out a self-assessment. Group 1 reported an average 60% of time spent on either group or individual work, Group 2 reported 67%, and Group 3 had 78%. However, the second group had perceived more general improvement, higher satisfaction, and stronger attitudes towards their design abilities than the other groups. This could be an indicator that the right balance of lecture material (or attendance) and time spent working on projects is needed to reach an optimal level of satisfaction for fans of passive and active learning. Fernandes, Flores and Lima interviewed students six months after participating in a project-based learning course and found that although they noted the benefits of the approach, the students, now taking a traditional-learning format course, enjoyed the extra free time and the fact that their grades are dependent on their work, not that of their group [11]. Nepal and Jenkins also found that blending the two formats minimized both of their characteristic issues and highlighted their benefits [23].

2.2 Engineering Self-Efficacy

2.2.1 Self-Efficacy

In the previous section, the concept of self-efficacy was introduced while explaining, often at length, that the effectiveness of a course in giving students the skills they need for their desired position post-graduation is not measured by grades on a test, but how they feel they can properly apply that knowledge. Another way of phrasing this definition of self-efficacy is the perception that one is "capable of producing given attainments" [25]. Tracing back to the early 1970s, it was popularized by Stanford University faculty member Albert Bandura, who has been heavily cited in relevant publications since its inception. Self-efficacy is quantitatively and qualitatively observed from responses in questionnaires and interviews with participants. In layman's terms, it can be commonly described as a calculated version of self-esteem, both of which are not accurate predictions that a person will succeed or fail in completing a task. A possible reason is that we as humans constantly absorb many sources of information to come to this "conclusion," some of which are accurate, while others are faulty.

Table 3: Self-efficacy information sources, descriptions and level of influence [2]

Self-Efficacy Information Source	**Description**	**Level of Influence**
Performance	Personal experiences	Strong
Vicarious	Experiences of others that serve as examples	Strong
Physiological	Physical or emotional stimuli associated with the experience	Medium
Verbal Persuasion	Words of encouragement	Weak

Shown in Table 3 are the four categories of self-efficacy information sources: performance, vicarious, physiological, and verbal persuasion [2]. Performance information is noted as the strongest (most influential) source in self-efficacy because it relies on past experiences in the relevant task. If there are enough positive experiences, self-efficacy in that task or category is likely to be higher than with constantly negative experiences. A high self-efficacy in one category of activities can also raise efficacy in similar tasks and, eventually, markedly different categories. This all depends on a person's personal experience, but low self-efficacy can be attributed to never having interacted with the situation at hand. A reason for this is by employing vicarious sources of information, which come from the experiences of other individuals. This is especially effective when the "model" from whom someone is obtaining experience information is similar enough to the person with low self-efficacy. In reference to capstone courses, this could be an accomplished mentor with a similar professional, gender, ethnic, or experiential background as the student. Simply knowing that the model has achieved a task of interest is grounds for improving the self-efficacy of a "watching" individual.

Physiological information, which includes emotions, overlaps with performance information. An environment that is not filled with stressors is one in which most people believe they can complete a task successfully. If the task, however, causes emotional or physiological stress, such as knee pain during a basketball game or rude behavior during a customer service job, performance can be impacted. Additionally, expecting these disruptions to reoccur the next time the task is attempted, and recalling the difficulty in managing them, can further lower self-efficacy. Last is the influence of verbal persuasion, which is the weakest of the four categories. A common example is the "You got this!" pep talk. Someone receiving the verbal persuasion may have a substantial amount of negative experiences to counter the positive messaging, but the pep-talker might be more successful if they were to introduce specific successful experiences or other useful information to the contrary.

Self-efficacy can be applied to any professional field or task, even snake handling [26]. Research areas in which findings are consistently published are career choice and clinical applications such as anxiety, depression and substance abuse [27]. Anxiety, a state of apprehension over an uncertain and harmful future event, includes physiological aspects that distinguish itself from fear [28]. The root of anxiety is a low self-efficacy to control a situation once it becomes unexpected and threatening. Merely thinking about an event that could elicit anxiety is sufficient to elevate blood pressure and heart rate, as well as start the excretion of the hormones epinephrine and norepinephrine. A high self-efficacy can still exist in the presence of anxiety given that the individual has experienced situations where they were then able to exercise some control to mitigate a harmful impact. This consequently can reduce the level of hormone excretion. Fear is not as immobilizing as severe anxiety, but it can also co-exist with high self-efficacy. Although feelings of fear may exist, constant exposure to positive experiences, verbal persuasion, and modeling can overcome it, and Bandura determined in a prior study that fear intensity is a function of coping self-efficacy strength [26]. An example he gave was that those who are afraid to drive down a mountain will expect the worst, but drivers who know that they can handle twists, turns, and unexpected objects on the road will envision and be rewarded with beautiful natural sights.

Tenets of self-efficacy theory have proven valuable in academic research. The traditional methods of learning involve an instructor conveying information to students and demonstrating the use of concepts. This is an example of a vicarious source of information [29]. A step further in concretizing the belief that the material is within grasp and that academic success is possible is noticing that fellow students, some of which are similar in background and experience, are performing well. Students act as models for each other, similar to the constructionist concept of babies learning from each other. Maddux writes that one clinical application of vicarious means is showing children that find social interactions difficult a film where the young character is similar to the child and is able to navigate typical situations so that the child can know what to expect [27]. Motivation, a form of verbal persuasion, can help students new to a topic develop cues that they are progressing well in lectures. Schunk and Cox observed students with learning disabilities, giving a portion of them feedback on their progress [30]. These students had higher motivation and increased their learning self-efficacy. In a Corno & Mandinach study featuring college students that developed their own successful learning strategies, it was concluded that further success is due to their high control self-efficacy, as they believed they could influence their own academic outcomes [31].

2.2.2 Self-Efficacy Scales

To compliment his many publications regarding self-efficacy research, Bandura released guidelines for constructing self-efficacy scales that optimize the amount of usable data that can be obtained [25]. Perceived self-efficacy concerns capability, so in this regard, each item should involve *can* statements because, as Bandura puts it, "*will* is a statement of intention." *Will* implies that the outcome is certain, and given that humans utilize both confirming and disconfirming information in reaching these conclusions, the logic is skewed. Items are scored on a 0 – 100 scale from 0 ("Cannot do") to 100 ("Highly certain can do"), with 10-pt. increments in between. It is recommended to follow this eleven-option structure because anything lower is not seen as reliable due to participant tendencies to avoid each end of the scale, further reducing the valuable insight. The scale developed for use in this thesis follows these guidelines and can be seen in Appendix C. The literature mentions that assuring participants that their data will not be evaluated or traced back to them alleviates the desire to produce what they see as socially acceptable responses. Anonymizing the data, therefore, guarantees representative data. Cronbach alpha numbers are used to determine questionnaire consistency and a Pearson coefficient is used to find any correlation between items. If the reliability of the scale is not sufficient after its initial version, items with high inter-item relationships should be removed or reworded.

Self-efficacy scales are useful in a variety of research applications and can produce surprising insight. Fogg-Rogers and Moss developed the Engineering Outreach Self-Efficacy Scale (EOSS) to determine the perceived capability of engineers to engage in engineering education in public events in England [32]. The article states that engineers are usually comfortable in conversations with their colleagues, but interacting with families to get children interested in science, technology, engineering and mathematics (STEM) requires skills not typical of their profession. The researchers wanted the scale to be broadly applicable, so the invited participant population included student undergraduate engineering students, professional engineers, and junior and senior female engineers. 12% of England's engineers are female, but represented 51% of the participants in this scale validation. Since there was no statistical difference between male and female participants in engineering outreach self-efficacy, having more women engaging with children could lead to more representation (vicarious experience through modeling) in the STEM class of the future.

A study by Heyne et al. focused on creating a self-efficacy scale to understand why some students chronically refused to attend school [33]. The Self-Efficacy Questionnaire for School Situations (SEQ-SS) contained statements referencing academic, social, emotional and discipline-related situations. The results showed that the average highest response for self-efficacy (3.87 on a five-point Likert scale) pertained to ability to complete schoolwork, and the lowest (3.03) was for coping with questions about their low attendance. Understanding and completing course material was not a reason these students missed class – the reason was a relatively lower perceived efficacy to answer questions from peers about why they fail to show up. The benefit of this scale is that this conclusion, or other issues that individual student responses imply, can be achieved with only twelve items, and its brevity makes it ideal to use in conjunction with other assessment instruments. However, a scale should ideally not prioritize scale administration time over reliability. For example, the original General Self-Efficacy Scale has ten items, but Romppel et al. removed four questions with low discrimination with respect to the scale topic [34]. By doing so, the Cronbach alpha decreased from a high of 0.94 using the original format to 0.79 in one experiment and to 0.88 in another, with a similar range of reliable retesting. The authors noted a 40% saving in scale administration time and resources, but also mentioned that reliability should be the goal.

2.2.3 Engineering Self-Efficacy Scales

Engineering self-efficacy is the perceived ability of an individual to complete engineering-related tasks, such as calculations, communicating using professional jargon, and constructing prototypes with tools and machinery, to name a few. Unlike other professions or majors, engineering is a broad category. The ABET Engineering Accreditation Commission, which sets guidelines for accrediting university engineering programs in the United States, lists 28 categories of undergraduate engineering disciplines [35]. Regardless of the specific program, the seven student outcomes are the same. Should a student expect that they would be able to solve complex equations, collaborate in groups, apply the engineering design process and understand how to carry out experiments, he or she would become successful in whichever facet of engineering they choose. Universities utilize anonymous end-of-semester course evaluations to gauge program and instructor success in achieving these outcomes. While this can be effective when done properly, these surveys are not specific to any one program or course, since it would be costly, in terms of both time and money, to implement a different set of questions for each course across the university. Bandura notes that a survey tied specifically to the domain of interest will produce relevant insight [25]. Properly determining an engineering student’s self-efficacy to apply the skills they learned in college to the workforce, therefore, requires psychometric engineering self-efficacy scales.

Schar et al. constructed a scale based on the ABET Criterion 3 student outcomes with the goal that such an instrument would be used for evaluating courses and assist with program accreditation [36]. Items include the seven student outcomes (Criterion 3, 3.1-3.7), as well as the

Table 4: ABET student outcomes (Criterion 3)

Student Outcome	Description
1	an ability to identify, formulate, and *solve complex* engineering problems by applying principles of engineering, science, and mathematics
2	an ability to apply *engineering design* to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3	an ability to *communicate* effectively with a range of audiences
4	an ability to recognize *ethical* and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5	an ability to function effectively on a *team* whose members together provide *leadership*, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6	an ability to develop and conduct appropriate experimentation, *analyze* and interpret data, and use engineering judgment to draw conclusions
7	an ability to acquire and apply new knowledge as needed, using appropriate *learning strategies*

eleven outcomes that were in place before a 2009 revision that saw rewording and item reduction (Criterion 3, 3a-3k). The current ABET student outcomes are listed in Table 4 above. Both versions were included in the Schar et al. study to determine if such a change was even necessary and whether either format properly measures the two categories of engineering self-efficacy: academic self-efficacy and engineering task self-efficacy. Following Bandura's guidelines, responses followed a 0 – 100 scale with 10-pt. intervals using a slider, and a Cronbach alpha of at least 0.8 showed strong reliability. After analysis, both student outcome formats were deemed valid and reliable, with the 3.1-3.7 outcomes gaining a Cronbach alpha of 0.87 and 3a-3k a 0.91.

For test-retest purposes, one university, out of the six that participated, had students take the questionnaire again after two weeks, resulting in no statistically significant differences. This set up the researchers to do a follow-up study, comparing changes in engineering self-efficacy at the beginning and end of a semester [37]. Instructors at three universities described to the researchers the focus of their course, which was assigned to the ABET Criterion 3 student outcome to which it most closely aligned (3.2, *engineering design* for Location A, and 3.1, *solve complex* and 3.7, *learning strategy* for both Locations B and C), and students filled out the questionnaire before and after the semester. Post-semester results showed a statistically significant increase in student engineering self-efficacy for the instructor at Location A (Criterion 3.2) and for 3.1 for Locations B and C. While students at Location B also had a statistically significant increase in self-efficacy relating to Criterion 3.7, students at Location C had an average decrease in that same category. Researchers also observed increases in criteria that were not the main intent of instructors at any of the three locations, but this may be attributed to the other courses in which those students were concurrently enrolled that same semester. A "positive and significant correlation" was noted between course grade and engineering self-efficacy scores at the end of the semester, as well.

As part of her dissertation, Mamaril reviewed the validity of scales that already existed in literature in order to develop one for the engineering self-efficacy of undergraduate students [38]. What sets this scale apart from others like it is its decomposition of a broader engineering self-efficacy into separate SE categories: *general engineering, engineering skills, tinkering, technical* and *engineering design*. Each category pulls items from scales by Schreuders et al. [39] (*engineering skills, tinkering*), Baker et al. [40] (*tinkering, technical*), Carberry et al. [41] (*technical, engineering design*) and Schubert et al. (2012, also *technical, engineering design*). Naturally, mechanical engineering majors had higher tinkering self-efficacies than disciplines that notably lack project-based courses in their curriculum, such as chemical engineering. Academic achievement was also found to be correlated to general engineering and tinkering self-efficacies. A relationship between these self-efficacies and a student's intent to remain in the program, surprisingly, could not be determined, although this was not the main purpose of the study.

The engineering design process is a relatively new addition to the university engineering curriculum. On top of this, there seems to be no consensus for the exact wording or order of its steps. In developing an engineering design self-efficacy scale, Carberry, Lee and Ohland used the 2001 framework set forth by the Massachusetts Department of Engineering, which, in turn, was imitated across the country [41]. The eight steps are as follows: *identify a design need,* *research a design need, develop design solutions, select the best possible design, construct a prototype, evaluate and test a design, communicate a design,* and *redesign*. Self-efficacy is one of four self-concepts incorporated into this study, the other three being motivation, outcome expectancy, and anxiety. Carberry et al. specify that people can simultaneously display more than once concept, such as being motivated to complete a task and feeling anxious about it the entire time, thus they explored these intersections by asking participants to consider the effect of each self-concept on nine items (*conduct engineering design* along with the eight engineering design process steps) for a total of 36 items in the scale. For example, they would rate their degree of anxiety in constructing a prototype or their degree of success (outcome expectancy) in identifying a design need on a scale of 0 (low) to 100 (high). The participant population varied in engineering experience, from students and professors to non-engineers with no science background. Each self-concept came back with a Cronbach alpha of 0.94 or greater. The inclusion of *conduct engineering design* statement was to observe any correlation between it and an average score of the eight engineering design process steps. With Pearson correlations ranging from 0.79 (anxiety) to 0.89 (self-efficacy), the authors concluded that the engineering design process steps would be well represented if participants rated their degree of each self-concept in response to *conduct engineering design* alone. The authors also discovered that motivation and outcome expectancy had a positive significant correlation to self-efficacy, while a correlation between anxiety and self-efficacy was significant and negative, leading to the conclusion that more experience in engineering causes positive outcome expectancies and minimal anxiety. The inverse is true for those with little-to-no engineering experience, such as undergraduate students or non-engineers.

2.2.4 Suggestions to Raise Engineering Self-Efficacy

Using the self-efficacy concepts and literature discussed up to this point, it can be surmised that a low engineering self-efficacy could possibly point to one of four causes: lack of sufficient positive personal engineering experiences, lack of proper background representation or demonstration of engineering concepts (vicarious experiences), harmful emotional or physical responses to carrying out engineering activities, or, to a lesser extent, a lack of encouraging words (verbal persuasion) that would aid as a gauge of progress. Any positive combination of these causes could lead to positive outcome expectancies. One demographic that stands to benefit are women, who, for years, have been underrepresented in STEM and, when recruited, tend to opt for fields such as biomedical engineering. Schreuders, Mannon and Rutherford surveyed 969 graduate and undergraduate engineering students at 21 universities to determine an exact cause for this trend [39]. 72.3% of participants were female and 53.3% were either freshman or sophomores. Out of the six common math courses taken in high school (trigonometry, geometry, calculus, and three levels of algebra), five were taken significantly more by women, who also took chemistry and biology more than men. Each group had about 50% report an engineer in the family, which the authors believe may be a stronger recruiting tool than engineering outreach events.

This all shows that women are just as qualified educationally as men, if not more, by the start of an engineering program, but how can the tendency to choose chemical or biomedical engineering over disciplines like mechanical engineering be explained? When ranking “comfort” statements regarding different aspects of engineering on a five-point Likert scale, women scored *working in a laboratory* and *writing* significantly more than men, who overwhelmingly favored designing things and working with tools, machines and computers. Women also showed more preference for engineering outcomes that involved working with people, which explains the trend towards biomedical engineering. The authors suggest that a more balanced representation throughout STEM disciplines could be achieved by raising comfort for all students in using machinery and incorporating course content that is both gender-neutral (topics interesting to both men and women) or gender-balanced (topics interesting to either men or women). Huang, Chang and Chou saw no significant difference in creative self-efficacy between male and female 8th grade students in Taiwan, but noted that the low confidence among some of the female students in applying engineering concepts may be due to stereotypes [42]. Those authors also recommended focusing on enhancing comfort during the prototyping process and providing better access to engineering education for these students.

An alternative suggestion to curricular changes is increased frequency of personal projects, especially while utilizing makerspaces. These are spaces provided by universities, libraries or community centers where people can work with machinery to build prototypes and work alongside like-minded people for support and ideas [43]. At first glance, makerspaces seem to efficiently contribute to each of the four sources of self-efficacy information: positive experiences of learning by using tools in a non-judgmental manner, observing fellow “makers” of varying expertise, receiving and giving encouragement and advice, and reducing anxiety with each makerspace visit or project completion. The impact of makerspace participation on design self-efficacy was observed by Hilton et al. [44]. Participants were freshmen in an introductory engineering design course who also had varying levels of attending their university's makerspace. Surveys were filled out before and after taking the course. Students with low makerspace involvement at the beginning and end of that semester (LowLow) resulted in the lowest motivation, and significantly less confidence and success expectancy than students that ended the semester with high makerspace involvement (LowHigh). There were also no significant differences in anxiety between the three groups (the third being students who maintained high involvement, HighHigh). Both Low groups were initially low in confidence or success expectancy, but the LowHigh group finished the semester more confident and certain of success than LowLow. The conclusion by the authors was that consistent makerspace involvement is as effective as an introductory engineering design course in increasing self-efficacy for design novices.

2.3 Online Learning Modalities

2.3.1 Background and Statistics

The idea of taking a class on the internet has its roots in the 1980s. Although sources differ on the exact origins, the first fully online course that was taken for credit traces to 1986, when University of Toronto professors Dr. Linda Harasim and Dr. Dorothy Smith launched their *Women and Computers in Education* course [3]. Because the waitlist was always full each semester it was offered, the need and interest for this new medium of education was apparent. 44% of institutions with over 15,000 students started offering online courses prior to 1999, and only 17.7% started in 2007. The reverse trend is true for institutions with less than 1,500 students enrolled, as 4.6% debuted the program prior to 1999 and 33.2% in 2007 [4]. In 2002, under 50% of colleges saw online courses as a part of their long-term strategy, but that number rose to 69.1% in 2013 [45]. 75% of universities with these offerings agree that it was one way of expanding the reach of the campus past its geographic confines [4].

By Fall of 2002, of the 16 million students enrolled in a degree program, 1.6 million took at least one class online that semester. Five years later, that number climbed to 3.9 million students, an 12.9% increase over the previous year. A large portion of that online enrollment, 80%, were undergraduate students. That semester, 21.9% of all students at American colleges took at least one course online (3.9 million out of nearly 18 million), growing to 32% in 2012 [45]. By the time this report came out, the economic recession of the late 2000's was in effect, so it was timely to include economic reasons for taking an online course. Primarily, it was supposed to aid in navigating the job market, whether it was to get ahead and further job prospects or simply to postpone dealing with the job shortage by focusing on education [4]. There was also a trend with rising gas prices, as one way of saving money on fueling up for a commute was to stay at home and learn.

As much as online learning has grown over the years, various factors have possibly hindered greater widespread adoption. A greater number of academic leaders felt that an online translation of a course took more time and effort: 44.6% in 2012 vs. 41.4% in 2006 [45]. Additional factors included a lack of acceptance of online degrees by potential employers and low retention rates for online course, where 88% of faculty believed that those students needed more discipline, up from 80% in 2007. Early on, confidence in one's technical competency played a role. Those who were comfortable with using the required technology for online classes experienced less issues with social interaction, less administrative/instructor issues, more learner motivation, and increased time and support for studies [46]. Students have become more skilled technically since then, but classic barriers, such as a lack of motivation (79.6%), procrastination (81.2%), and general feelings of lack of support and home interruptions have all stuck around. Nonetheless, 77% of academic leaders rated online learning as the same or superior to traditional methods (up from 57.2% in 2003). Institutions that offer these courses tend to view this modern method more favorably than institutions that do not offer them [45].

2.3.2 Learner-Content Interaction

The most widely concluded factor of online learning contributing to student satisfaction is accessibility to information, known as "learner-content interaction." A study by Kuo et al. showed that, when surveyed, students of courses in instructional technology and learning sciences had rated learner-content interaction as responsible for satisfaction in their online experience more so than students of psychology, physical education, or family, consumer and human development [7]. In another study by the same researchers, the conclusion went further to state that even though learner-instructor interaction and internet self-efficacy also predicted student satisfaction, the largest unique variance was best explained by learner-content interaction [47]. Nazarenko created an online course to study student views towards the format and found that 96% of the 62 university students viewed it favorably, commenting specifically on the intuitive interface, ease of access to information and interactivity [48]. Therefore, learner-content interaction includes not only access to information, but how the information is framed for its audience. A non-university example comes from Aria and Archer, in which 84 patients with at least one chronic illness participated in their study to become accustomed to a self-management support system to track their symptoms [49]. They were split into two groups: in-person video demonstration with a nurse nearby to answer questions, and an online group that was solely shown a video. Both groups were surveyed after their specific demonstrations and were determined to have achieved a similar amount of support system competency, thus the online system was more time efficient since a post-video question and answer session was not needed.

Although learner-content interaction has thus far been described as making information accessible and understandable, it is not always limited to what the instructor has planned to teach. Researchers at the University of California Santa Cruz compared student data of their *Intro to Field Research* course before and during the COVID-19 pandemic [50]. Students taking the course online during the Spring and Summer 2020 semesters lamented not being able to share experiences with fellow classmates, but enjoyed researching the variety of animals and plants in their community and feeling connected to their field. It was mentioned that had they been on campus, they would have been limited by class time and instructor preference of course materials. This can be seen as nearly the purest form of learner-content interaction, with the student (learner) analyzing the wildlife (content) in their backyard. An added benefit of the online format in this case was the flexibility for students to take mental breaks to combat the stresses of going to school during a pandemic. However, in pre-COVID times, the amount of stress that online students perceived was found to be no different than that experienced in-person [6].

Thai, De Wever and Valcke compared four academic settings: blended, traditional, e-learning, and the “flipped classroom” concept [5]. This was done to examine how combinations of in-person and online content, shown in Table 5, affected learning performance, self-efficacy beliefs, perceived flexibility and intrinsic motivation. Learning performance was tracked using pre- and

Table 5: Academic settings tested by Thai, De Wever and Valcke [5]

Academic Setting	Lecture Format	Guided Question Format
Traditional	Face-to-Face	Classroom
Blended learning	Face-to-Face	Online
Flipped classroom	Online	Classroom
E-learning	Online	Online

post-semester tests. 90 students in a university *Invertebrates* course were split among the four academic settings and given the same printed textbook and guided questions to follow along with the material. Results showed that students in the flipped classroom setting learned more (higher learning performance score) compared to the e-learning and traditional settings, which had equal learning performance outcomes. The rationale that was given is that students had more time to process the data, such as rewinding videos of the lectures and working at their own speed. The flipped classroom setting also increased participant self-efficacy over e-learning. Between the two settings with online guided questions – blended learning and e-learning – a significantly lower learning performance was found with the latter. No setting saw a noticeable change in perceived flexibility. The authors suggested that since the web system, used to access lectures and guided questions, was a new experience for the non-traditional group participants, the limited amount of time to acclimate to this environment prior to the study may have caused a decrease in motivation, so a future, larger study would have to take that into account.

2.3.3 Lab Courses Held Online

As the consensus of universities in the mid-2000s started to shift towards seeing distance learning as critical to their long-term strategy, not every program was equally fully offered in this way. The ratio of universities offering a program fully online out of the total number of universities that offer it either online, in-person or in other ways, is known as the “penetration rate” [4]. The rate for engineering programs offered fully online was at 16%, which is paltry compared to health, education, liberal arts and business, which all had a penetration rate of 30%. Translating a traditionally in-person course, such as a lab or project-based course, was rare back then, but technology is advancing enough to make it much more commonplace. A study in Brazil determined that a family health course taken by healthcare professionals either online or in-person was successful in equally educating its students, regardless of modality [51]. Looking closer at the data, however, reveals modality-specific tendencies. Procrastination of study habits was more likely, and self-regulation was less likely, for the online students, who also reported a lower self-efficacy. Face-to-face students felt stronger socially than the other group, but not so much that it was statistically significant. This sentiment was echoed in an observational study taking place during the first college semester of the COVID-19 pandemic [52]. Two biomedical engineering courses at the University of Arizona, similar to other institutions, had to quickly find solutions to keep as much of the course material intact as possible. Working with on-campus machining equipment to make prototypes was relegated to CAD models and quickly fashioned lab kits shipped to students' homes. Because these were group projects, students had to manage geography and time of shipped parts and fellow group members. It was estimated that it takes about 80 hours to put a course online, assuming the online infrastructure is available. Students were reported to still gain from the course, but the "social aspect suffered the most." In a separate study observing differences between an in-person and online physics lab course, students on campus placed a higher value on the immediacy of interactions with their laboratory partners and fellow classmates [53]. In-person interactions with the lab TA was not statistically different than online students, who sought assistance or clarification via email.

2.3.4 Issues Concerning Online Learning Research

Although an overwhelming majority of studies, 92%, point to online and distance learning being as good, if not better, than traditional learning methods [54], not every study follows the same procedure to come to this conclusion. A true determination of no significant difference between the two modalities of course delivery would come from randomization of format assignment, where participants were not aware of how they would be taking the course for research purposes. However, many studies have either allowed for or have been impacted by modality preference. The previously mentioned Brazilian family health course study had 60% of its initial participants drop out at enrollment because they were randomly assigned to a modality they did not prefer [51]. It is also believed that the academic backgrounds of online students may lead to this false equivalency in learning outcomes. Online programs are known to lack a social aspect found in the classroom, but the type of student that still enrolls for web lectures is willing to overcome that barrier due to their having more positive views towards the subject than those on campus [8]. Therefore, studies that include participants that are assigned to the modality of their choice, instead of a true randomization, lack merit in their claims of generality in class format.

A review of the literature also showed that these modality studies mostly employed undergraduate students as participants [54], leaving only a few to consider the impact on graduate students. A case involving graduate students reported a higher quality experience intellectually in the online course [55]. They may have even been primed to seek a master's or PhD because of taking senior courses online during their bachelor's program [56]. While other studies have concluded that both undergraduate and graduate online students are naturally motivated, it may actually be too complex to quantify, and the online environment and learner-content interaction may actually define student motivation in a course [57].

3. METHODS

3.1 Introduction

The African Drone and Data Academy in Malawi (ADDA) is a partnership between UNICEF and Virginia Tech, where students in the program learn how to design and operate low-cost drones for applications such as medicine delivery, analysis of aerial data to prevent flooding, and timely responses to emergency situations [58] [59]. Of the five courses offered, *Certificate of Drone and Data Technology Level 2* (CDDT 2) involves prototyping an onboard drone mechanism that will automatically engage to complete a specified mission. Students come from varying technical backgrounds and in a six-week span, they are taught the basics of Solidworks, 3D printing constraints, flight and drag principles, and prototyping tools. This culminates in day filled with flight tests from each group of four to five students. The design challenge, dropping and retrieving a payload, was crafted to have real applicability – aerially distributing vaccines to remote areas, as well as picking up blood samples. Students were given a document that contained payload specifications, mission guidelines (height of payload drop, flight pattern), available materials and a scoring rubric detailing six design criteria to consider: reliability, weight, payload capacity, manufacturability, originality and mission success.

Originally, the goal of this thesis was to develop additional applicable design challenges for the ADDA, construct proof-of-concept prototypes of said challenges, and obtain in-person engineering self-efficacy data of the students before and after challenge completion.

Unfortunately, the COVID-19 pandemic forced a change in plans, as in-person instruction could not be held. As a result, this thesis took on two alterations. First was the addition of an online component to project completion. The coronavirus has forced universities, companies and other institutions to conduct work online in preparation of a post-lockdown environment. This also lays the groundwork for individuals that are geographically separated from the organization of interest to be just as engaged and productive as those in the office. While vaccinations take place, people may still have medical, financial or other circumstantial reasons that prevent them from appearing in-person, but the quality of contribution and education should not have to be sacrificed. Secondly, this thesis now acts as a pilot study for a future larger scale study at the ADDA, where the diverse educational backgrounds of program participants can provide a basis for scale validity and broad applicability. Once the concept has been proven to show little-to-no impact of online project completion on engineering self-efficacy, additional future studies could be held at the university level to determine application to project-based learning curriculum over the course of a semester. Suggested guidelines for conducting such a study are available in the "Future Work" section of this thesis.

3.2 Participants

Two groups of two students each were tasked with completing the same design challenge. The difference between these groups is the manner in which the design challenge was assembled and tested. Members of one group (the "in-person" group) collaborated in the same space to develop CAD models, 3D print, post-process (remove support material) and assemble those parts, and test the prototype themselves. Members of the other group (the "remote group") were not in the same space, instead collaborating online to ideate and create CAD models. This second group then sent these files, along with assembly instructions and a list of additional parts to buy, to a third-party that would 3D print the CAD files, assemble the prototype and test it. In-person participants were undergraduate aerospace and mechanical engineering students, while the remote group was composed of a computer science undergraduate and a mechanical engineering undergraduate, both with extensive 3D printing experience.

3.3 Design Challenge

The intent in crafting the design challenge was to require a simple design that could quickly be iterated in future studies. For this reason, groups were tasked with creating a servo-based prototype mechanism that drops rolled-up paper balls via automated Raspberry Pi code. Although meant for use during a drone's flight path, a drone was not used to test the mechanism, but was instead supported four feet above the ground and placed in the orientation prescribed by group, as the example in Fig. 1 displays. The model of the servo used by both groups was a Corona CS929MG, of which a Solidworks CAD model was provided to each group for dimensioning purposes. Paper balls were rolled to approximately 1.5 in. in diameter. Because these solutions were intended to be automated, groups could only load paper balls prior to testing.

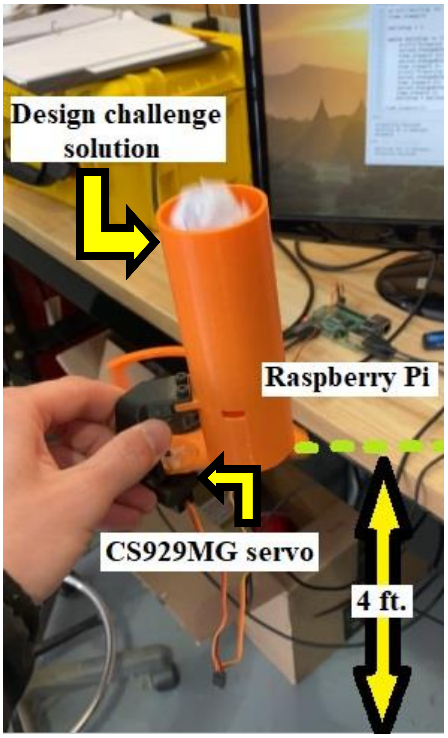

Fig. 1: Design challenge test setup

3.3.1 Scoring

Each design challenge solution was scored using four criteria: *manufacturability, complexity, mission success,* and *reliability*. An overview of the rubric is available in Table 6, while more detailed scoring for complexity and manufacturing can be found in Appendix A.

Table 6: Design challenge rubric

Design Criteria	Criteria Weight
Manufacturability	**20%**
• Assembly time	5%
• Part cost	7.5%
• Prototype generation time	7.5%
Complexity	**10%**
• Originality	3%
• Number of parts	7%
Mission Success • 25*X% (X = # of successful payload drops, maximum of two)	**50%**
Reliability • 2*X% (X = # of survived actuations, maximum of ten)	**20%**
<u>**Total:**</u>	**100%**

- Manufacturability: 20%
    - Manufacturability includes three sub-criteria: cost of parts, prototype generation time, and assembly time. Participants were asked to keep a record of the time spent completing each facet of the challenge. A higher score would be awarded for designs made cheaply and quickly. Prototype generation time includes determining a design, fabricating/printing, and post-processing. For any 3D-printed parts, the cost was converted using a $20/kg model.
- Complexity: 10%
    - The complexity score is composed of the number of parts needed to make the solution function, as well as its level of originality. A unique design with as few parts as possible was eligible to receive a maximum score in this criterion.
- Mission Success: 50%

    - Groups were allowed three attempts to successfully drop two individual paper balls. If a payload did not descend straight down, if more than one dropped at once, or if none dropped during an attempt, there was a deduction of 25%. If no target actions were achieved, the full 50% was deducted.
- Reliability: 20%
    - To ensure reliability of the mechanism as a whole, a stress test was also conducted. Solutions were exposed to ten rapid actuations of the servo. Any noticeable change in mechanism functionality or appearance impacted the reliability score. Paper balls were not inserted during this test.

3.3.2 Materials

Participants were permitted to use any parts and combination of traditional fabrication and 3D printing. For uniformity, 3D print times were estimated using a MakerBot Replicator 5th Gen using PLA filament. For testing, a CS929MG servo, accompanying servo horns, differing models of the Raspberry Pi computer, and jumper cables were used. Materials were selected to replicate those that would be available in Malawi once restrictions loosen and in-person instruction resumes.

3.3.3 Code

Two scripts of code were made available to each group, one for testing the ability of the mechanism to complete the intended mission, and one to assess prototype reliability. These scripts were adjusted to match the anticipated servo actuations specific to that group’s design solution and was run using a program built into the Raspberry Pi called “Thonny.” An example script is available in Appendix B.

3.3.4 Testing

Scored demonstrations of the prototype were conducted online with the researcher via Zoom. The in-person group conducted the demonstration themselves while the researcher watched to observe that testing protocol was appropriate. Inversely, the remote group observed the researcher test the prototype.

3.4 Scale

Participants filled out a questionnaire prior to starting the design challenge and after receiving a final score. Both groups responded to similar questions and statements, but the remote group had additional questions in both survey administrations regarding sentiments towards an online collaborative format. Mamaril's 2014 dissertation, "Measuring Undergraduate Students' Engineering Self-Efficacy: A Scale Validation Study," was used as a starting point in the review of scales that existed in literature [38]. The scale developed in this thesis for use at the ADDA either used items from these scales or followed their structure. Mamaril compiled these statements and placed them into multiple categories, only three of which were used in this thesis: *tinkering self-efficacy items*, containing items from Schreuders et al. [39] and Baker et al. [40]; *engineering design self-efficacy items*, taken from Carberry et al. [41] and Schubert et al. [20]; and *engineering skills self-efficacy items*, again using Schreuders et al. items. Example statements from the *tinkering self-efficacy* category are "I can fix machines" and "I can disassemble things." This is somewhat similar to *engineering skills self-efficacy* items, where statements include "I can work with tools and use them to fix things" and "I can design new things." The similarity in some of these statements prompted Mamaril to remove them from her final scale, but they were kept in this pilot study due to the interest in observing how participants would respond to two questions of similar verbiage. Lastly, example *engineering design self-efficacy* items are "I can identify a design need" and "I can recognize changes needed for a solution to work." Overall, these three categories produced fourteen items, listed in Table 7.

Table 7: Engineering skills scale items used in pilot study [38]

Scale Item Identifier	Engineering Skills Scale Item
ESSE5	I can work with tools and use them to build things
ESSE6	I can work with tools and use them to fix things
ESSE7	I can design new things
ESSE8	I can solve problems using a computer
ESSE9	I can work with machines
ESSE10	I can build machines
ESSE11	I can fix machines

ESSE21	I can manipulate components and devices
ESSE22	I can assemble things
ESSE26	I can disassemble things
ESSE13	I can identify a design need
ESSE15	I can develop design solutions
ESSE18	I can evaluate a design
ESSE20	I can recognize changes needed for a design solution to work

Carberry et al. showed participants nine items regarding engineering design steps, requiring a response according to each of the four self-concepts: *self-efficacy, motivation, outcome expectancy* and *anxiety*. In total, there were 36 items, each on a 0 – 100 scale with 10-pt. intervals. Following this structure, participants of this study were shown the fourteen statements discussed in the previous paragraph and responded twice, once to consider outcome expectancy and another to consider effects of perceived anxiety. Outcome expectancy, worded in the questionnaire as “Rate how successful you would be in performing the following tasks,” was chosen in this pilot study over self-efficacy, which replaced “success” with “confidence,” because as a proof-of-concept, estimating success and estimating confidence appear similar to most people, running the risk of overwhelming participants with a lengthy survey. The contrast between perceived success and anxiety was thus clearer to differentiate. Another departure from the authors was the use of a 10-pt. slider scale, with zero assigned to “Not expecting success/Not anxious” to 10, “Highly certain of success/Highly anxious.” This was due to common familiarity with a 10-pt. rating system (although the authors similarly justified a 100-pt. scale as students are usually graded out of 100%).

The textbook used in the University of San Diego’s *Introduction to Engineering Design* course included steps of an engineering design process and students were asked to write the order of the steps they used in completing a class exercise in a study by Schubert, Jacobitz and Kim [20]. Participants in this pilot study were shown these steps and asked to order them in both the pre- and post-challenge surveys in order to see if challenge completion has any effect in this domain. The steps were presented in an alphabetical order, an aspect that Schubert et al. regretted as a noticeable portion of the freshmen engineering students reportedly conducted the exercise in that order. Though they advised against it, it was not seen as an issue in this pilot study since the participants already had prior design experience. Each step had the wording used in the introductory course, except *perform post-implementation review and assessment* was changed to *perform review and assessment*, as seen in Table 8, to avoid automatic ordering bias with the step *implement and commercialize*.

Table 8: Modification of engineering design process used in Schubert et al. study [20]

Step #	Engineering Design Process Step
1	Identify the problem/product innovation
2	Define the working criteria/goals
3	Research and gather data
4	Brainstorm/Generate creative ideas
5	Analyze potential solutions
6	Develop and test models
7	Make the decision
8	Communicate and specify
9	Implement and commercialize
10	Perform review and assessment

The last scale used for reference was that of Schar, Brackin, Chew and Sheppard, who used the student outcomes listed in ABET's Criterion 3 to observe student confidence [37]. Five of the seven outcomes were, again, scored by the pilot study participants in response to the degree in which they felt they could successfully perform the tasks (a student outcome). The two student outcomes that were not included were 3.1 (*an ability to identify, formulate, and solve complex engineering problems*…) and 3.6 (*an ability to develop and conduct experimentation*) as the problem was already presented to participants and the short timeline did not allow for student experimentation to occur. This further reduces the total possible number of items on the scale, as well as the time needed to complete the survey. Participants were also asked qualitative questions in the post-challenge survey regarding their views towards the design challenge, the scores they received, and the study overall. Appendix C contains a version of the questionnaire used in this study.

3.4.1 Analysis

Since the resulting dataset was small, Excel was used for analysis. Literature shows that a valid self-efficacy scale requires a Cronbach alpha of at least 0.8 [25]. Pearson correlation coefficients were also calculated to determine any statistical relation between members of a group, between groups, between survey administrations, and between success expectancy and anxiety statement responses.

4. RESULTS

4.1 Design Challenge

Table 9: Results of design challenge

Design Criteria	In-Person	Remote
Complexity (10%) • Originality (3%) • Number of Parts (7%)	Original design: **3%** 11 parts: **0%**	Original design: **3%** 10 parts: **2.5%**
Manufacturability (20%) • Assembly Time (5%) • Prototype Generation Time (7.5%) • Part Cost (7.5%)	Assembly time of 45 minutes: **5%** Prototype generation time of 12 hr 39 min (print and post-processing: 7 hr 54 min): **2.5%** $1.64: **7.5%**	Assembly time of under 2 hours: **5%** Prototype generation time of 24 hr (print and post-processing:16 hr 34 min): **0%** $9.10: **7.5%**
Mission Success (50%)	Successful drops: **50%**	Unsuccessful: **0%**
Reliability (20%)	Durable and consistent: **20%**	Failed on first motion: **0%**
Total Score (100%)	**88%**	**18%**

The results of the design challenge are shown in Table 9. The complexity score concerns design originality and total number of individual parts. Originality is defined in this study as designs that were unexpected by the researcher. Both groups produced original designs that employed two-point paper ball separator systems worth the full 3%. CAD models, section views and dimensions of the design solutions are shown in Fig. 2. The system used by the remote group was composed of two flaps separated by 1.7 in and offset by 60°, with the intention of preparing a payload in one servo actuation and releasing it when returning to the rest position. The servo and the two flaps were fastened to the same dowel using press fits, a servo horn converter and an adhesive. The in-person system rotates a 3D-printed plate with a 1.5 in-diameter hole and a tapered arm 1.5 in directly above the hole to drop each payload individually as the curved arm penetrates a matching slot in the housing. This solution had a total of eleven parts, composed of three 3D-printed pieces, four screws and four nuts, resulting in no awarded points. The remote group, however, was one part under this threshold, as their design included six 3D-printed parts and four dowels to earn 2.5%.

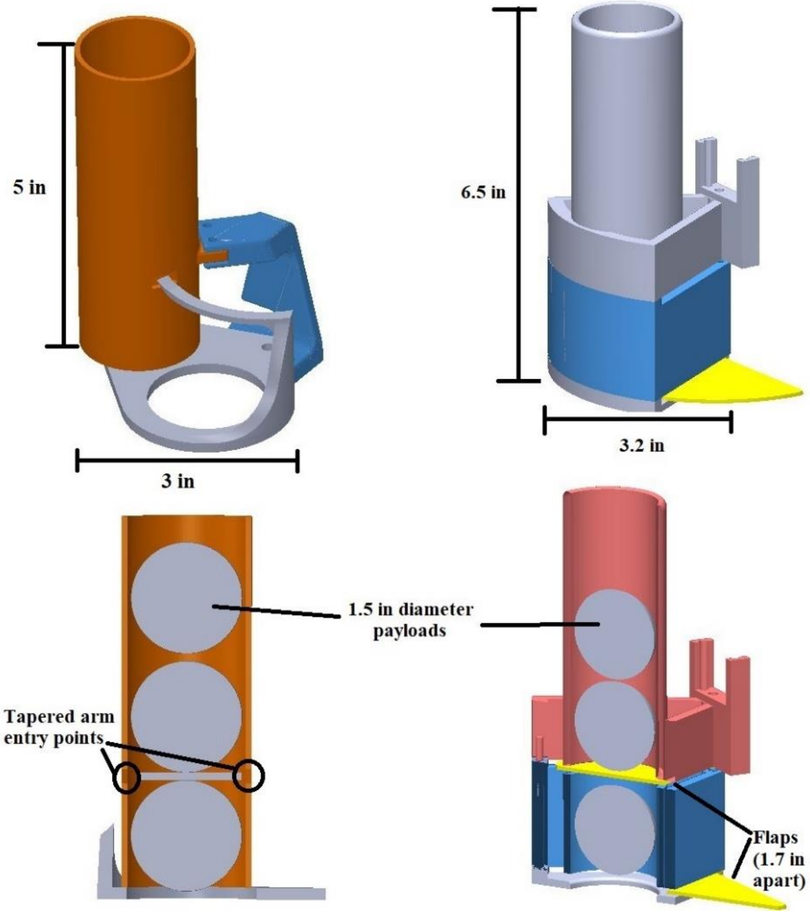

Fig. 2: Design challenge solutions produced by in-person (left) and remote groups (right)

For the design criteria of manufacturability, the scoring allocation of cost and time were meant to incentivize quick and cheap prototype production. Part cost included unit price of each part and a $20/kg model for 3D printing. The remote group required the purchase of a 36 in. x 1/8 in. steel rod (of which just over 10 in. were used for dowels) and an adhesive (which could not be converted to a unit cost and was not counted in the scoring as a part). The cost for 3D printing was less than $2 for each group, but this low price came with long print and post-processing times. Nearly eight hours of additive manufacturing for the in-person group and over 16 hours for the remote group constituted the bulk of the prototype generation time subscore, resulting in 2.5% and 0%, respectively. Both teams earned an additional 5% for an assembly time of under two hours.

The in-person group had a successful mission demonstration of their design solution. Each of the three rolled-up paper balls individually dropped straight down from a height of four feet. This carried into the reliability test, where the servo was actuated ten times rapidly (compared to the mission test) without the paper balls in place. No degradation of performance or parts were evident. In total, the in-person group received the full remaining 70% for a total of 88%. The remote group, however, was not as successful. A flaw in the design caused the servo attachment to lodge in a cavity of the 3D-printed paper ball housing, preventing a proper motion to release the payloads. Additionally, the adhesive that was used to convert the rotation of a dowel to the movement of a release flap was not set as intended and became loose during the abrupt servo motion. This resulted in failing the mission test, as well as the first actuation of the reliability test. None of the remaining points were awarded to the remote group, finishing with 18%.

4.2 Expectations of Success towards Engineering Statements

Table 10: Average success expectancy responses to engineering statements

Scale Item	In-Person Group Pre-Challenge Average	In-Person Group Post-Challenge Average	Remote Group Pre-Challenge Average	Remote Group Post-Challenge Average
ESSE5	8.5	8.5	8.5	8
ESSE6	6.5	9	8	8
ESSE7	7	8	9	8.5
ESSE8	8.5	9	8.5	8
ESSE9	7.5	9	7.5	8

ESSE10	5	6.5	7	7
ESSE11	5.5	7.5	6.5	7.5
ESSE21	7	8.5	8	7.5
ESSE22	8.5	9.5	9	9
ESSE26	9.5	10	8.5	8
ESSE13	7	7.5	7	7.5
ESSE15	8	8.5	7.5	7.5
ESSE18	6.5	8.5	7	7
ESSE20	7.5	9	7	8

Responses by both members of each group were recorded before and after the design challenge took place. The average responses for student expectations of success towards the fourteen engineering statements can be found in Table 10. These means were then separated by group and placed into bar graphs to highlight the changes perceived by participants. Fig. 3 corresponds to the remote group, which did not achieve a satisfactory design challenge score. Averages ranged from a low of 6.5 to a high of 9.

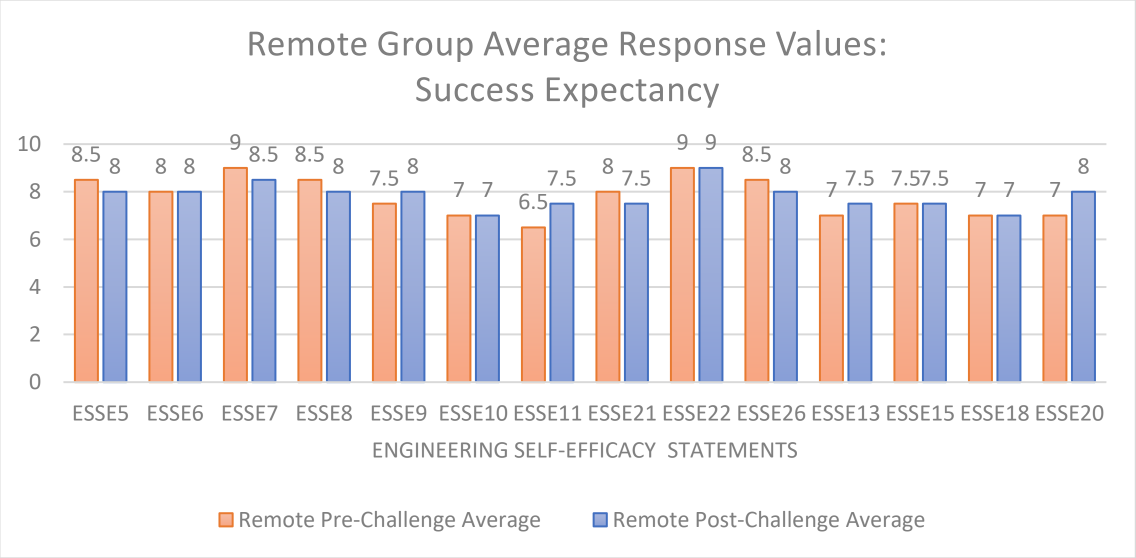

Fig. 3: Average remote group success expectancy responses to engineering statements

The in-person group, on the other hand, had a wider range of 5-10, which can be seen in Fig. 4. Two-tail paired t-tests revealed that these changes were significant for the in-person group ($p = 3.807$ e -5) but not for the remote group ($p = 0.807$). Two, two-tail two sample t-tests were also conducted to compare the two groups before and after completion of the challenge. There were expectedly no significant changes between pre-challenge scores ($p = 0.254$), whereas post-challenge responses were statistically significant ($p = 0.025$).

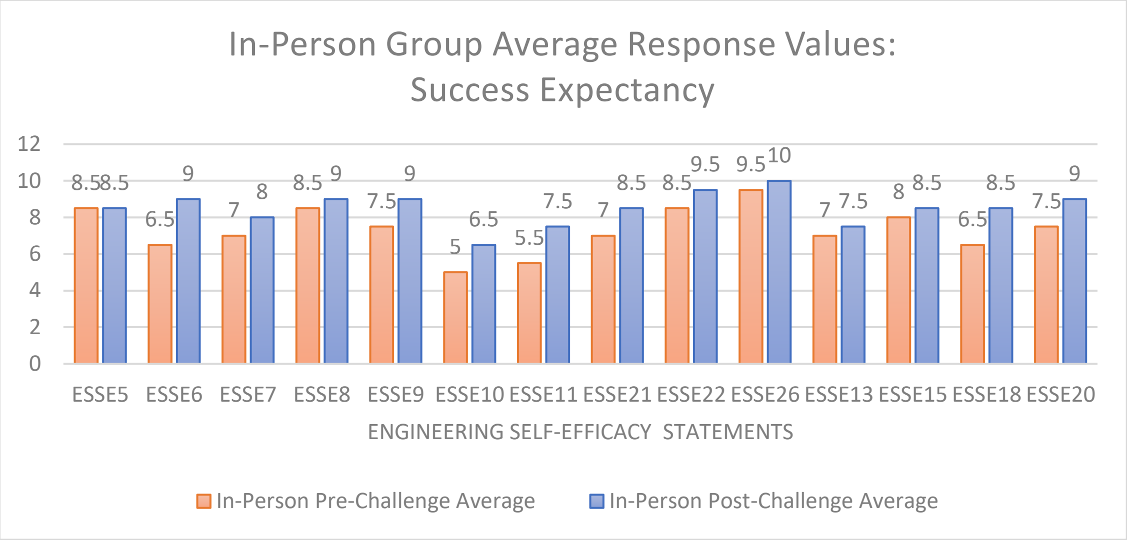

Fig. 4: Average in-person group success expectancy responses to engineering statements

The statements for which the remote group perceived higher expectations of success after the challenge include ESSE11 (*I can fix machines*), ESSE20 (*I can recognize changes when needed for a design solution to work*), ESSE13 (*I can identify a design need*) and ESSE9 (*I can work with machines*). The in-person group reported increased efficacy in thirteen of the fourteen task statements, especially ESSE6 (*I can work with tools and use them to fix things*) and ESSE18 (*I can evaluate a design*). Fig. 5 interprets this data using the magnitude of average response change difference between the groups. For example, the remote group decreased their expectation of success in manipulating components (ESSE21) by 0.5 pts, whereas the in-person group increased their perception in this task by 1.5 pts, which results in a difference magnitude of 2 pts. The largest difference, 2.5 pts, came from ESSE6 (*I can work with tools and use them to fix things*). Aside from ESSE13 (*I can identify a design need*), for which both groups perceived the same change, the in-person group had a larger increase (or lower decrease) in success expectations for each task. Appendix D contains additional graphs that arrange engineering self-efficacy statements arranged by descending average response values for each portion of the scale.

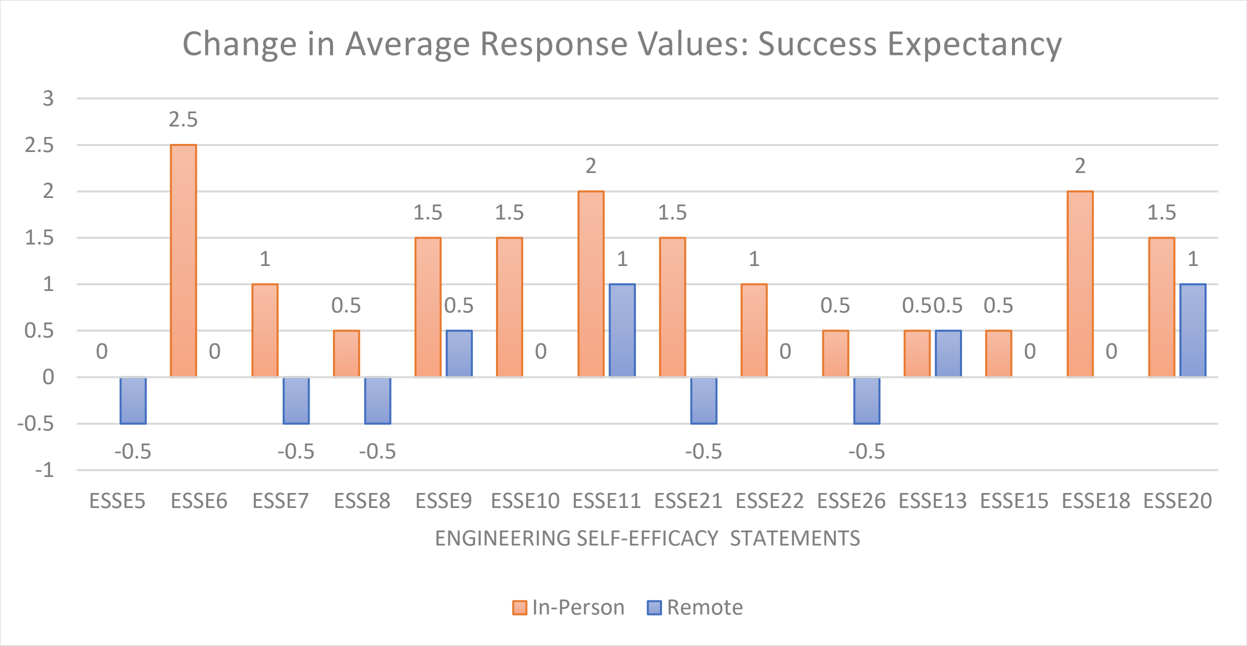

Fig. 5: Change in average success expectancy responses to engineering statements

4.3 Anxiety towards Engineering Statements

Table 11: Average perceived anxiety responses to engineering statements

(Red: average group response calculated using zero for empty response)

Scale Item	In-Person Group Pre-Challenge Average	In-Person Group Post-Challenge Average	Remote Group Pre-Challenge Average	Remote Group Post-Challenge Average
ESSE5	1	2.5	1.5	0
ESSE6	1	1.5	1	0
ESSE7	1.5	3.5	**0.5**	0
ESSE8	2.5	**1**	**2**	1
ESSE9	**1**	**1.5**	**1.5**	0
ESSE10	3.5	2.5	0.5	0.5
ESSE11	2.5	2.5	1.5	2.5
ESSE21	**1**	1.5	0.5	0

ESSE22	**0.5**	**1.5**	1.5	0
ESSE26	**0**	**0**	2	3
ESSE13	1.5	2	2.5	0
ESSE15	1.5	**1**	2.5	0
ESSE18	3	1	2	1
ESSE20	**1**	2	2.5	0

Participants were shown the same engineering self-efficacy statements as before, but were now asked to respond with regards to perceived anxiety in carrying out the task. The averages of those responses are shown in Table 11. Bolded values in red boxes represent values that were averaged with zero due to one group participant not clicking on the slider to select a survey response value for the task. The survey's initial placement of the slider is on zero, thus the inactive or blank response is assumed to be zero as the participant may have left the response at this value to signify no anxiety, whereas other "zeroes" imply the value for that response was initially different. Again, average response values were placed in bar graphs to distinguish the change in responses according to group and task. This time, only the remote group had statistically significant changes from pre-challenge scores (p = 0.006). Both groups were statistically significant from each other after the challenge (p = 0.003).

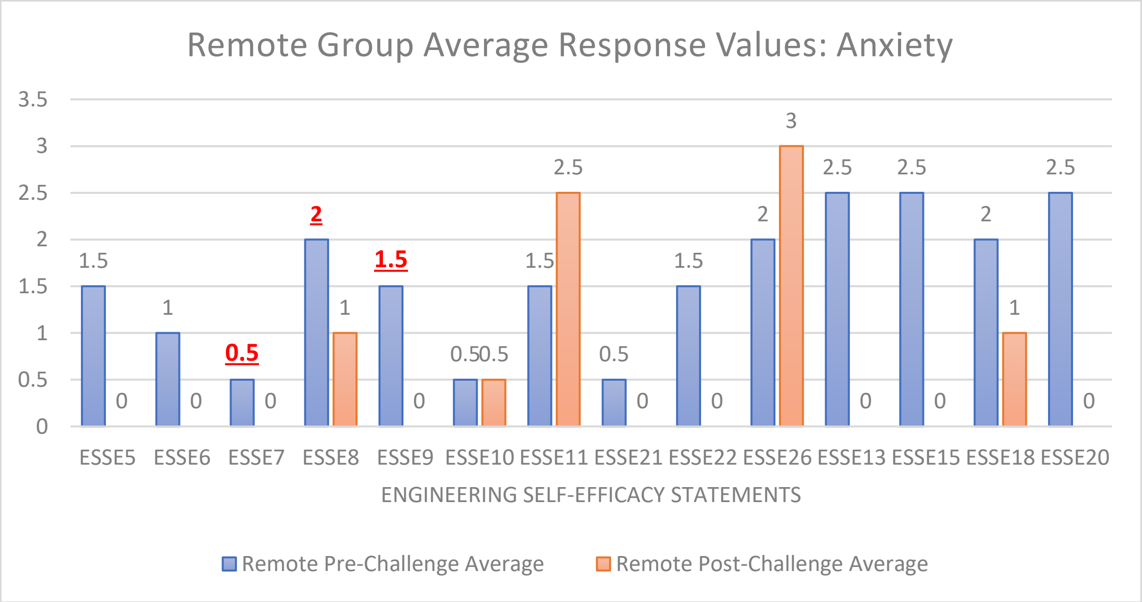

Fig. 6: Average remote group perceived anxiety responses to engineering statements

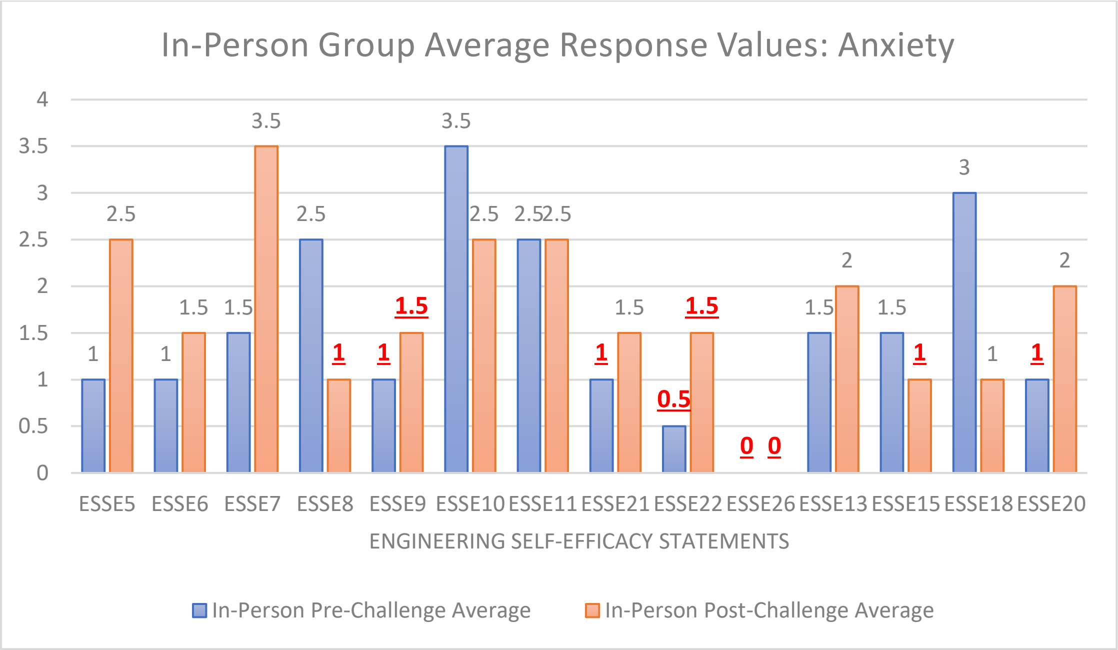

Fig. 7: Average in-person group perceived anxiety responses to engineering statements

The remote group post-challenge perceived lower anxiety towards engineering tasks more often than did the in-person group. In Fig. 6, nine of the fourteen tasks had perceived anxiety eliminated compared to the pre-challenge survey scores, as only ESSE11 (*I can fix* machines) and ESSE26 (*I can disassemble things*) raised anxiety for the remote group. The in-person group reported higher anxiety in eight tasks, including ESSE7 (*I can design new things*), ESSE5 (*I can work with tools and use them to build things*), and ESSE22 (*I can assemble things*), as shown in Fig. 7. The source of the largest magnitude of difference is ESSE20 (*I can recognize changes when needed for a design solution to work*), about which the remote group reported to have no more anxiety. Solving problems with computers (ESSE8) had the smallest difference between groups (Fig. 8).

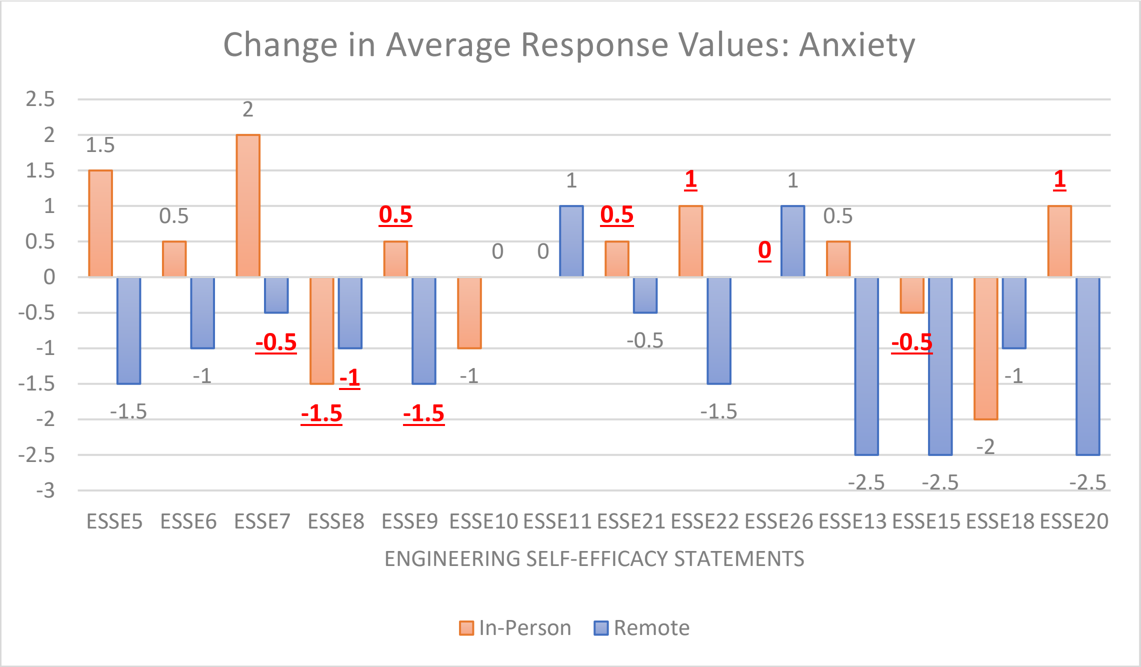

Fig. 8: Change in average perceived anxiety responses to engineering statements

4.4 Expectations of Success Regarding ABET Student Outcomes

Table 12: Average success expectancy responses to ABET student outcomes

Scale Item	In-Person Group Pre-Challenge Average	In-Person Group Post-Challenge Average	Remote Group Pre-Challenge Average	Remote Group Post-Challenge Average
Criterion 3.2	7	7	6.5	7.5
Criterion 3.3	7.5	6.5	5	6.5
Criterion 3.4	8	7	7.5	7.5
Criterion 3.5	8.5	7.5	9	6.5
Criterion 3.7	8	8	7.5	7.5

Participants were again asked to consider expectations of success in their responses, however, the survey items had changed from engineering statements to student outcomes (Criterion 3) listed by the ABET. Paired t-tests of the average values shown in Table 12 indicate no significant changes for either group (remote, p = 1; in-person, p = 0.071) or between groups (pre-challenge, p = 0.366; post-challenge, p = 0.785). Both groups exhibited similar behaviors for Criterion 3.5 (*team leadership*, decrease) and Criterion 3.7 (*learning strategy*, no change) (Figs. 9-10).

Criterion 3.3 (*communicate*) was the source of the largest gain between the two survey administrations for the remote group, as well as the largest discrepancy between the two groups (Fig. 11). In-person participants, however, generally reported lower success with criterions 3.3, 3.5 and 3.4 (*ethical solutions*).

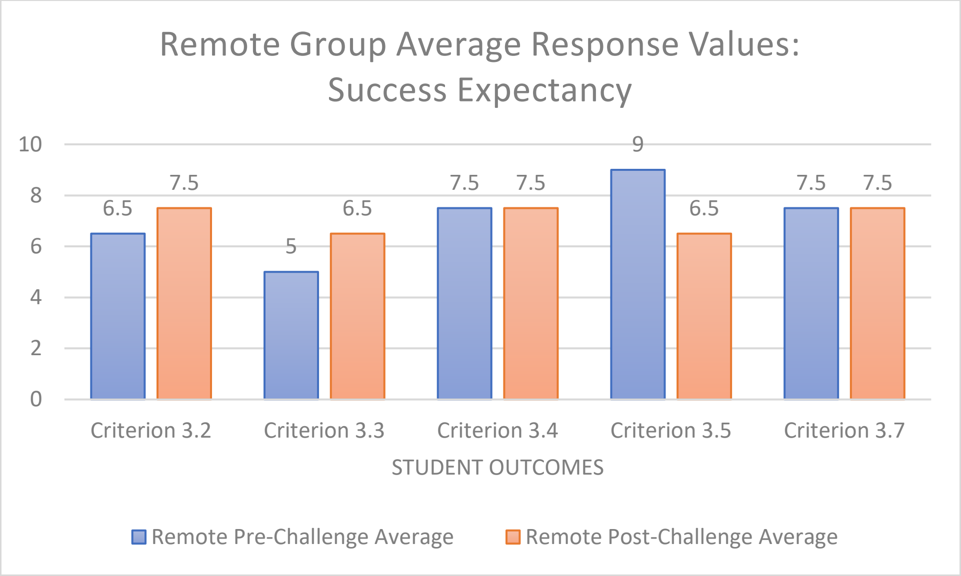

Fig. 9: Average remote group success expectancy responses to ABET student outcomes

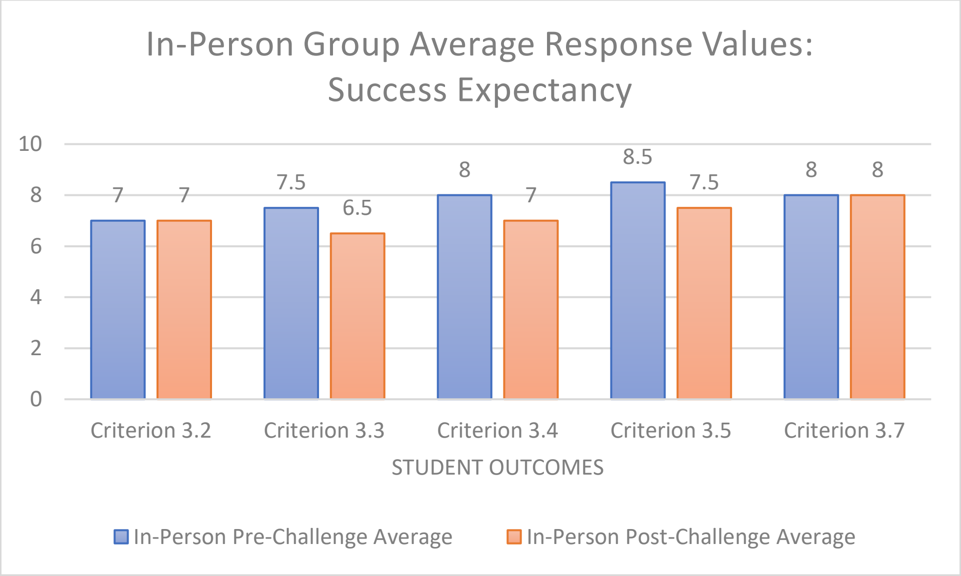

Fig. 10: Average in-person group success expectancy responses to ABET student outcomes

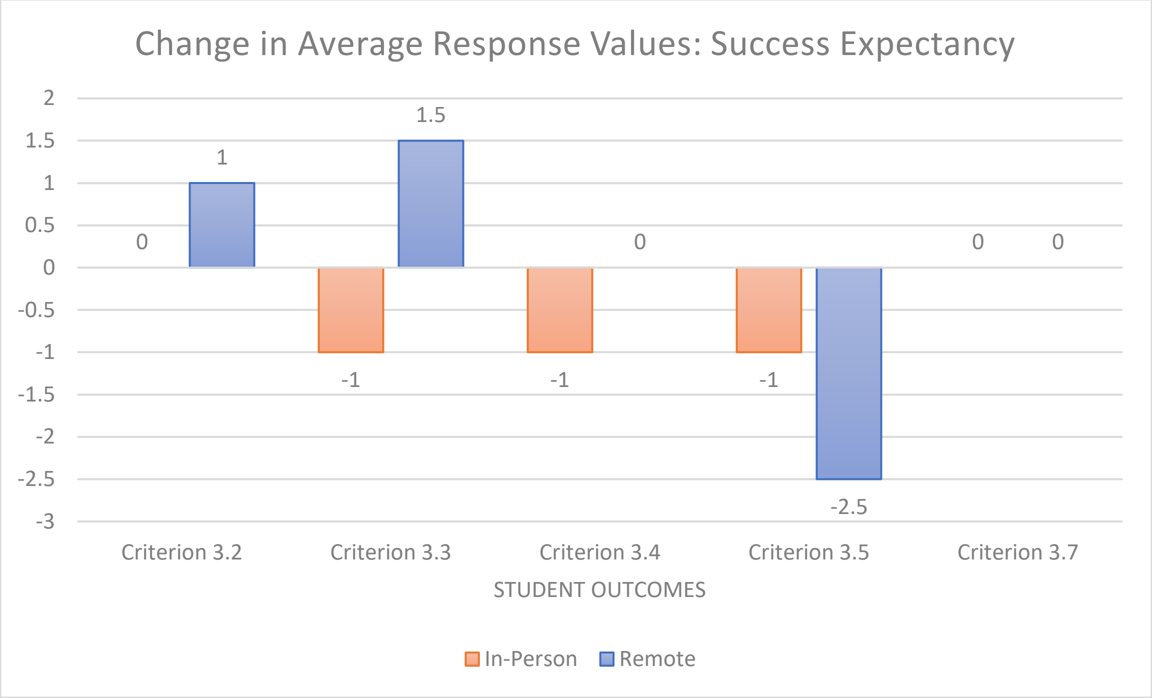

Fig. 11: Change in average success expectancy responses to ABET student outcomes

4.5 Engineering Design Process

Participants were asked to arrange steps of the engineering design process to the best of their ability. Steps were presented alphabetically to observe the effect of this arrangement on participant ordering. Table 8 lists the order of the process used by Schubert et al. in his study of freshman engineering students without prior design experience [20]. The results from the surveys are found in Table 13. The correct order is listed in the far-left column and the order selected by each participant is listed in their respective column, with row position corresponding to estimated design process step position. For example, remote group member #1 (Remote 1) correctly assigned *identify the problem/product innovation* to the first position (which is why that cell is shaded green), but incorrectly placed *communicate and specify*, the eighth step, just below it. The letters Y and Z represent responses before and after the design challenge, respectively.

Each participant correctly matched a step at least once in the pre-challenge survey. Although a complete match of the engineering design process order was not achieved, participants occasionally matched up sequential pairs of steps. In the post-challenge survey, in-person participant #1 (In-Person 1Z) correctly placed *brainstorm/generate creative ideas* before *analyze*

Table 13: Participant responses to ordering engineering design process before (Y) and after (Z) design challenge completion

Correct Process Order	Remote 1Y	Remote 2Y	In-Person 1Y	In-Person 2Y	Remote 1Z	Remote 2Z	In-Person 1Z	In-Person 2Z
1	1	6	4	4	1	4	7	4
2	8	4	1	5	8	1	4	5
3	3	2	3	6	2	7	5	8
4	2	7	5	1	3	5	8	6
5	4	5	7	9	4	2	1	9
6	5	3	8	7	6	3	6	1
7	7	1	2	8	10	6	2	10
8	6	9	6	3	5	8	3	3
9	10	10	10	2	7	9	10	7
10	9	8	9	10	9	10	9	2

potential solutions, even though this pair was not perfectly aligned with the Schubert et al.'s ordering. Half of the respondents kept four of the step positions in agreement with their previous survey response. Each step was correctly placed at least once throughout both surveys, except for brainstorming (step #4) and defining criteria/goals (step #2). Brainstorming was most often estimated to be the first step (four times out of the eight responses), while steps #9 (*implement and commercialize*) and #10 (*perform review and assessment*) were consistently switched in those positions.

4.6 Correlations

Schar et al. used the Pearson correlation coefficient, r, to determine test-retest validity [36]. For this study, the test-retest reliability was done by group and by scale section. A Pearson coefficient was calculated using average group response values to compare scores before and after the design challenge was conducted. A returned value of 1 signifies positive correlation, while a value of -1 implies negative correlation. A p-value was derived from the Pearson coefficient calculation to determine if the correlation was significant. The r- and p-values can be found in Table 14. Both the remote and in-person groups had positive and significant correlations in the survey portion regarding expectations of success in engineering tasks (r = 0.769, p = 0.001 and r = 0.815, p = 0.0004, respectively). The remaining correlations in the matrix trend toward nonexistent and insignificant.

Table 14: Test-Retest validity between survey administrations (group and scale section) (Green = statistically significant)

	Success (Engineering Tasks)	**Anxiety (Engineering Tasks)**	**Success (Student Outcomes)**
Remote	r = 0.769 p = 0.001	r = 0.151 p = 0.607	r = 0.062 p = 0.921
In-Person	r = 0.815 p = 0.0004	r = 0.281 p = 0.331	r = 0.539 p = 0.349

Carberry et al. observed significant correlations between self-efficacy and motivation, outcome expectancy (r = 0.779 and r = 0.919, respectively) and anxiety (r = -0.593), the idea being that more engineering experience can reduce anxiety to a minimal amount. In this study, success and anxiety were tested for correlations according to group type before and after the design challenge, as shown in Table 15. Both the pre-challenge and post-challenge survey responses from the remote group indicate a slight negative, but insignificant, correlation. A stronger and statistically significant negative correlation was found in the two average survey responses from the in-person participants (pre-challenge: r = -0.703, p = 0.005; post-challenge: r = -0.663, p = 0.009).

Table 15: Correlations between engineering statement success expectancy and perceived anxiety responses (Green = statistically significant)

	Remote Group	**In-Person Group**
Pre-Challenge	r = -0.292 p = 0.311	r = -0.703 p = 0.005
Post-Challenge	r = -0.188 p = 0.519	r = -0.663 p = 0.009

4.7 Scale Reliability

Table 16: Scale portion reliabilities before and after removal of low-value items (Green: strong reliability; Red: weak reliability; Black: sufficient reliability)

	Success (Engineering Tasks)	**Anxiety (Engineering Tasks)**	**Success (Student Outcomes)**
Pre-Challenge	Original α = 0.340 Revised α = 0.805 (ESSE10, ESSE21, ESSE26, ESSE15 and ESSE20 removed)	α = 0.818	α = 0.899
Pre-Challenge (ESSE10 and ESSE26 removed)	α = 0.641	α = 0.920	
Post-Challenge	Original α = 0.697 Revised α = 0.826 (ESSE6, ESSE7, ESSE10 and ESSE26 removed)	α = 0.906	Original α = 0.787 Revised α = 0.816 (Criterion 3.7 removed)
Post-Challenge (ESSE10 and ESSE26 removed)	α = 0.785	α = 0.960	

Bandura's guidelines state that a Cronbach alpha of at least 0.8 is necessary for a scale to be considered "good" [25]. Should the value be under this threshold, removing statistically irrelevant items will increase reliability. Schar et al. used this method to get an instrument with as few items as possible while not sacrificing reliability [36]. A two-way ANOVA between remote and in-person responses was conducted across the three main portions of the survey. The results are located in Table 16. Pre-challenge responses between the two groups indicate naturally (un-edited) strong validity when measuring engineering task-based anxiety and student outcome-related success. However, reliability in measuring expectations of success in engineering tasks was weak (α = 0.340). A process of elimination, starting with high variance items, found that by removing ESSE10 (*I can build machines*), ESSE21 (*I can manipulate components and devices*), ESSE26 (*I can disassemble things*), ESSE15 (*I can develop design solutions*) and ESSE20 (*I can recognize changes when needed for a design solution to work*), the Cronbach alpha increased to α = 0.805. Similarly, removing ESSE6 (*I can work with tools and use them to fix things*), ESSE7 (*I can design new things*), ESSE10 and ESSE26 from the same portion of the post-challenge questionnaire raised α from .697 to 0.805. The same method was applied to the student outcome expectancy portion of the post-challenge questionnaire, where α climbed to 0.816 after the removal of Criterion 3.7 (*acquire and apply new knowledge as needed*).

Since the removal of scale items ESSE10 and ESSE26, along with other items, contributed to the increase in reliability in both the pre- and post-challenge surveys, another two-way ANOVA was conducted with those two items removed alone. As a result, Cronbach alpha values increased markedly. Anxiety-related responses in both survey administrations cemented a strong validity, going from α = 0.818 and α = 0.906 to α = 0.920 and α = 0.960, respectively. The largest jump (88%) is attributed to pre-challenge success expectancy responses to engineering tasks, although this new alpha of 0.641 is still not considered acceptable. The reliability of post-challenge responses to the same scale items saw a less substantial increase from 0.697 to 0.785, which is considered technically acceptable, but not “good,” as prescribed by Bandura.

5. DISCUSSION

5.1 Design Challenge

The design solutions submitted by both groups similarly employed a two-point system, where one point prevents remaining payloads from falling while another point drops the intended payload. This was the solution to the mission success constraint that no more than one paper ball at a time may fall. Even though the groups came to this same design conclusion, their executions differed. The remote group attempted an alternating approach, having two flaps offset by 1.7 inches and 60° that never overlap. Starting from rest, the intent was to have the top flap, firmly inside the housing, rotating clockwise and horizontally to release one paper ball into a temporary space, during which the lower flap, also rotating clockwise from an initial position outside the housing, would “catch” this payload and close off the temporary space, thus ending the first half of the first servo actuation. In the second half, the flaps move towards their rest positions, with the lower flap making way for the temporary payload to drop and the top flap holding back remaining payloads. Due to a servo motor jam and a weakening of the adhesive, this did not occur, but another flaw would have presented itself. This design requires rapid actuation to prevent remaining payloads from descending too far before the top flap catches it, and if not timed correctly, flaps would jam against the paper balls and further weaken the adhesive converting servo motion to flap rotation. Aside from this, three dowels were used for structure between the three housing parts. This could have been reduced to two, but with the current design criteria, this would have given them the same complexity score.

The in-person group used a simultaneous approach to the two-point system. The lower plate has a tapered arm that slightly coils above it and is intended to move along with it, since they derive from the same part. Additionally, this plate contains a hole to allow desired payloads drop, where the top surface is flush with the bottom of the stationary paper ball housing. As the plate rotates clockwise and horizontally, the tapered arm enters through one payload housing slot, designed for its cross-section, and peeks through the slot on the other side for an uninterrupted 90° rotation. These slots are placed approximately 1.5 inches from the bottom of the housing, meaning that when operated correctly, the tapered arm separates the lower 1.5-in diameter payload from those that are not meant to be dropped. The plate was deliberately designed to simultaneously align its hole with the payload of interest during this time, and since the tapered arm is continuously preventing other payloads from descending, only one will be allowed to drop. To the surprise of the in-person group member present to test the design, each of the three payloads successfully and individually dropped, surpassing the minimum of two paper balls. This was the correct approach to utilizing a two-point system, as it guarantees individual deployments and could even be done at a slower servo rotational speed. The only downside to this design was the inclusion of too many parts, specifically four nuts and four screws. Reviewing the design shows that this amount was redundant and that a future iteration could reduce these parts in half to add at least 3% to the group's complexity score.

3D-printing parts took a significant portion of each group's prototype generation time, which hindered their manufacturability scores. Given that rapid, proof-of-concept prototypes for class assignments typically rely heavily on additive manufacturing, the design challenge rubric was updated to take the lengthy printing process into account so that teams are not penalized to this degree. As a result, the maximum allotted time to receive any points in this subcriteria has been extended to 40 hours per iteration. All facets of prototype generation, including post-processing and assembly of parts, now falls under a unified prototype generation time subcriteria. Teams will still be incentivized to make a prototype quickly, especially under ten hours, but those who take longer will not be severely penalized. Those changes can be seen in Table 17.

Table 17: Update prototype generation time rubric

0%: 40+ hours
2.5%: 30 – 40 hours
5%: 20 – 30 hours
7.5%: 15 – 20 hours
10%: 10 – 15 hours
12.5%: 0 – 10 hours

Both groups produced similar designs and were given the same full points for originality for the sole reason that it was not what the researcher had expected to see. Removal of this subcriteria does not mean the participants in this pilot study did not make creative solutions, but the importance of considering the weight of automated mechanisms for drone applications merits its inclusion in an updated rubric. Therefore, “complexity” was replaced with “number of parts” and 20% was taken from “mission success” to create a “weight” design criteria, as shown in Table 18. Mission success was determined to be overvalued at 50%, given that it was worth as much as all the other previous design criteria combined.

Table 18: Updated design challenge rubric

Design Criteria	Criteria Weight
Manufacturability	**20%**
• Part cost	7.5%
• Prototype generation time	12.5%
Number of Parts	**10%**
Weight	**20%**
Mission Success	**30%**
Reliability	**20%**
Total:	**100%**

5.2 Success and Anxiety

Having two different design challenge outcomes creates a basis for understanding how project experience may impact self-efficacy aspects, albeit with a small sample size. Regarding expectations of success in engineering tasks, the average in-person group response values after challenge completion increased for all ESSE items except for ESSE5 (*I can work with tools and use them to build things*), which saw no average change. Conversely, the remote group experienced post-challenge increases (four items), decreases (five items) and no change (five items) in almost equal parts. It was not assumed that a low design challenge score would result in decreased expectations of success across the board, thus this variety of response changes provides insight into areas for improvement.

The remote group relied on a third-party to assemble and test their design, so decreases in average group response to ESSE7 (*I can design new things*), ESSE8 (*I can solve problems using a computer*) and ESSE21 (*I can manipulate components and devices*) are understandable because participants may feel they lacked the proper conceptual knowledge to produce successful design solution plans. Most change values for this group were half a point, with the largest gain, one point, coming from the abilities to fix machines (ESSE11) and recognize necessary design changes (ESSE 20). This was apparent during the Zoom demonstration, as participants were already discussing the failure point and how they would remedy it. The largest disparity between groups was the magnitude of change in their average response value to ESSE6 (using tools to fix things). The remote group had no change (as they did not use tools), whereas the in-person participants added 2.5 pts., using tools to fix their design when assembly was first done incorrectly.

Post-challenge responses towards anxiety in engaging in engineering tasks produced interesting results. The remote group, which received a low design challenge score, mainly lowered or eliminated their perceived anxiety, while the in-person group, producers of a winning design solution, mostly did the opposite. Interestingly, the group's largest gain in this metric was in response to item ESSE7 (*I can design new things*). This is at odds with ESSE15 (*I can develop design solutions*), ESSE18 (*I can evaluate a design*) and ESSE10 (*I can build machines*), scale items that had lower perceived anxiety. A possible reason behind this cognitive dissonance is that creating a new design from scratch can often seem more daunting than progressing from an established starting point. It is impossible to evaluate, build and develop (improve) a design that does not exist in the first place. The ability to recognize necessary design changes (ESSE20) was the source of the largest magnitude of change between groups. As explained before, the remote group was able to notice a flaw in their design immediately and would focus on that for a future iteration if given the chance. The in-person group produced a perfect design solution, so finding room for improvement, while not impossible, would prove difficult.

Participants responded to five ABET student outcomes in terms of expectations of success. The remote group average responses include increases (two items), a decrease and no change (two items) from pre-challenge responses. The in-person group had no increase in success expectancy, but a decrease in average response values were observed for Criterion 3.3 (*communicate*), Criterion 3.4 (*ethical solutions*) and Criterion 3.5 (*team leadership*). The benefits of an in-person collaboration, as lamented by remote participants, are immediate and clear communication and group effort. No indication was given by either participant of the in-person that the team dynamic was strained during the course of the study, and the same can be said for the remote group, which also reported a lower response average for this criterion. It is worth mentioning that participant responses are most likely not a reflection on their group member and that while the engineering task statements in the earlier portion of the scale are individualized, the ABET student outcomes require respondents to consider other people (communication, teamwork, and global impact of design choices).

5.3 Engineering Design Process Ordering

As Carberry et al. notes, there is no consensus on what constitutes the engineering design process [41]. In fact, the wording, ordering and number of steps used in that study differs from those used by Schubert et al., which was the basis for this thesis [20]. *Implement and commercialize* and *define the working criteria/goals* are not mentioned in the Massachusetts Department of Education's engineering design process model (used by Carberry et al.). The participants in this thesis are undergraduates in aerospace engineering, mechanical engineering and computer science, programs with their own version of how to develop a solution. Initially, this lack of agreement was assumed to be the reason that only one of the four participants successfully placed *identify the problem/product innovation* as the first step. Informal post-challenge conversations revealed that the reason for this was the ambiguity of what was being asked. Preceding the alphabetized order of the engineering design process were instructions to rank the steps “to the best of your ability.” One participant understood this to mean a hierarchy of steps arranged by current skill level, i.e., their ability to brainstorm is higher than that of analyzing solutions, and so on. Another respondent followed the same line of thinking, adding that because the problem (the design challenge) was already defined, identifying it was no longer important as a first step, choosing to instead start with brainstorming. Therefore, the wording of scale items and instructions is crucial in obtaining data meant to measure student performance and, in the case of the ADDA, program quality.

Additionally, presentation can affect ordering bias. Schubert et al. noted that when the engineering design process steps were arbitrarily presented alphabetically (*Analyze potential solutions, Brainstorm/generate creative ideas, Communicate and specify*…), 8.5% of the participants in that study entirely followed the steps in this order, and another 10% changed course after brainstorming. Since this presentation format was employed in this thesis study, this may explain why brainstorming (Step #4) was often selected first instead of identifying a problem, especially since analysis of potential solutions (Step #5) cannot occur first. A solution to this would be to have steps be strewn around on a page (similar in fashion to puzzle pieces fall out of the box and onto the table) with no immediate relationship evident between any two steps. This forces participants to fully read and organize each step.

5.4 Correlations

A test-rest reliability experiment was conducted to determine how effective the survey is when taken twice by the same population. A Pearson correlation coefficient, r, was used as the metric. The data suggests that the developed scale, in its current state, reliably and significantly measures respondent success expectancy towards engineering tasks between the two survey administrations, regardless of design challenge completion modality. The same cannot be said for tracking anxiety or success in ABET student outcomes, as no correlation could be concluded for either. Participants recorded interesting anxiety responses in the survey held after the design challenge, nearly or completely eliminating perceived anxiety (in the case of the remote-group) or doubling values after receiving a high score (as did the in-person group). This large shift in either direction from somewhat neutral pre-challenge responses may be the cause of low and insignificant correlations. As for the student outcome responses, the low number of scale items (five) could not allow for a more identifiable or significant trend. The remote group post-challenge responses indicated two increases, a decrease and two constant values over pre-challenge values, comprising a nearly even split of all possible changes (r = 0.062). The in-person group was in a somewhat similar situation, as average response values decreased in three scale items and held constant in two (r = 0.539).

Perplexing correlations between self-concepts (success expectancy and anxiety) were observed. In the first survey, both groups mainly responded with values in the 6-8 range for success expectancy towards engineering tasks, and in the 1-3 range for anxiety towards those same statements, implying a negative correlation. However, the in-person group had a stronger and statistically significant correlation (r = -0.703, p = 0.005) than the remote group (r = -0.292, p = 0.311). It was assumed that these values would be similar at that point in the study: either both groups show a correlation in scores, or neither do. The only knowledge that participants had by this point was the group to which they were assigned, which perhaps was sufficient to impact responses. Post-challenge data further results in interesting correlation behavior. In-person participants converted the confidence they felt in earning a high design challenge score into increased success expectancy responses across thirteen of the fourteen engineering tasks. This also somehow translated into higher-than-expected anxiety values for eight tasks. The remote group reported decreased values or no changes in success expectancy for ten of the tasks, while lowering anxiety for eleven. The post-challenge data, nonetheless, implies a medium-strength negative correlation for in-person responses (r = -0.663, p = 0.005), while remote participants had a slightly negative, but insignificant trend between success and anxiety (r = -0.188, p = 0.519). A larger sample size in either group modality would most likely produce more logical correlations, but the current data suggests a more reliable relationship can be observed between the two self-concepts when projects are conducted hands-on.

5.5 Scale Reliability

In developing a scale to measure undergraduate students' engineering self-efficacy, Mamaril removed items that seemed similar in content or language to other items [38]. For example, the scale in this thesis contains two items regarding fixing things (ESSE6 and ESSE11), two for building (ESSE5 and ESSE10), one for assembly (ESSE22) and another for disassembly (ESSE26). Therefore, the removal of half of these items is justified only if reliability of the scale is intact or improved. This was the case for success expectancy of engineering tasks portion of the post-challenge survey, where ESSE6, ESSE10 and ESSE26, along with ESSE7, were removed, bringing that portion to a more than acceptable validity range. Having similar items in the same scale not only unnecessarily adds to its length, but also may impact response accuracy. The participant may expend more effort in trying to decipher the researcher's intent in including similar items and assume that there is a difference when none actually exist. A review of the data shows that items of similar verbiage produced different response values in this thesis for each participant in each survey administration and in each portion. Statements with low item-total relationships are high priority removal items, followed by items that either do not encompass the intended metric or are not worth the additional time participants spend answering it. Scales need to be designed specifically to their target demographic, who may have other activities aside from participating in a study, thus only items that have merit should be included.

5.6 Participant Composition

The freshman and sophomore participants in this study were part of a larger group of students that was invited due to their technical background. Each student has experience with rapid prototyping using a CAD program, a 3D printer and an onboard computer of some kind (Arduino, Raspberry Pi, etc.), meaning no time would be lost to hardware and software tutorials. This put these participants technically on par with African Drone and Data Academy students, who are typically recent college graduates. However, technical parity is not sufficient to guarantee a successful and direct translation from American college students and their African counterparts. In the United States, although attending higher education is costly, students from low-income households can still make their academic goals a reality through scholarships or loans. In some parts of the world, such as in many African countries, education is a luxury usually reserved for wealthier families. With this lopsided representation of financially gifted program participants, what results is a lack of diversity in ideas, especially since underprivileged students have been known to develop creative solutions with whatever materials are available.

There is also a difference in priorities that exists between the pilot and target groups. The pilot group was comprised of first- and second-year students (18-20 years old) who had to balance completion of this design challenge with the demands of their other courses. ADDA participants are around 22 years old and would have more time to develop multiple prototype iterations and conduct any relevant research since they had already completed a university program.

Additionally, for any ADDA students that come from disadvantaged backgrounds, there is more incentive to gain as much as possible from the program to compensate for all the time and money that could have been spent supporting one’s family or participating in agricultural activities that require dedication and discipline. Most American students see attending college as a basic next step, and while this is not to say that this would cause them to not put as much effort into their studies, the overall cultural attitude towards higher education is expected to noticeably differ between the two groups.

The focus of this study has been to stress the importance of methodology over data due to the low sample size. Survey responses from only four participants are not sufficient to come to any logical and statistically-based conclusion, yet it does allow for an opportunity to expand upon the hurdles encountered in this study and how having more participants would minimize their influence on the data. Half of the participants left scale items blank at least once during the anxiety-based portion, leading to an assumption of a value of zero and averaging the response with that of their group member. With a larger sample size, these rare occurrences would no longer play such a dominant role that it changes the interpretation of the average group response. The same principle holds true for indecisive participants struggling to choose between two similar values (either six or seven, for example). However, if the majority of participants reported having this issue on specific scale items, the researcher would have to determine if that scale items needs to be amended (either reworded or removed) or if the average response does in fact represent the entirety of the sample size. For the latter, that could mean displaying an error bar on relevant graphs.

There is an unknown effect of the non-study-related ongoings of each participant. Schar et al. observed that students increased their engineering self-efficacy in the ABET student outcome most similar to the intent of the studied course, as well as additional outcomes [37]. The researchers of that study concluded that this may be due to students being concurrently enrolled in classes relevant to those surrounding outcomes. Considering that pre- and post-challenge surveys for this pilot study were completed a month apart, there were plenty of opportunities for background factors (approaching end-of-semester exams, projects and assignments) to skew results. This could be remedied by having more study participants, as doing so “averages out” the unique background events of a few individuals. If increasing the sample size is not feasible, a simpler solution would be to set strict deadlines for survey completion and shorten the time between administrations to reduce the likelihood of such events occurring.

6. CONCLUSION

The methodology presented in this thesis aims to provide a framework for engineering self-efficacy impacted by project-based learning activities that are not limited to geographic restrictions. The ability to cater to students who possess the ingenuity to engage in the construction and operation of drones regardless of physical location, for example, brings STEM fields closer to the goal of diversity and inclusion. The trend towards an online work environment that is just as productive as working in the office was already taking place before the COVID-19 pandemic, which only sped up its adoption after this year-plus-long preview. Research is limited in observing the unique intersection of project-based learning, self-efficacy and online learning modalities, where studies mainly focused on one or two of these factors at once. The goals of this thesis were to explore the research gap of comparing engineering self-efficacy between two learning modalities and lay the groundwork for a larger scale study, which have been achieved and where the latter is discussed in the “Future Work” section.

In conducting this small-scale study for validity, development of an engineering self-efficacy scale, design challenge, guidelines and rubric were the main priority. With a sample size of four participants divided into each of the two design challenge completion modalities, less emphasis was placed on the accuracy of the data, while the importance of a process in which to analyze this data in a manner that would improve future study iterations was stressed. Therefore, the clearest aspect ripe for improvement, should this study be repeated, would be to increase the number of study participants, which would have led to solving other survey response inaccuracies, such as responses unintentionally left blank, indecisive participants and the effect of background events happening between survey administrations. Increasing the sample size will not eliminate the presence of each of these three issues, but the extent to which they influence the data should be minimal.

The majority of literature concerning online distance learning concludes that there is no significant difference between online and in-person academic achievement. However, the limited data in this thesis points to the contrary for two of the three survey portions (not including the engineering design process order responses). The first success expectancy portion, regarding fourteen engineering task statements, had a p-value of 0.025 between the groups in the post-challenge questionnaire, while anxiety-based responses were even more significant ($p = 0.003$). The success expectancy towards ABET student outcomes, with its five included scale items, showed no significant difference ($p = 0.785$). Therefore, it is not statistically possible at this time to say that there is no difference between developing a mechanism hands-on and outsourcing design plans to a third party for fabrication and testing. Yet, the data that led to this conclusion cannot be assumed. The in-person group reported higher success expectancy alongside higher perceived anxiety, while the remote group reported opposite trends. These both counter the notion that building positive engineering experiences, such as successful project completion, productive collaborations and increased mastery of skills, generally leads to lowered perceptions of anxiety. Additional testing with a larger sample size is needed before confidently countering the consensus in literature of not only engineering self-efficacy, but that of online learning modalities, as well.

6.1 Future Work

Until sufficient testing has been conducted to merit use in university engineering courses, either after one design exercise or throughout the semester, the next suitable research application after this thesis is implementation in the African Drone and Data Academy (ADDA). Program participants have diverse educational backgrounds, technical skills and reasons for being enrolled. This variety will be incredibly useful in attaining widespread applicability, regardless of prior engineering experience. As a foundation, students are taught basic prototyping skills to prepare them for developing an automated drone mechanism, so utilizing the developed scales at discrete points throughout the program should be able to highlight these self-efficacy gains. ADDA students are first required to take a five-week online course that covers flight physics, coordinate systems, communications and computer vision concepts, among others, providing exposure to an online lecture environment that can be translated to engineering design for a future study.

6.1.1 Team Assignment

The average in-person ADDA course has at least 16 students and runs for six weeks. Outside of lectures, students work in groups to develop their automated mechanism for an end-of-course flight test. Ideally, each group is comprised of members that know how to use Solidworks, use tools, write programming code and test prototypes. No one group should be without members than can provide crucial skills. To prevent this, a questionnaire was constructed. Meant to be taken prior to the beginning of the in-person course, each student checks the boxes of the skills they possess and rank the offered design challenges in order of preference. Because the goal is to make sure each group is balanced and no two groups can work on the same challenge, some students may not receive the design challenge of their choice.

6.1.2 Online vs. In-Person

16 students can be broken up into four groups of four, where two groups ideate, fabricate, and test their design solutions in-person, while the other two groups outsource prototype fabrication and testing to a third-party who has access to the required materials and equipment. Since students simultaneously attend lectures, assigning online attendance to both one online group and one in-person group would further aid in determining a link between engineering self-efficacy and modality. Thai, De Wever and Valcke [5] tested four blends of learning environments that incorporated an online component and found an increase in academic self-efficacy in the "flipped classroom" format (lectures recorded and held online, with guided questions reviewed in-person).

6.1.3 Design Challenges

The in-person portion of the ADDA previously had only one design challenge that was used to gauge students' comprehension of the physical and digital concepts taught during both courses. While this provided uniformity in grading the final flight test, providing additional mission options that follow the same rubric would enhance originality and possibly increase engineering self-efficacy. The six newly-proposed options are an emergency drone parachute, a payload parachute, a net-deployment mechanism based on altitude, a water retrieval system, an enclosure for a Raspberry Pi-enabled camera, and a slingshot. The aim is to provide a challenge that matches the concepts taught in the course with a relevant problem to solve, such as developing an emergency parachute if a drone needs to descend quickly, or a slingshot to safely deter invasive animals from an area. One of the reasons why some students find project-based learning courses to be ineffective is due to what they see as an unrealistic premise, especially in regards to the challenge itself [12]. If a project topic aligns with the student's interests, or, at the very least, had a real-world application, the purpose becomes clearer and a higher engineering self-efficacy could follow suit. Groups will make three iterations of their prototype, using feedback from the instructors or third-party (for the online group) to enhance each design. The third iteration is the one that is properly scored during a flight test in the field. Scoring will follow the rubric used in this thesis, except for changes in what constitutes as a successful mission or a reliable mechanism.

6.1.4 Scale and Administration

The scale that was developed in this thesis is planned for use in the ADDA with select item removal and wording changes as needed. Additionally, the values assigned to statements in the different self-concepts will increase from 0 – 10 to 0 – 100, with the same 10-pt. slider interval structure in place. Students will also be given the ability to further distinguish between self-concept strengths by typing in a specific value between the 10-pt. intervals, such as 47 or 92. Survey respondents rarely select the extreme values on a scale, which would make a typical 5-pt. Likert scale unreliable [25], and being able to provide more response options can counteract this. Students will fill out the questionnaire six times: before the design challenge, after the design challenge, and four weekly surveys (not including the first week). This will be sufficient to track incremental changes in self-efficacy on a week-by-week basis and could determine which specific activities or concepts taught in lecture led to noticeable increases, or, when applicable, decreases. It will also track changes caused by feedback from each design solution iteration. As in this thesis, responses will be analyzed for reliability (a Cronbach alpha of at least 0.8) and correlation. The expansion of group types in the ADDA study would permit correlations between groups of the same type: online vs. in-person fabrication and testing, online vs. in-person lectures, and blended formats vs. “pure” formats.

7. SUMMARY

This thesis acted as a pilot study for a larger-scale study to be held in the future. The viability of completing a design challenge online was contrasted with a traditional in-person approach. A literature review indicated that online distance learning is generally as effective, if not more so, than in-person lecture attendance, with no significant difference between the two methods, and that successful engineering experiences increase overall engineering self-efficacy and minimize perceptions of anxiety. The limited data produced by the less-than-ideal sample size refuted both these claims, highlighting the importance of a satisfactory number of participants in any study.

With the statistically significant difference between the two methods, it is unclear which is better, but the consensus, as well as comments from remote group members, leads to the conclusion that the tried-and-true hands-on, in-person approach is preferred by engineering students. The lessons learned from this study were used in crafting guidelines for a larger-scale study: implementation at the African Drone and Data Academy. This includes removal of survey items that hinder overall scale reliability, a restructuring of the portion pertaining to ordering steps of the engineering design process and reducing the amount of time between survey administrations. Though this study did not produce the amount of data found in other self-efficacy or online learning experiments, its merit can be found in identifying research hurdles to avoid and providing the methodology necessary for successful and relevant data analysis.

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APPENDICES

Appendix A: Initial Design Challenge Criteria

Complexity: 10%

Originality: 3%

- **0%:** Not original
- **1.5%:** Somewhat original
- **3%:** Original

Number of Parts: 7%

- **0%:** 11+ parts
- **2.5%:** 8 – 10 parts
- **5%:** 5 – 7 parts
- **7%:** 1 – 4 parts

Manufacturability: 20%

Assembly Time: 5%

- **0%:** 4+ hours
- **2.5%:** 2 – 4 hours
- **5%:** 0 – 2 hours

Part Cost: 7.5%

- **0%:** $30+
- **2.5%:** $20 - $30
- **5%:** $10 - $20
- **7.5%:** $0 - $10

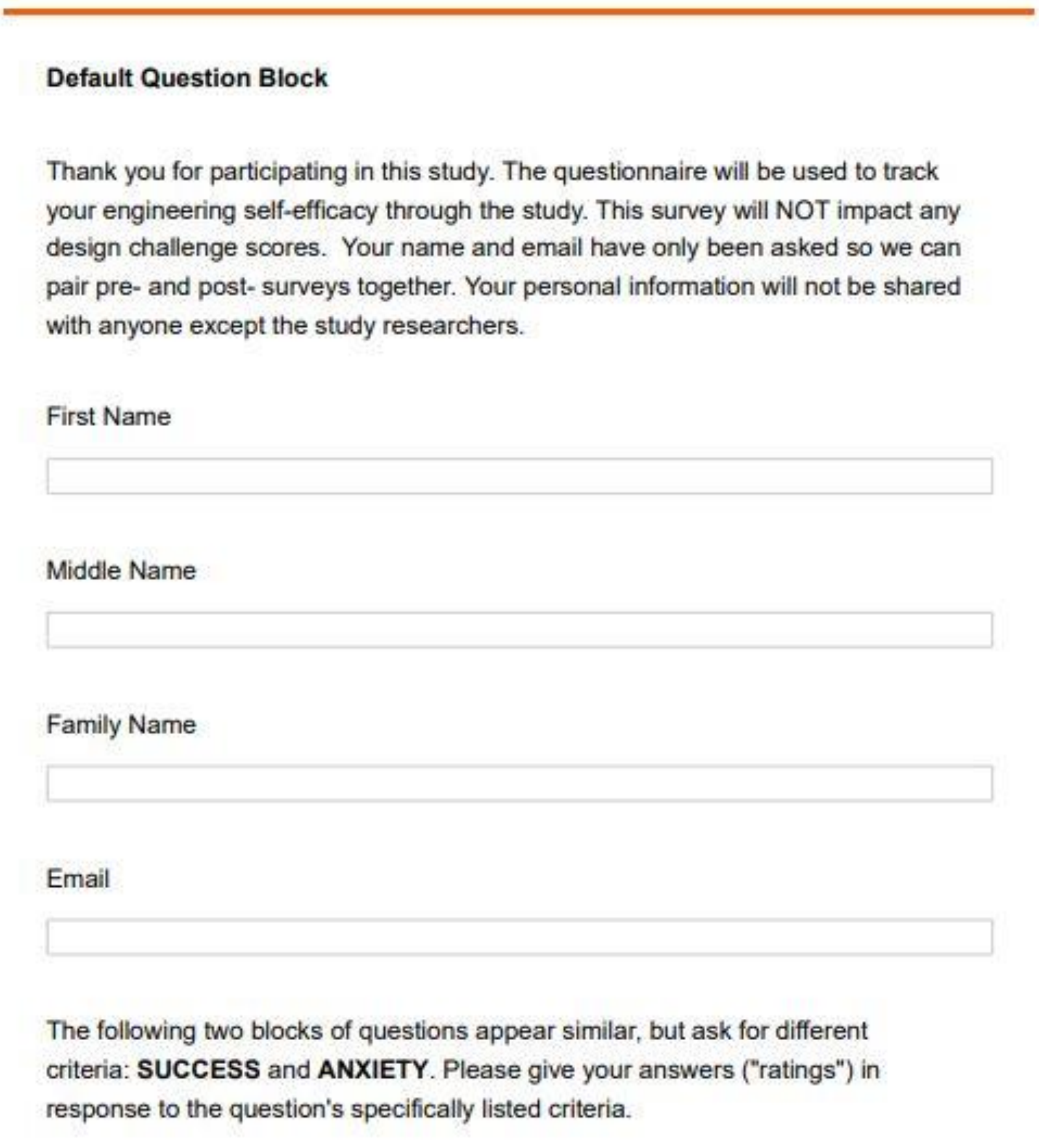
Prototype Generation Time: 7.5%

- **0%:** 20+ hours
- **2.5%:** 10 – 20 hours
- **5%:** 5 – 10 hours
- **7.5%:** 0 – 5 hours

Appendix B: Example Servo Script [60]

```
import RPi.GPIO as GPIO
import time

GPIO.setmode (GPIO.BOARD)

GPIO.setup(11,GPIO.OUT)
servo1 = GPIO.PWM(11,50)

servo1.start(0)
print("Waiting for 10 seconds")
time.sleep(10)

balldrop = 1

while balldrop <= 3:
    print("Dropping payload")
    servo1.ChangeDutyCycle(11)
    time.sleep(0.025)
    servo1.ChangeDutyCycle(11)
    time.sleep(1)
    print("Preparing payload")
    servo1.ChangeDutyCycle(6)
    time.sleep(0.025)
    servo1.ChangeDutyCycle(6)
    time.sleep(1)
    balldrop = balldrop + 1

time.sleep(1)
print("Resting at 0 degrees")

servo1.stop()
GPIO.cleanup()
print("Goodbye")
```

Appendix C: Post-Design Challenge Survey for Remote Participants



Default Question Block

Thank you for participating in this study. The questionnaire will be used to track your engineering self-efficacy through the study. This survey will NOT impact any design challenge scores. Your name and email have only been asked so we can pair pre- and post- surveys together. Your personal information will not be shared with anyone except the study researchers.

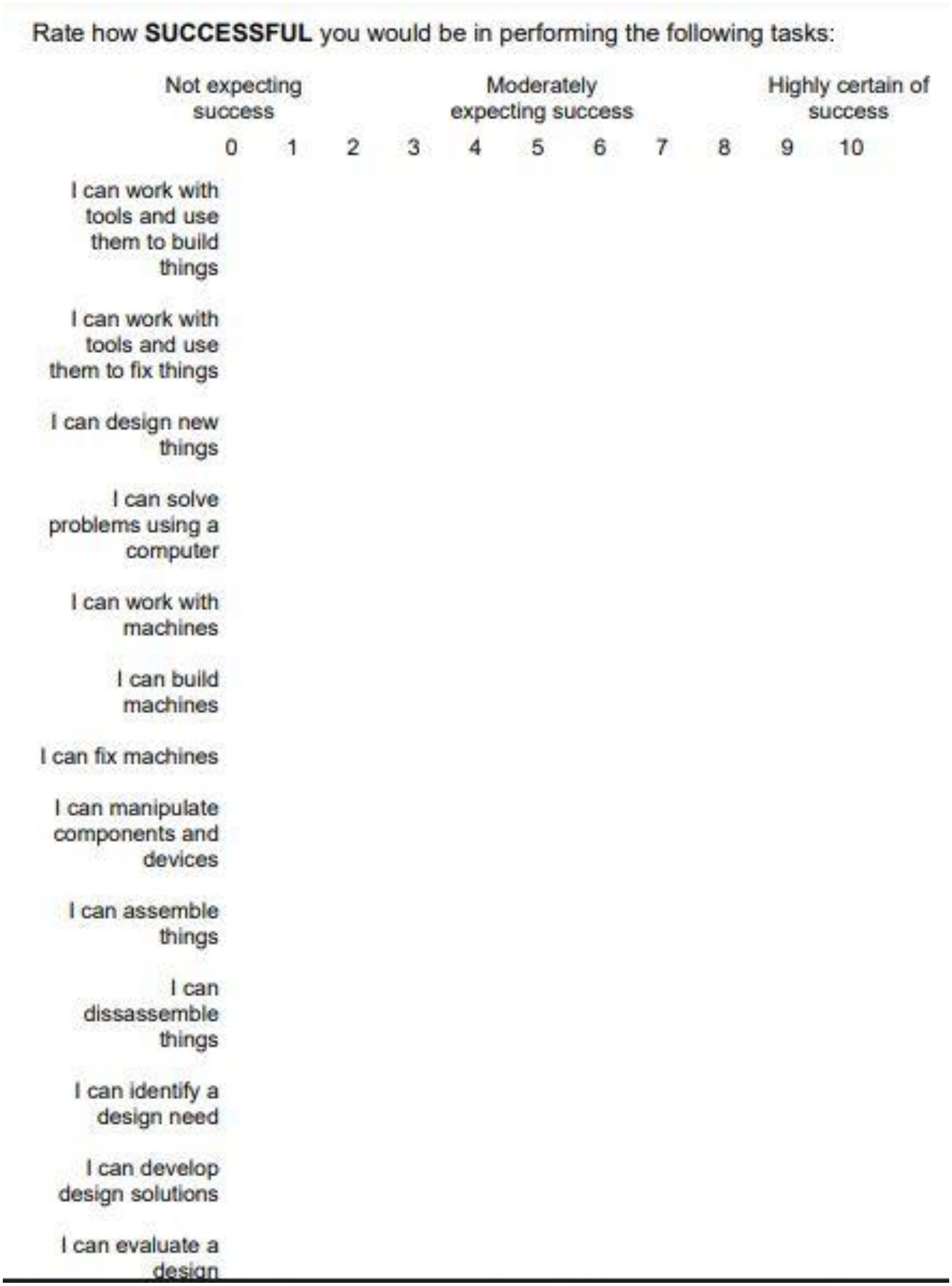
First Name

Middle Name

Family Name

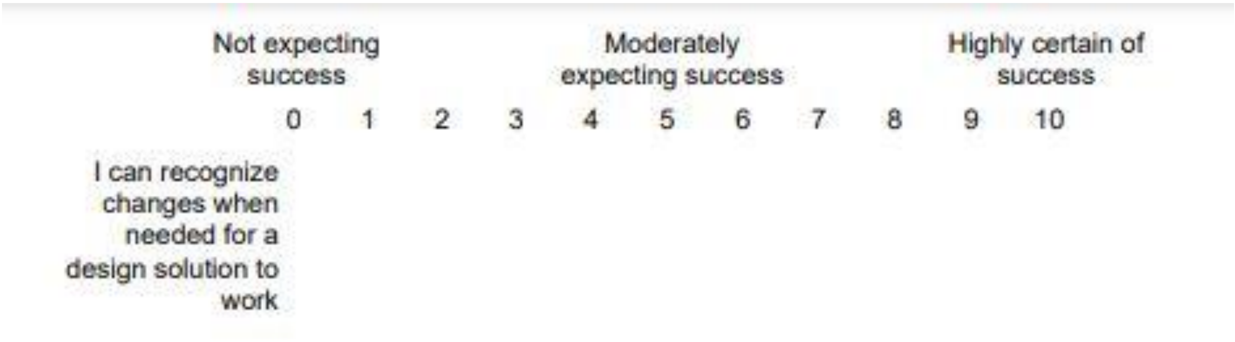
Email

The following two blocks of questions appear similar, but ask for different criteria: **SUCCESS** and **ANXIETY**. Please give your answers ("ratings") in response to the question's specifically listed criteria.

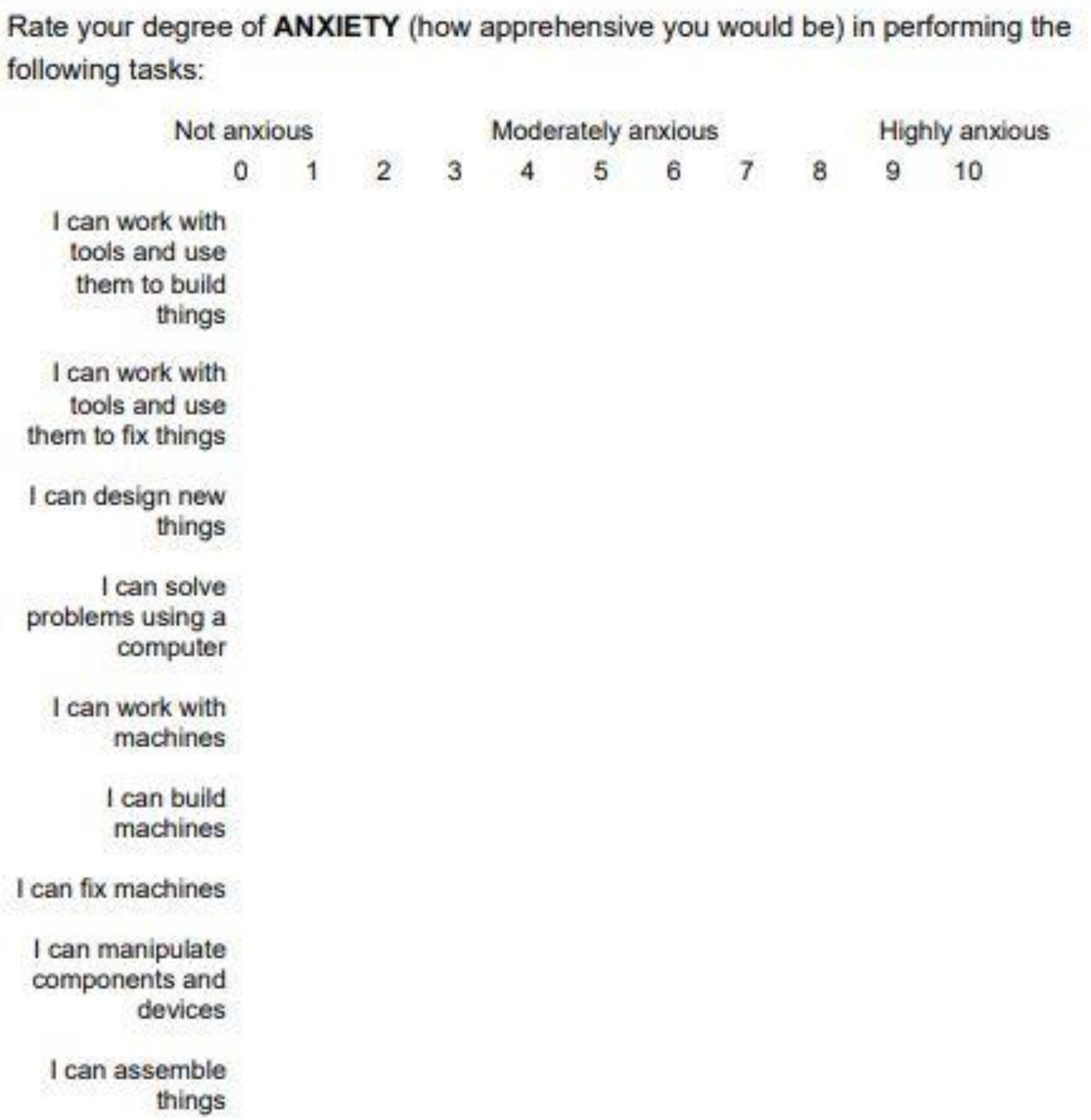


Rate how **SUCCESSFUL** you would be in performing the following tasks:

	Not expecting success					Moderately expecting success					Highly certain of success
	0	1	2	3	4	5	6	7	8	9	10
I can work with tools and use them to build things											
I can work with tools and use them to fix things											
I can design new things											
I can solve problems using a computer											
I can work with machines											
I can build machines											
I can fix machines											
I can manipulate components and devices											
I can assemble things											
I can dissassemble things											
I can identify a design need											
I can develop design solutions											
I can evaluate a design											

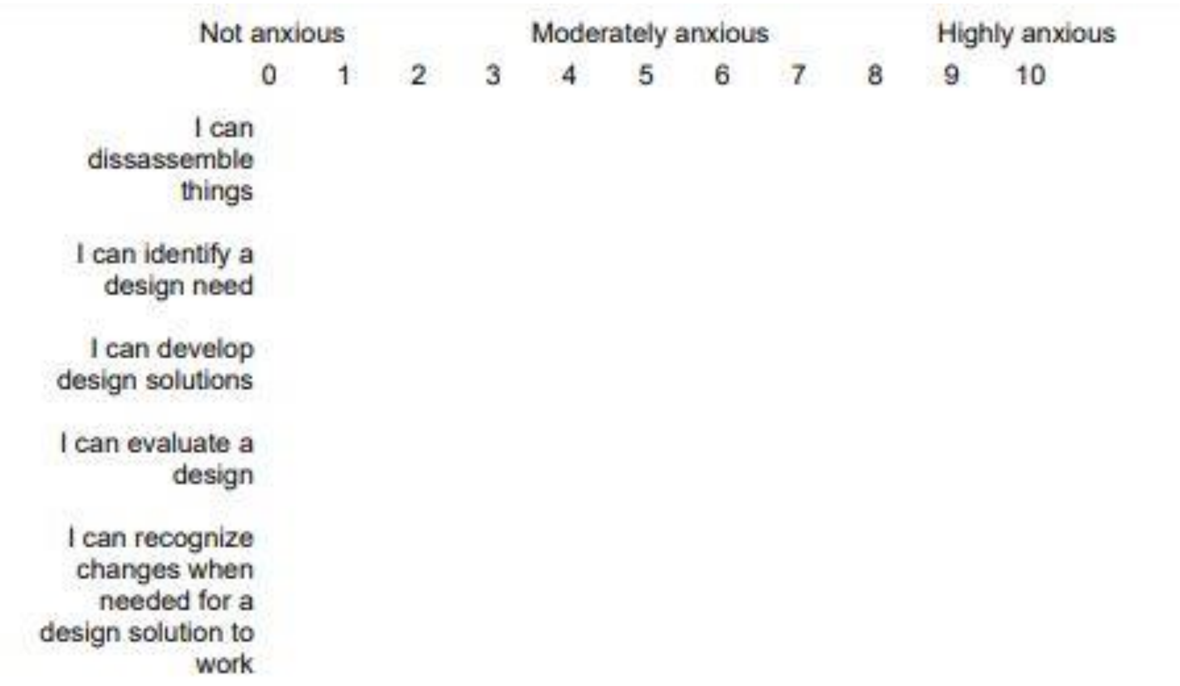


	Not expecting success				Moderately expecting success					Highly certain of success
	0	1	2	3	4	5	6	7	8	9	10
I can recognize changes when needed for a design solution to work											

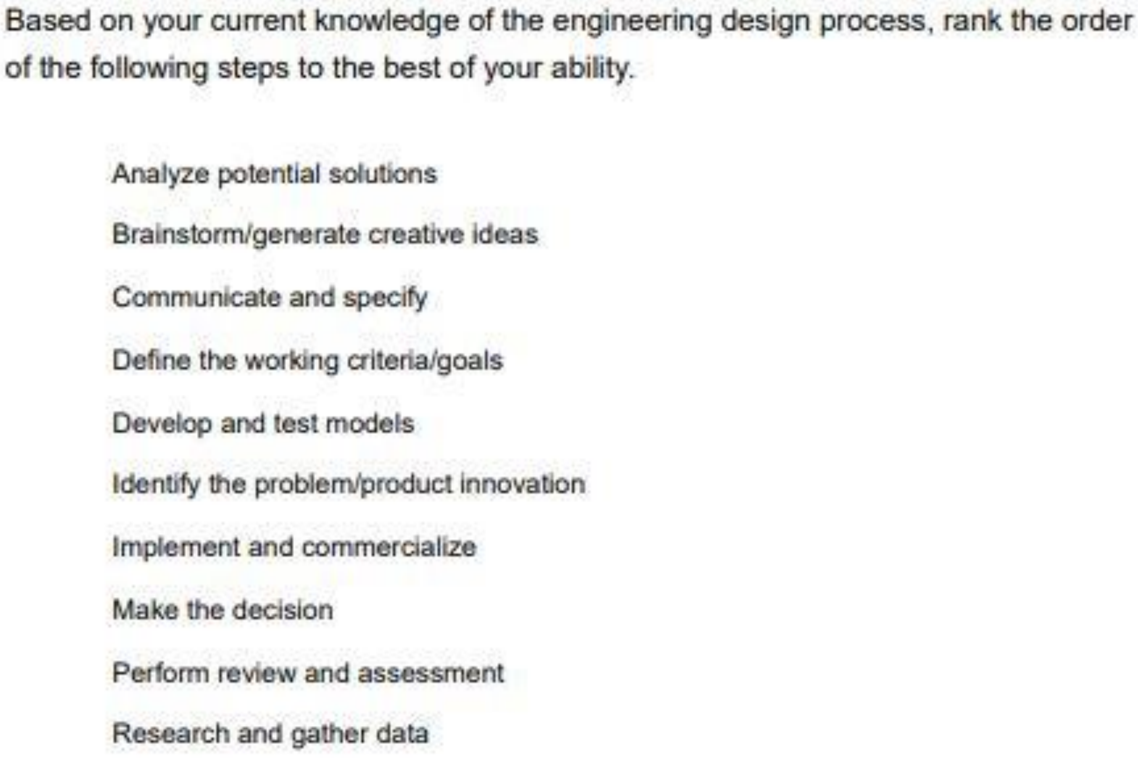


Rate your degree of **ANXIETY** (how apprehensive you would be) in performing the following tasks:

	Not anxious				Moderately anxious					Highly anxious
	0	1	2	3	4	5	6	7	8	9	10
I can work with tools and use them to build things											
I can work with tools and use them to fix things											
I can design new things											
I can solve problems using a computer											
I can work with machines											
I can build machines											
I can fix machines											
I can manipulate components and devices											
I can assemble things											



	Not anxious				Moderately anxious					Highly anxious	
	0	1	2	3	4	5	6	7	8	9	10
I can dissassemble things											
I can identify a design need											
I can develop design solutions											
I can evaluate a design											
I can recognize changes when needed for a design solution to work											



Based on your current knowledge of the engineering design process, rank the order of the following steps to the best of your ability.

Analyze potential solutions

Brainstorm/generate creative ideas

Communicate and specify

Define the working criteria/goals

Develop and test models

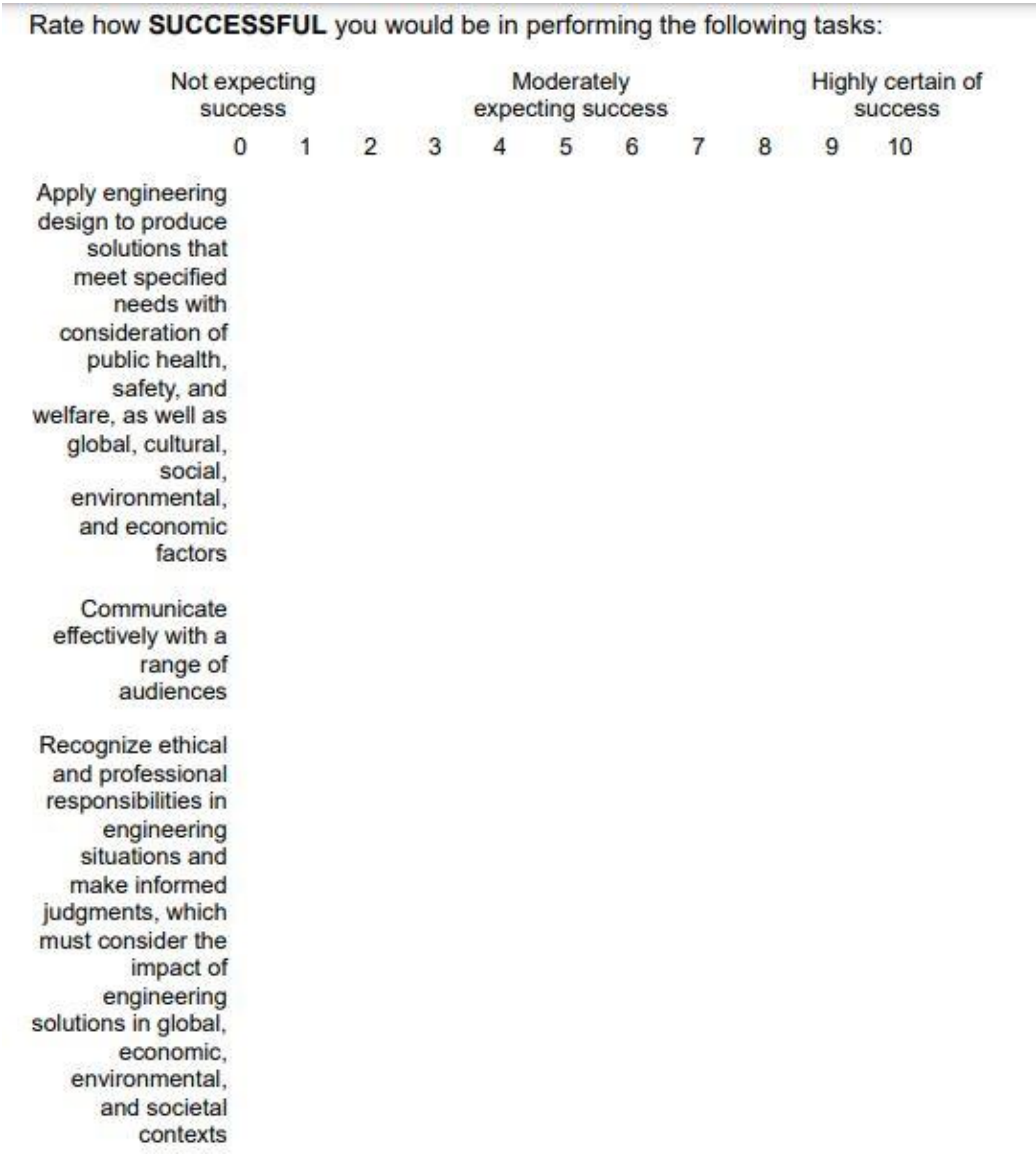
Identify the problem/product innovation

Implement and commercialize

Make the decision

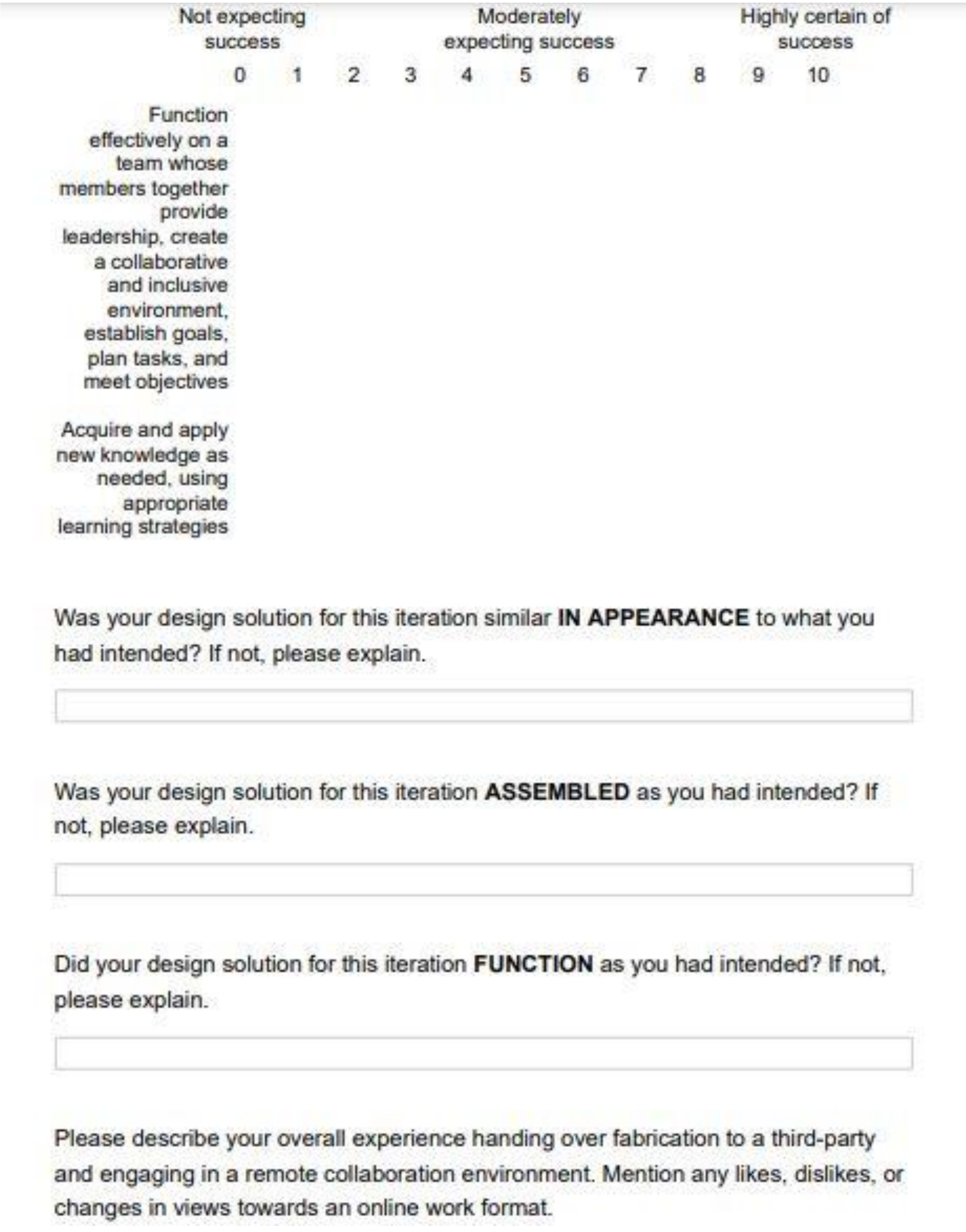
Perform review and assessment

Research and gather data



Rate how **SUCCESSFUL** you would be in performing the following tasks:

	Not expecting success					Moderately expecting success					Highly certain of success
	0	1	2	3	4	5	6	7	8	9	10
Apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors											
Communicate effectively with a range of audiences											
Recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts											



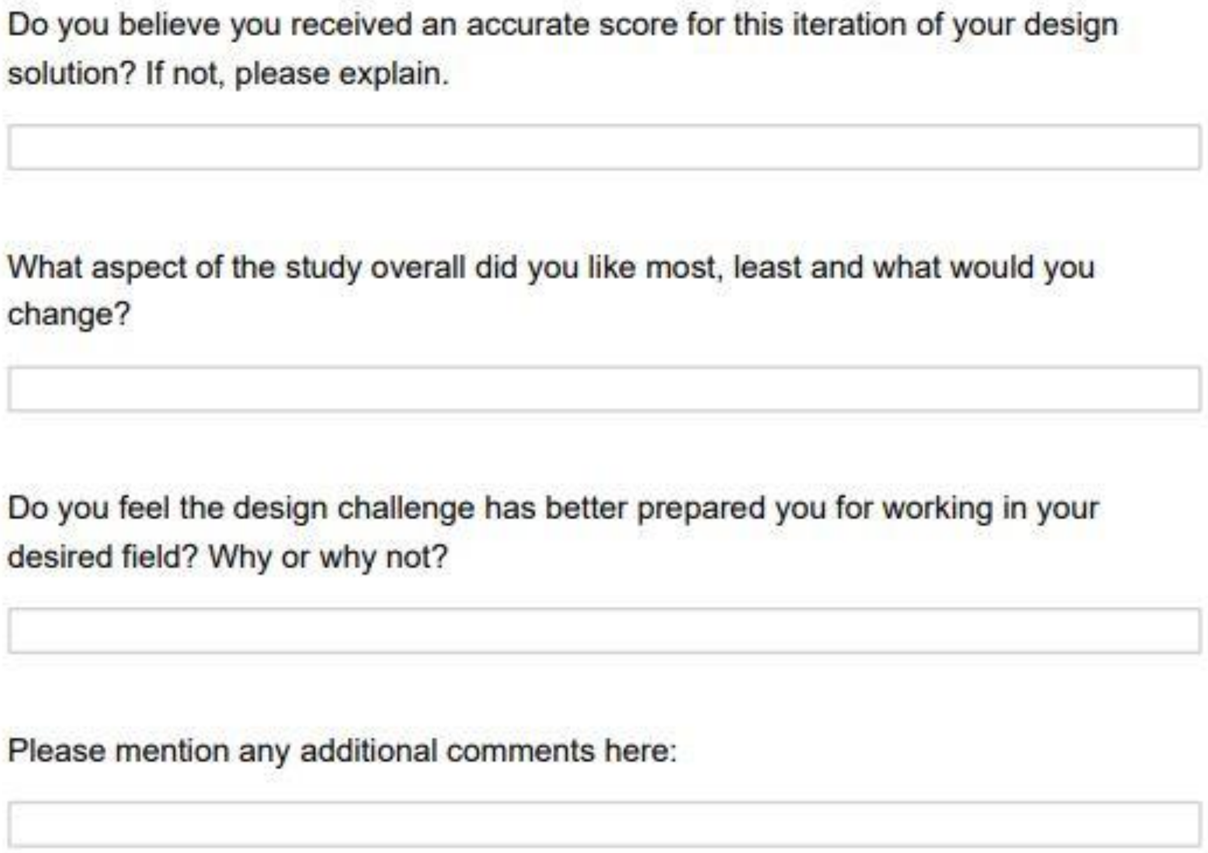
	Not expecting success				Moderately expecting success					Highly certain of success
	0	1	2	3	4	5	6	7	8	9	10
Function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives											
Acquire and apply new knowledge as needed, using appropriate learning strategies											

Was your design solution for this iteration similar **IN APPEARANCE** to what you had intended? If not, please explain.

Was your design solution for this iteration **ASSEMBLED** as you had intended? If not, please explain.

Did your design solution for this iteration **FUNCTION** as you had intended? If not, please explain.

Please describe your overall experience handing over fabrication to a third-party and engaging in a remote collaboration environment. Mention any likes, dislikes, or changes in views towards an online work format.



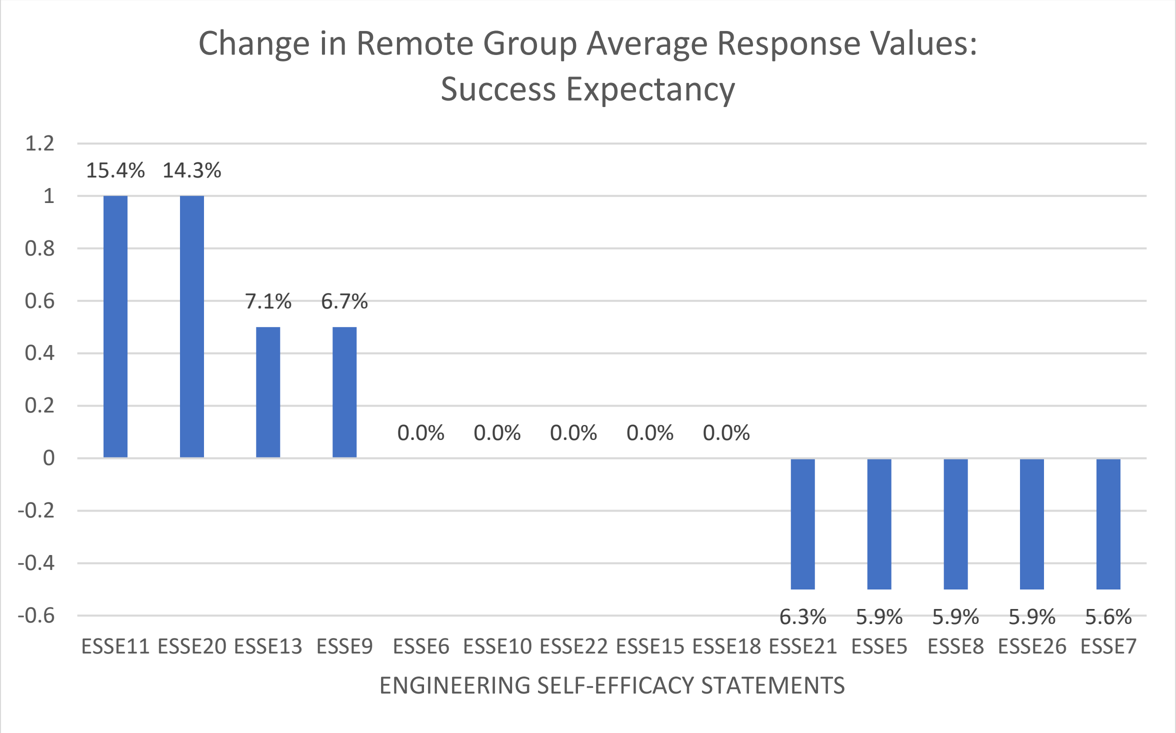
Do you believe you received an accurate score for this iteration of your design solution? If not, please explain.

What aspect of the study overall did you like most, least and what would you change?

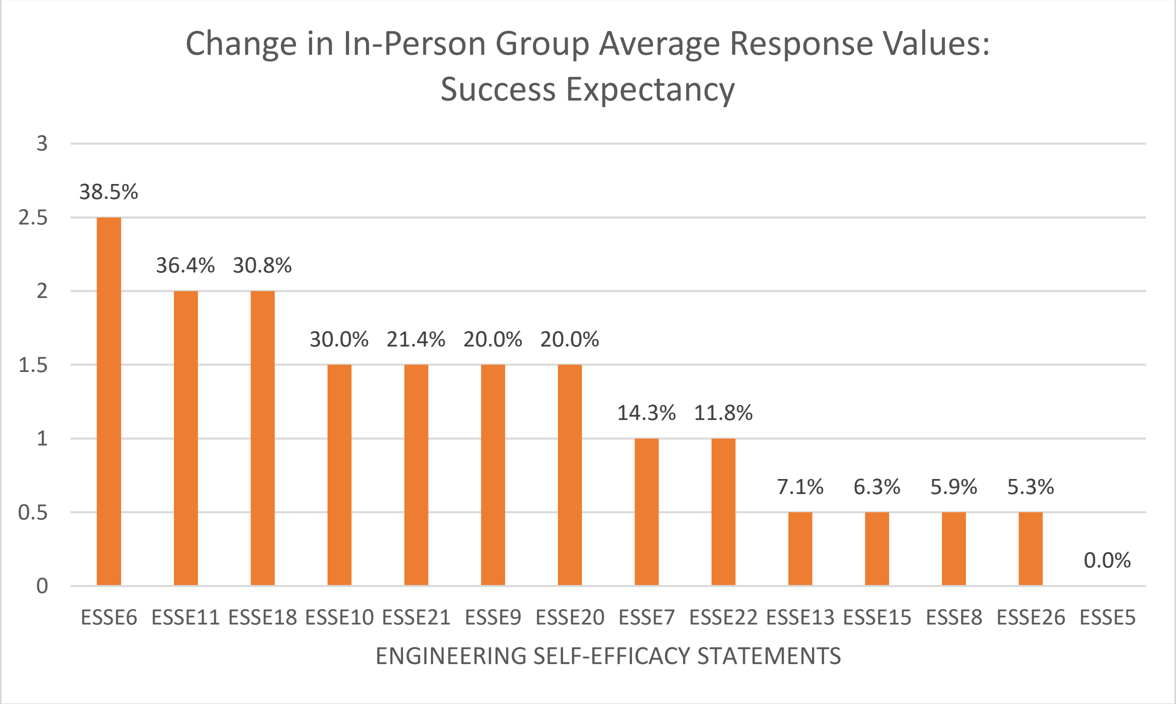
Do you feel the design challenge has better prepared you for working in your desired field? Why or why not?

Please mention any additional comments here:

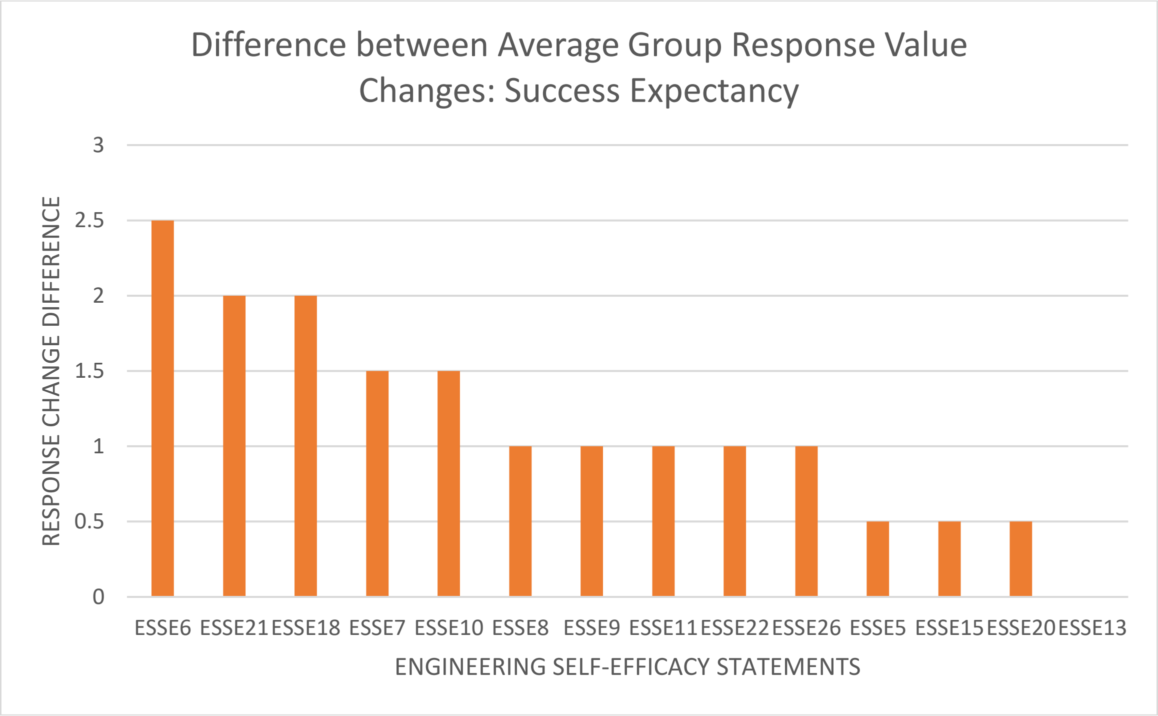
Appendix D: Scale Items Arranged by Decreasing Response Value



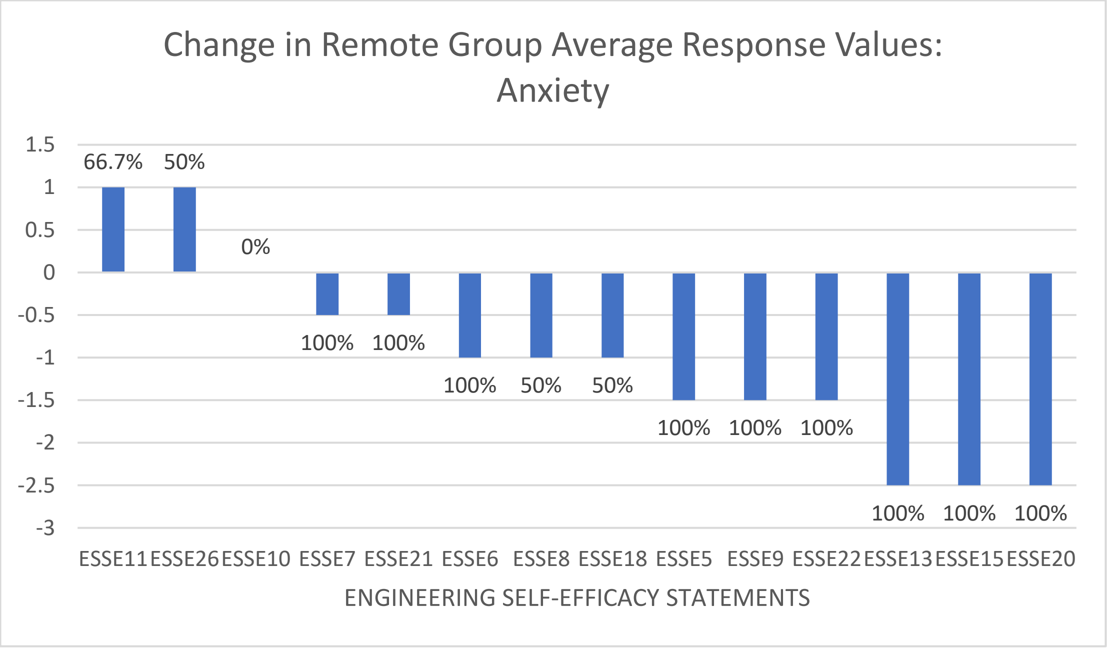
Change in remote group average response values: success expectancy



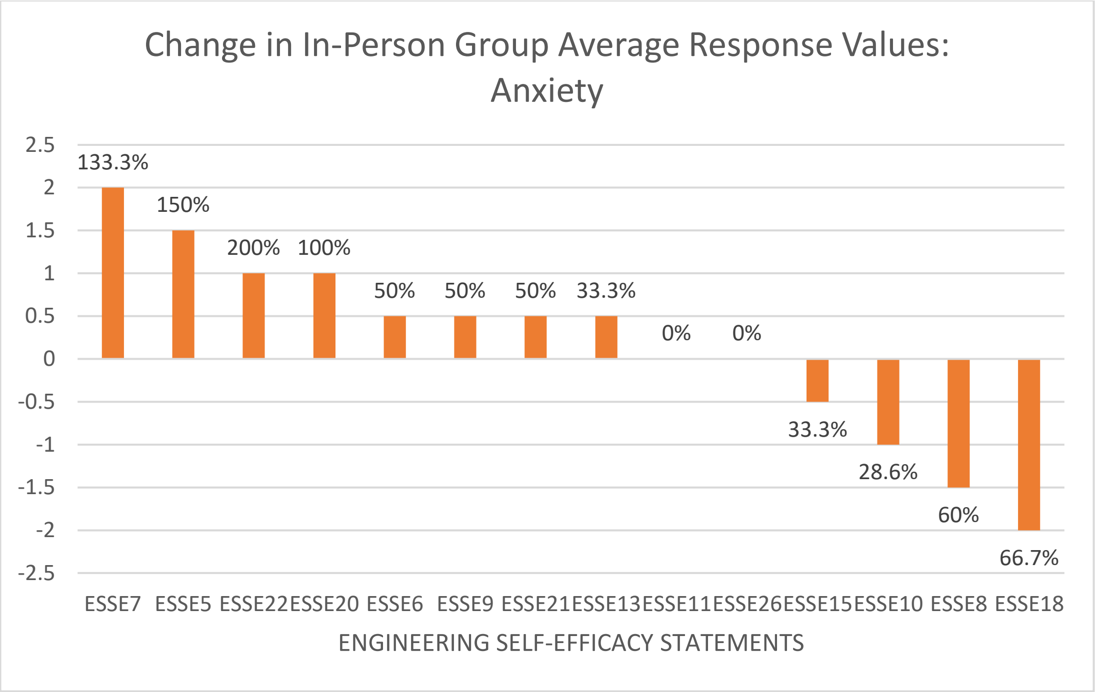
Change in in-person group average response values: success expectancy



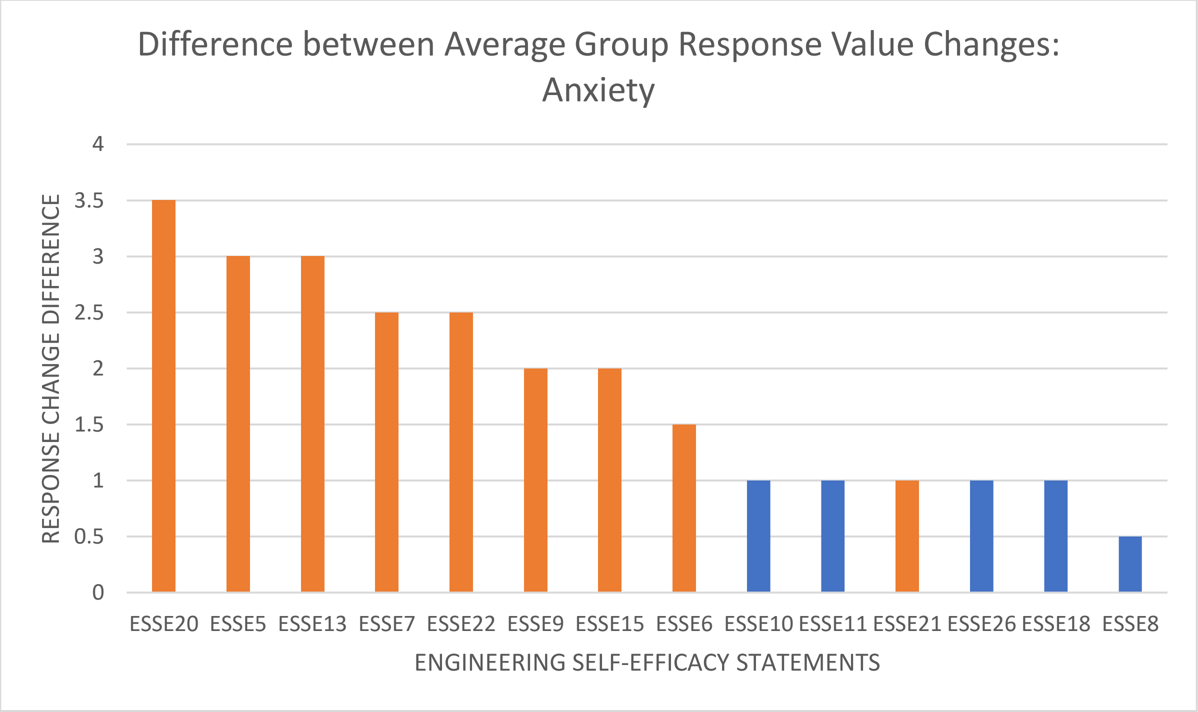
Difference between average group response value changes: success expectancy (Orange = in-person group)



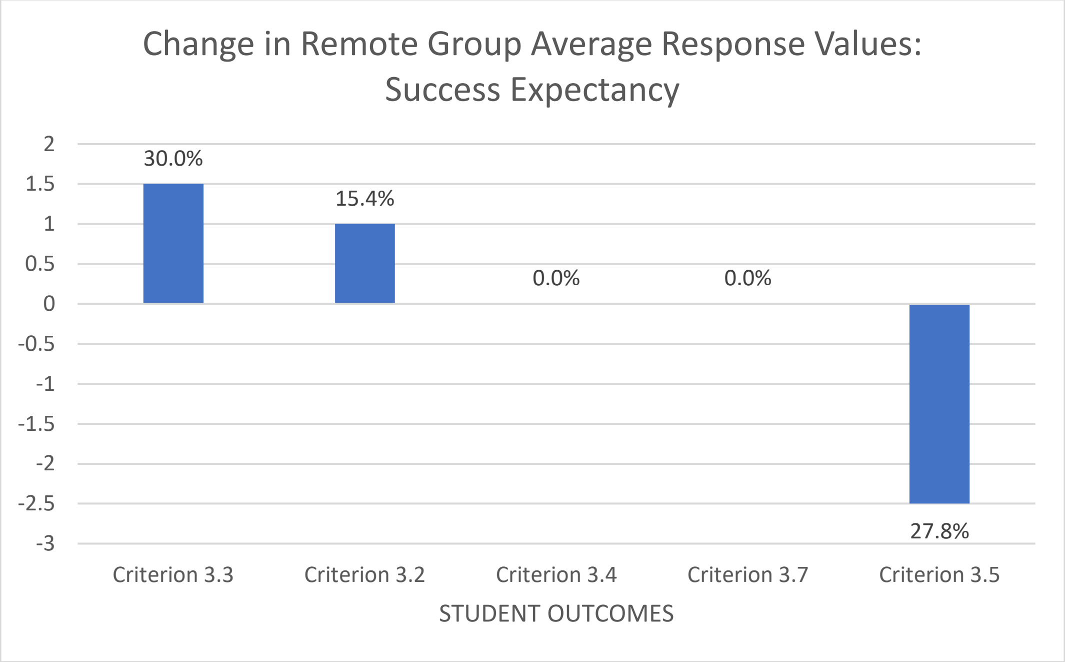
Change in remote group average response values: anxiety



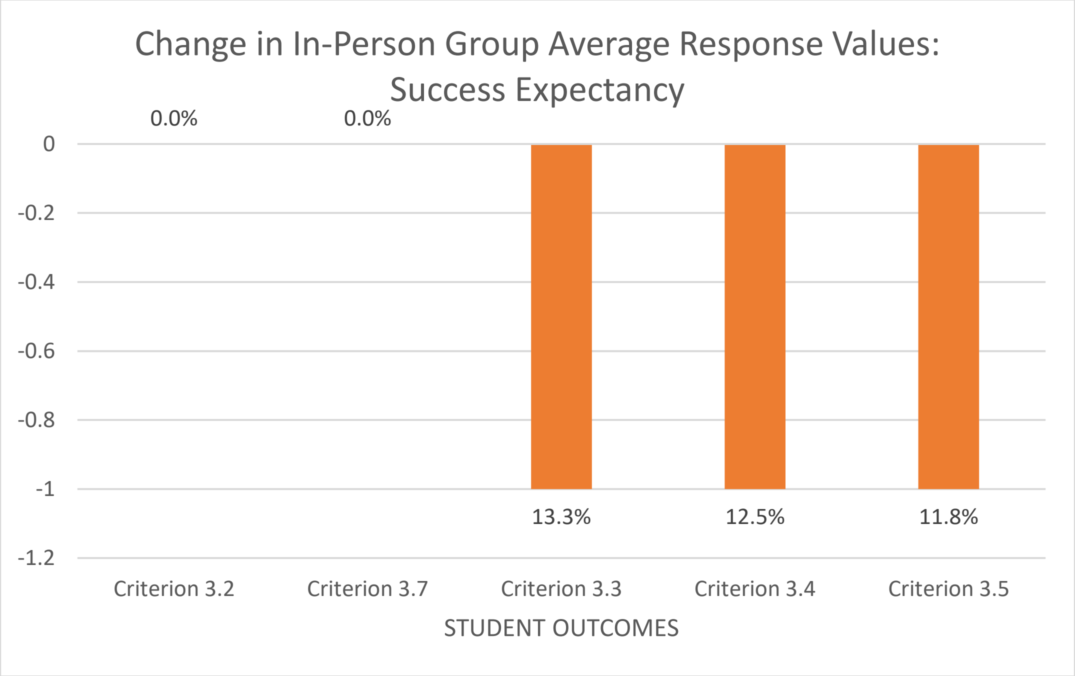
Change in in-person group average response values: anxiety



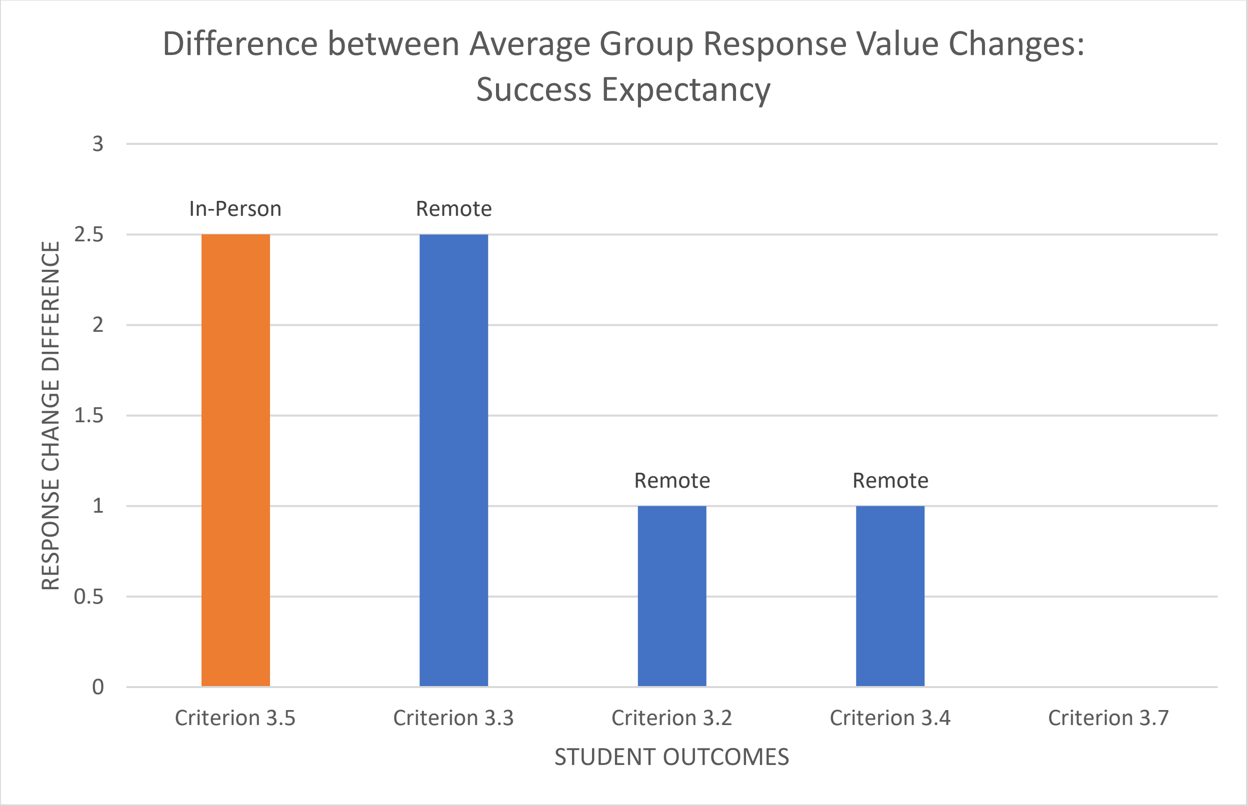
Difference between average group response value changes: anxiety
(Blue = remote group; Orange = in-person group)



Change in remote group average response values: success expectancy



Change in in-person group average response values: success expectancy



Difference between average group response value changes: success expectancy (Blue = remote group; Orange = in-person group)