CLASSIFYING AND CHARACTERIZING UNIVERSITY MAKER SPACE USERS: A FOUNDATION

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CLASSIFYING AND CHARACTERIZING UNIVERSITY MAKER SPACE USERS: A FOUNDATION

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SUMMARY

The popularization of maker spaces in academic institutions has raised the question of how these unique learning environments are impacting the students. With the ultimate goal of understanding this impact, it is necessary to identify what type of individuals are taking advantage of these spaces and how users are utilizing the resources and equipment available. This thesis presents two studies with the objective of providing a better understanding of university maker space users and their behavior and activities.

The first study describes the process of classifying and characterizing university maker space users and non-users. As part of a four-year longitudinal study, this thesis reports issues found within the first two semesters of data collection at Georgia Tech, and provides recommendations to ensure all the necessary data is being collected. One of the main contributions of this study is the development of a survey instrument capable of collecting the student's level of involvement and participation in maker spaces. This survey was developed by combining survey design theory with the author's experience and knowledge as a maker space user and student volunteer. It was then leveraged to compare students with high participation and, the more common, low participation students in terms of their engineering design self-efficacy evaluations. The participation level results were correlated with those of the engineering design self-efficacy. It showed that high participation students are more motivated and less anxious about performing engineering design related tasks than their low participation counterparts. Additional results show that there might be a migration of highly self-efficacious students from low to high participation as they progress in their academic career and encounter more opportunities to participate. While at this point the relationship found is only correlational, based on the previous findings there is reason to believe that higher motivation and lower self-efficacy may drive students to seek places that allow them to

explore engineering design related activities like university maker spaces. This also suggests that there might be barriers in place that prevent students with lower motivation and higher anxiety from participating in maker spaces and further supports the concern about introducing barriers when studying these environments. This study is in the process

To have a better understanding of university maker spaces as learning resources and quantify their impact on the users, it is important to understand to what extent and how these spaces are being used. Identifying the number of users that take advantage of these spaces and their characteristics could provide insight on the usage and inclusiveness of these environments. A pilot study was developed to assess the effectiveness of automatic people counters technology for maker space applications. This technology could allow researcher to collect traffic and usage data in a non-obtrusive manner, minimizing the introduction of unwanted barriers. The data collection methodology described leveraged the use of a video camera and automatic people counter technology to calculate the ratio of individual users and count data. This ratio allows one to estimate the number of users for any given day based on the automatically collected count data. The results from the pilot study show that, on average, users tend to enter the 3D Printing room associated with the university maker space two times a day, which is consistent with the expected use of a 3D printer. Moreover, the methodology was also used to identify the number of female users participating in the activities associated with this space. While this pilot study was limited due to a small sample size, the methodology developed for data collection and analysis proved to be promising for many different applications and objectives. Future studies will expand the sample size, calculate a more comprehensive user-to-count ratio, and leverage the methodology to capture other user characteristics.

CHAPTER 1

INTRODUCTION

Context and Motivation

In an effort to equip engineers with the skills to solve the most challenging problems and excel in an increasingly competitive job market, it is important that academic institutions continuously nurture the creativity and innovative skills of their students [1]. As a complementary resource to the engineering curriculum, university maker spaces provide an opportunity to foster creativity and innovation through the implementation of open environments that promote and stimulate designing, building, and collaborating outside the classroom. Due to the potential, but undocumented educational benefits associated with maker spaces, many academic institutions have developed or are in the process of establishing their own university maker spaces [2-5]. While this movement has sparked the interest of scholars to study the characteristics and processes that constitute an effective university maker space [6-10], there is a need to quantify their impact on students.

In order to pinpoint the influence university maker spaces have on their users, it is necessary to identify measurable criteria that could be directly stimulated by the use of these environments. Desirable influences may include positive educational, social, short and long term career benefits. Consequently, measurable criteria should be derived from and related to these valuable areas. The ideal method to capture the impact of university maker spaces would be by requiring students to actively and constantly report their involvement in maker spaces every time they take advantage of the resources and equipment available in these environments. This instrument would also require the student to accurately express why they are using certain equipment and resources. These characteristics would provide the ability to track the usage of the spaces throughout the students' academic career, and to measure how different classes, projects, and initiatives have an effect on the students' involvement. Moreover, the instrument would collect every possible activities occurring within these environments with a known validity, and no negative effect on the culture or involvement. However, based on the current lack of measurement scales and operational frameworks to assess usage and study these environments, there are no instrument capable of directly measuring the impact. Because of this, there is a need to capture usage by other means. This thesis presents a data collection methodology and survey instrument that aims to capture students' usage of maker spaces through self-reported data.

It is important to understand and quantify the impact university maker spaces have on different types of students. This goal could be achieved through measuring the number of students using these environments and identifying their demographic characteristics. Given the fast paced and open nature of university maker spaces researchers should minimize any interference with the common activities taking place within these subjected environments. To achieve this, automatic people counters can be leveraged with additional resources to gather count and demographic information in a non-obtrusive manner. Currently, this technology is used in a wide variety of applications and could be implemented in university maker spaces to capture the traffic patterns associated with these environments [7].

Research Scope

Maker spaces were created to satisfy the maker community's needs for a place to collaborate, build and share their creations [11]. They are the result of the maker community's rapid growth and the maker movement's rise of popularity. This movement began as design software and desktop fabrication tools became more accessible to the Do-It-Yourself (DIY) enthusiasts [12]. By offering an array of traditional (e.g., mills, lathes, and hand tools) and non-traditional (e.g., 3D printers and laser cutters) manufacturing equipment, maker spaces empower users to design, build, and test their creations [2, 6, 7, 11]. Both the culture surrounding these environments and the perceived educational benefits have sparked the interest of many academic institutions to develop maker spaces [2-5]. The activities associated with maker spaces have the potential to positively impact engineering skills as a complementary resource to engineering education. Current research has focused on identifying characteristics that make university maker spaces unique learning environments, such as tools available, culture, and other common practices [2, 3, 8-11, 13-15]. However, there is a need to quantify the benefits associated with these environments and understand how they are impacting the students.

To measure the impact of maker spaces in academic institutions, it is necessary to identify who takes advantage of the equipment and resources available in these spaces, and to what extent they are being used. Once users and non-users are methodically classified, it will be possible to quantify the characteristics that differentiate the students that self-select to use these spaces and the more common, low involvement students. This differentiation is the first step in understanding the impact of university maker spaces on students and engineering education as a whole. Furthermore, characterizing users and non-users will open the possibility to track how they are impacted by their dynamic involvement and how these specific traits change throughout their academic career. Understanding the characteristics that differentiate these two groups will aid in creating initiatives that increase the accessibility and inclusiveness of university maker spaces.

The goal of this thesis is to explore various methods and tools that will allow researchers to quantify the impact of maker spaces on users. Consequently, two studies are presented that explore students' utilization of Georgia Tech's Invention Studio, a well-developed university maker space. The first, User Characterization study, proposes and examines a method to classify and characterize university maker space users. The second, Space Usage study, seeks to identify a non-intrusive method to quantify the daily use of university maker spaces.

The User Characterization study analyzes the data collected from two semesters to determine the differences between users and non-users in terms of engineering design self-efficacy. In order to classify students as users and non-users, a survey instrument was designed, implemented, and analyzed to measure the students' university maker space participation level. Furthermore, the participation level was correlated to the student's engineering design self-efficacy through a survey instrument developed by Carberry et al. [16].

The two semesters represent a sample data set from an on-going four-year longitudinal study. While the current relationship between levels of participation and engineering design self-efficacy only show correlation at this point, the relationship will be tracked throughout the longitudinal study with the objective of identifying the causation. Furthermore, to ensure the success of the longitudinal study, the data was analyzed in this thesis in order to verify and identify any issues with the long term data collection plan. This study provides the foundational basis for comparison studies between the different universities participating in the longitudinal study. The information and data presented in this study has been accepted as a paper for the 2016 ASEE Annual Conference & Exposition.

Currently, the quantification of maker space usage is leveraged for two main reasons: as a measurement of success [4], and to communicate the magnitude of its impact [17, 18]. However, the methods used to quantify usage are not often reported. To better understand the impact and nature of university maker spaces, there is a need to create a method to accurately and effectively measure the traffic within these environments. Given the inclusive and fast-paced nature of university maker spaces, it is important that researchers minimize the use of intrusive methods to quantify user traffic. Obtrusive methods could create barriers that lead to undesirable changes in culture and the usage of these spaces. Quantifying people traffic is a common need in various industries, such as retail and public transportation. To satisfy this need, companies have relied on automatic people counting systems to measure traffic [19-21]. Due to the benefits associated with these systems [22-26], automatic people counters could offer a means to non-obtrusively measure the traffic within maker spaces. The Space Usage study explores the implementation of an automatic people counting system to understand the traffic and behavior of university maker space users, and more specifically, the students using the 3D Printing room at the Invention Studio. The focus of this study was to select an automatic people counter technology, as well as describe the methodology used to validate the accuracy and precision of the technology. Due to the complex traffic associated with the 3D Printing room, a methodology for determining the actual number of unique individuals using the room was developed. Unique individuals were identified via video footage based on specific characteristics. Once individuals were identified, the number of times the same user entered the selected room in one day was measured. With this methodology, it will be possible to estimate user characteristics like gender. In future studies, this data could be leveraged to identify the sample size required to determine several user characteristics, and moreover, the traffic could be used to quantify the impact of different initiatives to attract more students.

In the future, the quantification and characterization of university maker space users will aid in identifying how students are taking advantage of these unique learning environments, and determine barriers that prevent non-users from getting involved. Once the barriers are identified, actions can be taken to stimulate motivation and reduce anxiety for enhanced participation. Since these barriers could be a function of different demographic characteristics, it is important that steps are taken to quantify the extent of university maker space use by various demographic groups. With this information researchers and faculty can make operational and functional decisions to plan initiatives to improve the inclusiveness of these environments. Then the impact of initiatives can be assessed to ensure that they are attracting previously uninvolved students into the spaces.

Thesis Organization

Chapter 1 describes the context and motivation to support the development of this thesis, as well as the scope and focus of the experiments presented. Chapter 2 presents the background necessary to fully understand the development of this thesis and reviews the current work. Chapter 3 identifies the experimental instruments used in the thesis and describes the process for developing and validating the instruments. Chapter 4 focuses in the methodology created to characterize university maker space users and non-users with respect to their engineering design self-efficacy. Results from the first two semesters of a four-year longitudinal study are also presented. Chapter 5 describes the technology and methodology used to quantify the user traffic in one of the Invention Studios most used rooms. Finally, Chapter 6 concludes the thesis with the final remarks, lessons learned, and future work.

CHAPTER 2

LITERATURE REVIEW

This section provides an overview of the background necessary to understand the context and motivation for the thesis. The literature review consists in seven main topics: 1) Origin of maker spaces, and characteristics associated with these environments, 2) Maker spaces as a community of practice, and what constitutes a practitioner, 3) Student involvement in maker spaces, and how it is measured, 4) Retention in engineering education, especially for women and minorities, 5) Self-efficacy and its importance in engineering education, 6) Overview of people counting technologies and possible implementation in university maker spaces, and 7) Statistical approach to validating automatic people counting systems.

Maker Spaces

The maker movement was born as DIY culture got access to affordable digital design software and desktop fabrication tools. The movement gave rise to a community of practice that was significantly different from the older tinkerer and hobby communities. Defined as the maker community, this fast growing group has been characterized by the use of computer software to design products and digital prototypes, and the sharing of ideas, designs, products, and processes physically and digitally [12]. Maker spaces are locations where members of the maker community have access to the tools and workspaces necessary to design, build, prototype, collaborate, and share their work [11]. These spaces provide a non-traditional machine shop environment with a focus on rapid prototyping (e.g., 3D printers and laser cutters) and other more typical manufacturing equipment (e.g., lathes, mills, and hand tools) [2, 7, 8, 17].

Due to the perceived educational benefits associated with maker spaces and the promising future of the maker movement in education [3, 4, 6, 10, 14, 15], the development of these environments has rapidly gained commitment from many academic institutions [2] and other learning environments (e.g., libraries and museums) around the world [11]. The current research associated with maker spaces has focused in characterizing these spaces and their users, as well as providing lessons-learned from their development in academic institutions. Maker space users often come from different disciplines and are united by their common interest in making [13]. These users learn from each other informally through constructionism [11], where failing is considered a motivator and learning mechanism [10, 14, 15]. Successful maker spaces adapt to the users' interests [8, 9], and users are encouraged to drive their own learning [10, 13]. For these users, maker spaces provide an environment for learning, teaching, mentoring, advising, designing, building, fixing, collaborating, and participating.

This thesis will focus on the Invention Studio, one of the Georgia Institute of Technology's university maker spaces. The Invention Studio is a well-developed university maker space that originally opened its doors in 2009 (Figure 1). As of 2013, it was estimated that about 1000 students used the equipment and resources available per month [17], with estimates of 2000 users/month in 2015. The Invention Studio is staffed by a volunteer student population that is highly engaged in all the activities related to the maker space. These members have the title of Prototyping Instructors (PI) and as of 2014, there are about 74 PIs.

Figure 1: The Invention Studio's main entrance at the Georgia Institute of Technology

Maker Spaces as Communities of Practice

Maker spaces have been identified as the community of practice for makers [11]. The individual's regular participation in the activities that are considered important by the community helps them identify themselves as part of it [27]. Since participation can be defined as taking part of meaningful activities, where "meaning" is derived from the community of practice [28], it is important to determine the activities that are commonly related to university maker spaces. While some of the most common activities are the designing, building, and testing of devices, there are other types of activities that are equally important for the community of practice. Some of these revolve around the culture of collaboration between users, while others are related to events sponsored by the university maker space (e.g. attending training sessions, workshops, and other events). Through these events, university maker spaces like the Invention Studio invite students to participate in a project that takes advantage of the tools and equipment available. Figure 2 shows an example of a project that was done through a university maker space sponsored event.

Figure 2: An LED business card (3.5 by 2 inches) developed during an event sponsored by the Invention Studio. Project developed and photo taken by Ricardo Morocz.

Involvement in University Maker Spaces

Student involvement has been defined as the amount of energy the student invests in his or her academic experience [29]. It is often measured as the amount of time students spend on a specific activity (e.g. studying, participating in student organizations, interacting with faculty and other students, etc.) [29, 30]. Since involvement theory states that "the amount of student learning and personal development associated with any educational program is directly proportional to the quality and quantity of student involvement in that program" [31], it can be argued that high involvement in university maker spaces will enhance the benefits associated with these environments. Moreover, studies have identified that involvement in extracurricular activities has a positive effect on student retention in college [32, 33]. Given the nature of university maker spaces, there is reason to believe that different degrees of involvement will have an impact on the student's engineering self-efficacy and other factors of their academic career. The student's level of involvement will be determined through a series of questions about the time spent, and the frequency of use.

Retention in Engineering Education

A reoccurring topic of discussion in engineering education revolves around the need to increase retention and improve recruitment of students, especially women, minorities, and first generation students into engineering related fields. While the difficulty of the engineering curriculum and poor teaching have been recognized as factors influencing attrition, other issues like the "lack of belonging" in engineering have a great impact on the decision to leave [34-37]. In other studies, the lack of belonging is identified as one of the main obstacles for women [38] and minorities [39] to persist in engineering related fields. In these studies, lower involvement or participation in college and male-oriented curricula are thought to be causes for the lack of belonging. Due to the open and collaborative nature of university maker spaces, they could help individuals to become more involved at their college and increase their feelings of belonging.

Self-Efficacy

University maker spaces have the potential to assist engineering education in nurturing the student's self-efficacy and other valuable qualities outside of the classroom. Developing students to have strong self-efficacy, or the confidence an individual has in his or her ability to perform a task [40], can be valuable in engineering and science related fields for multiple reasons. In their study, Marra et al. [35] theorize that the student's feeling of belonging in engineering might be negatively affected by the lack of engineering self-efficacy. By strengthening the student's confidence in their engineering abilities, it could be possible to enhance their feeling of belonging in the field. Bandura [40] argues that through the development of strong self-efficacy, individuals can persevere even when facing adversity and failure. Other studies have shown a positive relation between student self-efficacy and their academic performance and persistence

[41, 42]. Due to the challenging nature of engineering, it can be argued that confident students are more likely to persevere in their field, regardless of the difficulty.

There are three university maker space characteristics that could positively influence students' self-efficacy: 1) observation of others successfully performing a task, 2) social persuasion due to the culture of the space, and 3) repetition of tasks with positively reinforcing results. Observing others successfully perform a task will have a strong positive influence on the observer's self-efficacy. Positive vicarious experiences will generate the feeling and expectation that, through enough effort, the observer can also be successful [40]. Since a part of the learning process in university maker spaces is through vicarious experiences, there is an opportunity for these environments to positively influence the user's confidence. As users gain experience performing a task, they become teachers or role models for other individuals trying to work on the same type of tasks [9]. Similarly, university maker spaces could have positive impact on the user's self-efficacy through social persuasion. According to Bandura [40], social persuasion is the positive or negative influence that others can have on an individual's self-efficacy. Through the culture of collaboration and the previously mentioned student to teacher mechanism [40], maker spaces could take advantage of social persuasion to reduce anxiety and strengthen self-efficacy. Through their failure-positive learning environment [14], university maker spaces could also have a positive effect on self-efficacy. In the maker culture, failure is considered a learning mechanism [10]. Through failure, individuals gain the experience and knowledge to successfully achieve the desired results. According to Bandura [40], being capable of performing a task successfully and repeatedly will have a positive impact on self-efficacy, while failing to perform the task multiple times will have a negative impact. Bandura [40] mentions, however, that as individuals gain experience in a situation in which they overcome failure through enough effort, their persistence when facing adversity becomes stronger [40]. By reducing the negative connotation of failure as part of the learning process, university maker spaces can help individuals to keep working on a task even when facing an obstacle. This will have a positive impact on the individual's self-efficacy by helping the individual persevere and achieve the desired results.

Automatic People Counter Technology

While understanding the impact of a maker space at the individual level is valuable, there is an opportunity to identify the overall usage of maker spaces. Since maker spaces foster an open and free access environment, it is important that researcher do not create barriers that might affect the culture of these spaces. Automatic people counters (APC) might offer the solution to quantify the use of maker spaces in a non-obtrusive manner. APCs are commonly used in a wide variety of industries (e.g., retail, casinos, transportation, etc.) for management, safety, and security purposes. These systems were developed to address the multiple issues of poor accuracy, reliability, and high cost associated with manual count methodologies [22-24]. In the public transportation industry, multiple case studies sponsored by the U.S. Department of Transportation showed that APCs achieved between 95% and 97% accuracy when compared to manually collected count data [22].

Based on the counting process and technology, APCs can be divided into three different categories: contact, sensor-based, and video-based counters [43, 44]. A well-known example of contact counters are turnstiles; as the persons walks through the spinning bars, the individual gets counted. This type of counter offers one of the most reliable and accurate ways to count people, but at the same time, contact counters significantly restrict the flow of traffic. Contact counters create a physical barrier that makes them inappropriate for many applications [44, 45]. Sensor-based APCs offer a less intrusive method for counting people. There are two main components for sensor based counters to work. First, they require an emitting component to direct light (e.g. infrared) to the receiving component. As a person passes through the beam, the connection is disrupted, and the counter records the pass. Since the system can only count one pass at a time, it tends to undercount when there is heavy traffic. Video-based counters were developed to take advantage of the non-obtrusiveness of sensor-based APCs, and at the same time being capable of counting multiple people simultaneously with high accuracy [25, 26]. These systems rely on a video camera and image processing algorithms to analyze the footage and count the individuals. Originally, the main issue with video-based counters was their dependency on computing intensive algorithms to determine the count. As the accessibility to more powerful computers increased and researchers developed more efficient, reliable, and accurate systems for people and crowd counting [43, 46-48], video-based counters became the standard for many applications.

Currently, an entire industry has been developed around the need for people counting systems. Through proprietary technology, multiple companies like SenSource Inc., Traf-Sys Inc., and Infrared Integrated Systems Ltd. are developing user friendly people counting systems and software for application in academic settings, retail, public spaces, etc. [19-21]. University maker spaces could utilize these systems to track usage of the environment in a non-obtrusive manner.

Estimating Population from Count Data

People counters are used to determine the number of people walking through a selected path. While APCs offer high accuracy and reliability, they are not perfect. To validate that the technology is working, the data collected through APCs needs to be compared to manually collected data over a certain time interval. This validation process is often performed by transit agencies, since they are required to report passenger count data to the Federal Transit Association (FTA) [22, 49, 50]. According the FTA, the count data has to show that there is no difference between manual and APC count with a precision of ±10% at a confidence level of 95% [49, 50]. If the 95% confidence interval

(CI) of the difference between APCs sample and the manually collected sample encompasses the value zero, then it is said that the APC provides an accurate estimate [49, 50]. Once the accuracy of the APC is validated, it is possible to demonstrate that the precision of the system falls within the ±10%. To do this, the standard error of the differences is divided by the average APC counts; if that percentage is lower than ±10%, then it is assumed that the counter is precise [22, 49, 50].

To find the confidence interval with a 95% confidence level for a small sample size, we will be using equation 1 [51].

$$C.I. = \bar{x} \pm t_{\alpha/2,n-1}\left(\frac{s}{\sqrt{n}}\right) \quad (1)$$

Where $\bar{x}$ represents the average difference between the APC and manual counts; $t_{\alpha/2,n-1}$ is the two-sided t-distribution value at the 95% confidence level; α equals 0.05; s represents the standard deviation of the differences between APC and manual data; and n is the sample size. This equation will allow measuring the confidence interval of the difference between APC and manually collected count data, validating the accuracy and precision of the technology for university maker space applications.

CHAPTER 3

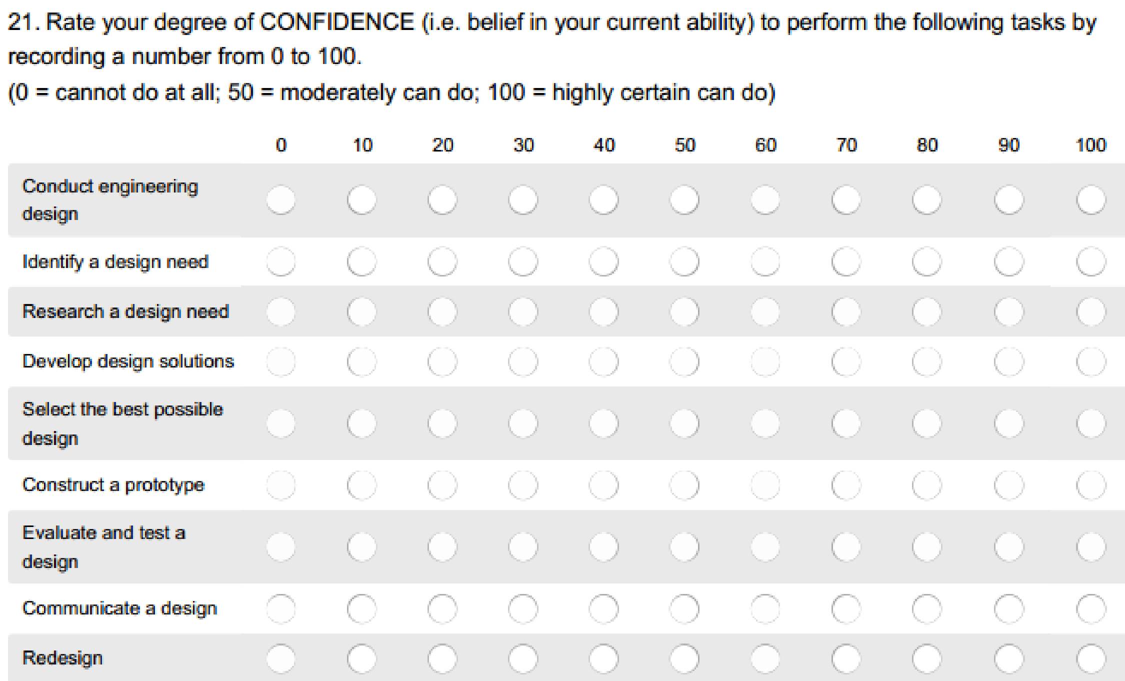
EXPERIMENTAL TOOLS

This chapter presents the survey instruments that were used to evaluate the engineering design self-efficacy and the level of involvement and participation of the respondents. The involvement survey instrument was subjected to multiple changes in order to improve the accuracy of the data collected, and to enhance the capabilities of the researchers to differentiate between high and low levels of involvement and participation. The multiple versions of the survey and the changes are presented in this chapter.

Engineering Design Self-Efficacy Instrument

The engineering design self-efficacy instrument, designed and developed by Carberry et al., measures the respondent's confidence to perform engineering design tasks, and it requires the participant to rate themselves in four self-concepts (self-efficacy or self-confidence, motivation, expectancy of success, and anxiety) [16]. Each one of the four self-concepts is composed of nine identical items, as seen in Figure 3. The nine items are: conduct engineering design, 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. The first item from each self-concept is used to calculate the engineering design (ED) score, and the engineering design process (EDP) score is calculated by averaging the remaining eight items of the instrument. The ED score is described by Carberry et al. as the participant's confidence, motivation, expectancy of success and anxiety when "conducting engineering design," while the EDP represents the participant's self-conception in different types of engineering design tasks [16]. According to Carberry et al., the tasks associated with the

EDP are used to capture the overall engineering design process, and when averaged, they correlate to the participant's ED score.


21. Rate your degree of CONFIDENCE (i.e. belief in your current ability) to perform the following tasks by recording a number from 0 to 100.
(0 = cannot do at all; 50 = moderately can do; 100 = highly certain can do)

	0	10	20	30	40	50	60	70	80	90	100
Conduct engineering design											
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											
Redesign											

Figure 3: Variation of the Engineering Design Self-Efficacy Instrument developed by Carberry et al. [16].

Since its original development, variations of the engineering design self-efficacy instrument have been implemented in research studies as a metric to quantify the impact of different learning methodologies, design tools, and student collaboration [52-56]. Since university maker spaces' related activities often involve different stages of the design process, there is reason to believe that users will become more self-efficacious towards engineering design related tasks. The data gathered using the engineering design self-efficacy instrument presented in this thesis was used to characterize the high and low participation populations.

Involvement Survey Instrument

A survey instrument was developed to differentiate between degrees of university maker space usage and to easily distinguish users from non-users. The author's knowledge and experiences, as an Invention Studio user and prototyping instructor, were leveraged in the design of the questions. The original version of the survey was developed to capture involvement in terms of hours of use and participation based on the purpose of use, but the survey was later refined and polished to collect richer involvement and participation data. This survey was improved as part of the author's final project for a survey research methodology and design special topics course. Throughout this course, the design and wording of the questions and overall presentation and organization of the survey was reviewed by Dr. Julia Melkers, an expert in survey design and survey research. Dr. Wendy Newstetter, an expert in survey theory and ethnographic research, also reviewed the final version of the survey before it was implemented.

The involvement survey was developed to measure three aspects of maker space use: exposure, involvement, and participation. Thus, the survey is divided into three corresponding sections to classify university maker space users and non-users in different ways. The survey was updated throughout the first two semesters of data collection to improve the definitions and classification of involvement and participation. The final version of the survey is located in Appendix C.

The exposure section was included to determine if the participant had ever used the university maker space. This section allowed for easy identification of non-users. The involvement section focused on measuring the frequency of use and the amount of time participants spend while using the university maker space. As explained in Chapter 2, involvement can be defined as the amount of time and effort one spends on a particular activity. Since involvement has been shown to positively improve the student's experience as well as retention in college, highly involved university maker space students could benefit in terms of improving design self-efficacy, retention, and other aspects [31-33]. Finally, the participation section measured the type and purpose of a student's participation in a maker space. As explained in Chapter 2, university maker spaces are the community of practice for student makers, and to become part of the community the individual needs to participate in the activities that are considered meaningful by this group. Being part of the community of practice might enhance the impact of using university maker spaces in terms of the student's design self-efficacy, GPA, and idea generation skills. The development of these sections was highly influenced by the author's knowledge and experience gained as a user and prototyping instructor of the Invention Studio.

Exposure Section

This section was used to understand the participant's exposure to the university maker space, and it is comprised of one question about the participant's level of familiarity with university maker spaces. This question has three levels of exposure: 1) The participant has never heard of any university maker space, 2) the participant has heard of university maker spaces but he or she has never used any of the resources or equipment available, and 3) the participant has used the equipment and resources available at the university maker space. The exposure question can be seen in *Figure 4*.

7. Select the statement that best describes your familiarity with university maker spaces.

- ◯ I have never heard of any university maker spaces
- ◯ I have heard of university maker spaces but I have never used any of the equipment and/or resources
- ◯ I have used a university maker space's equipment and/or resources

Figure 4: Question about university maker space exposure

Involvement Section

Originally, the survey instrument combined the involvement and participation questions into one (Figure 5). The question was designed to capture the participant's involvement by having the participant estimate the number of hours they spent in university maker spaces weekly over the past six years. Participation was captured by having the respondent estimate how the time using the university maker space was distributed over four different purposes: Classwork, personal use, research, and prototyping instructor related work.

This first iteration of the survey was implemented in Spring of 2015. Preliminary analysis of the data allowed us to discover two main issues with the instrument: 1) the involvement and participation question was excessively dependent on the ability of the respondent to recall the average number of hours spent participating in a routine activity several years in the past and over a long time period (one school year). Survey design theory suggests to limit the amount of information the participant is required to recall while they are taking a survey, because studies have shown that it will increase the cognitive burden of the survey, resulting in inaccurate or missing data [57]. 2) Differentiating between degrees of involvement and participation was very limited. Being capable of differentiating students with high involvement and participation from non-users is necessary to determine the extent of impact university maker spaces are having on the student population. Since students use the university maker spaces in different ways, it is important to understand how different degrees and types of participation and involvement are affecting the students in terms of design-self-efficacy, retention, GPA, and idea generation. For this reason, the first version of the survey was reviewed and improved.

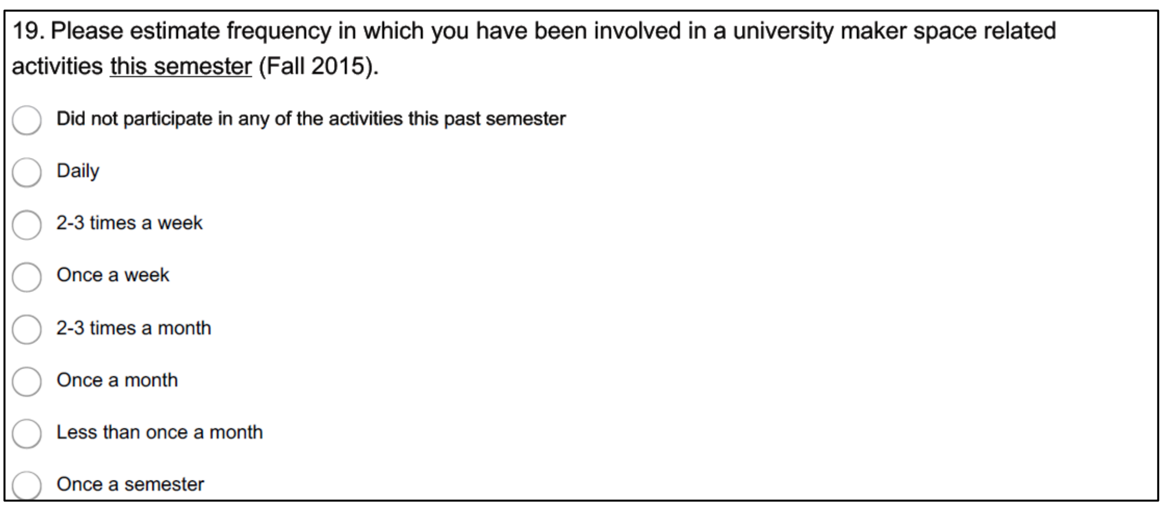
9. Please fill in the table to the best of your knowledge. Indicate your use of the Invention Studio during your college career

Year	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015
Average amount of hours per week						
Please estimate how your time was distributed in the Invention Studio per year						
Classwork Use (2110, Capstone, other)						
Personal Use						
University Lab Instructor (ULI)						
Research						

Figure 5: Involvement and participation question in the first iteration of the survey instrument. University Lab Instructor (ULI) changed their title to Prototyping Instructor (PI).

For the second version of the survey, the involvement and participation question was separated into two corresponding sections. The involvement section only included one question about involvement. This question required the participant to estimate the frequency with which they were involved in university maker space related activities during the current semester (Figure 6). To help the students estimate the frequency of use and collect more accurate data, the time period of the question was limited to the current semester (maximum of 3-4 months in the past). In survey methodology, there are multiple factors that affect the ability of respondents to recall events, and by shortening the reference period and tailoring the length to the specific event, the accuracy of the respondent's memory recall can be improved [58]. To further help respondents estimate the frequency of use, the different frequency levels were binned (e.g., daily, 2-3 times a week). To determine the ranges of the bins, the knowledge and experience of the author as an Invention Studio user and prototyping instructor were leveraged. The selection of the bins was then discussed with another graduate student that also had experience as a user and prototyping instructor.

According to survey theory, when respondents face questions that require estimating behavioral frequencies, they will rely on the options available for acceptable ranges of answers. To ensure the validity of these bins, it is important that the answer in the center is close to the average answer for the population, reducing the effects of under and over reporting [57, 58]. To validate the selection of the bins, the response distribution was found for two of the groups that were surveyed. Figure 7 shows that the center answered is the one that was selected the most, so we assumed that it represents the average response for the population, ensuring the validity of the question and bins selection. While the distribution of the answers are skewed towards lower frequency of use, it is important to note that this question was designed to differentiate students in terms of high and low frequency of use and not to determine the exact frequency with which highly involved students use the studio.


19. Please estimate frequency in which you have been involved in a university maker space related activities this semester (Fall 2015).

- Did not participate in any of the activities this past semester
- Daily
- 2-3 times a week
- Once a week
- 2-3 times a month
- Once a month
- Less than once a month
- Once a semester

Figure 6: Question designed to capture respondent’s frequency of involvement

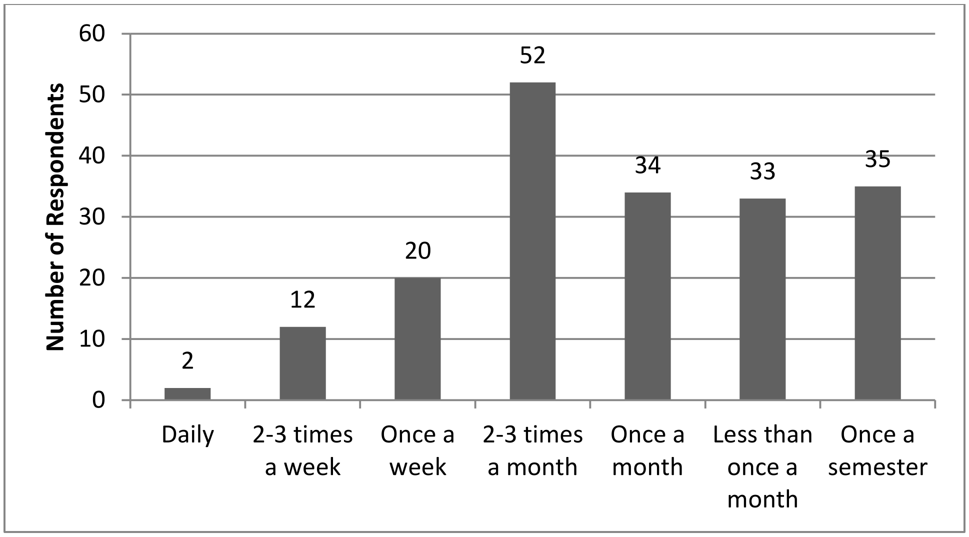


Figure 7: Distribution of responses for the frequency of involvement question

In order to create an enhanced definition of student involvement, the third and final iteration of the survey introduced a question about the average number of hours students used university maker spaces (Figure 8). Similar to the question about frequency of involvement, students were helped by limiting the extent of involvement to the current semester. As explained before, shortening the reference period and tailoring the length will have a positive impact on the accuracy of the student's memory recall [58]. Also, to help respondents estimate the amount of time spent using the university maker space, the answers to the question were binned (e.g., less than 1 hour, 1-2 hours). The distribution of the bins was based on the responses collected from the first version of the survey that was distributed. As previously explained the involvement and participation questions were combined in an open-ended format that required the respondent to write the number of hours they use university maker spaces during a typical week. The response distribution from this question was developed using SPSS and can be seen in Figure 9. The bins selected for this distribution are based on the normal distribution line, which is centered around the five hours of use option. The range of the bins was then selected by leveraging the knowledge and experience the author gathered as a user and prototyping instructor.

The ranges were then discussed with another graduate student with the same level of experience.

17. How much time have you spent this semester (Fall 2015), during a typical week, in a university maker spaces related activities?

- None
- Less than 1 hour
- 1-2 hours
- 3-5 hours
- 6-10 hours
- 11-20 hours
- Over 20 hours

Figure 8: Question designed to capture amount of time the respondent spends involved in university maker space related activities

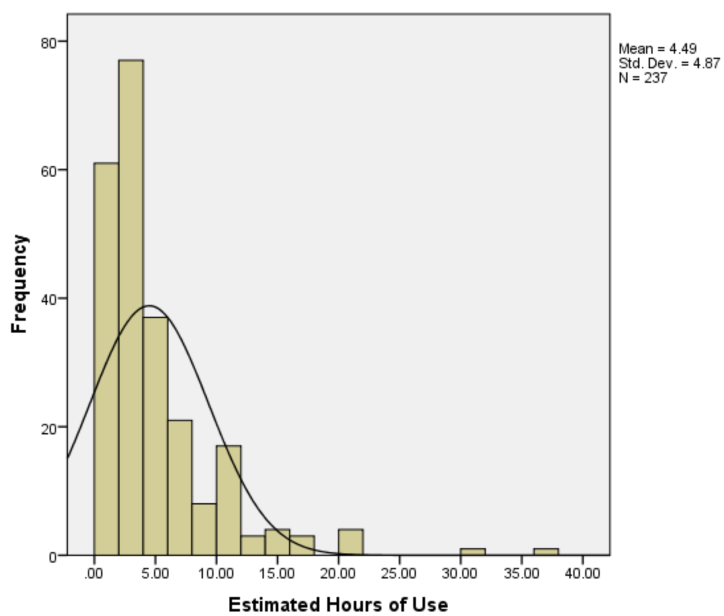


Figure 9: Distribution of responses for the hours of use question

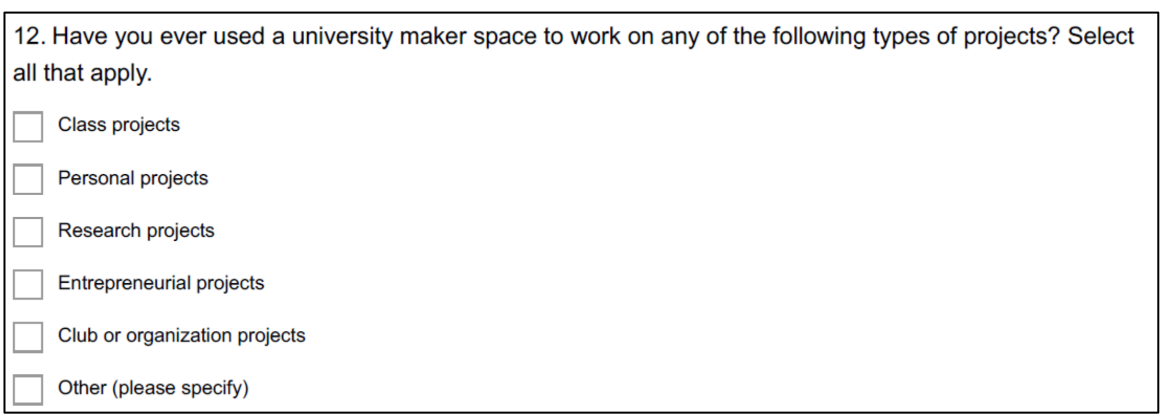
Table 1 shows the hypotheses behind the questions included in involvement section of the final version of the survey, as well as the rational for their inclusion.

Table 1: Relationship between hypotheses, survey questions and inclusion rationale for the questions in the involvement section

Question Hypothesis	Survey Question	Construct	Rationale for Inclusion
Highly involved students use university maker spaces more frequently	Estimate frequency in which you have been involved in a university maker space related activities	Frequency of use	To determine the relationship between frequency of use and other metrics (e.g., design self-efficacy, GPA, etc.)
Highly involved students spend more time (hours) in a typical week using university maker spaces	How much time have you spent in a university maker spaces related activities?	Range of hours spent	To determine the relationship between amount of time and other metrics (e.g., design self-efficacy, GPA, etc.)

Participation Section

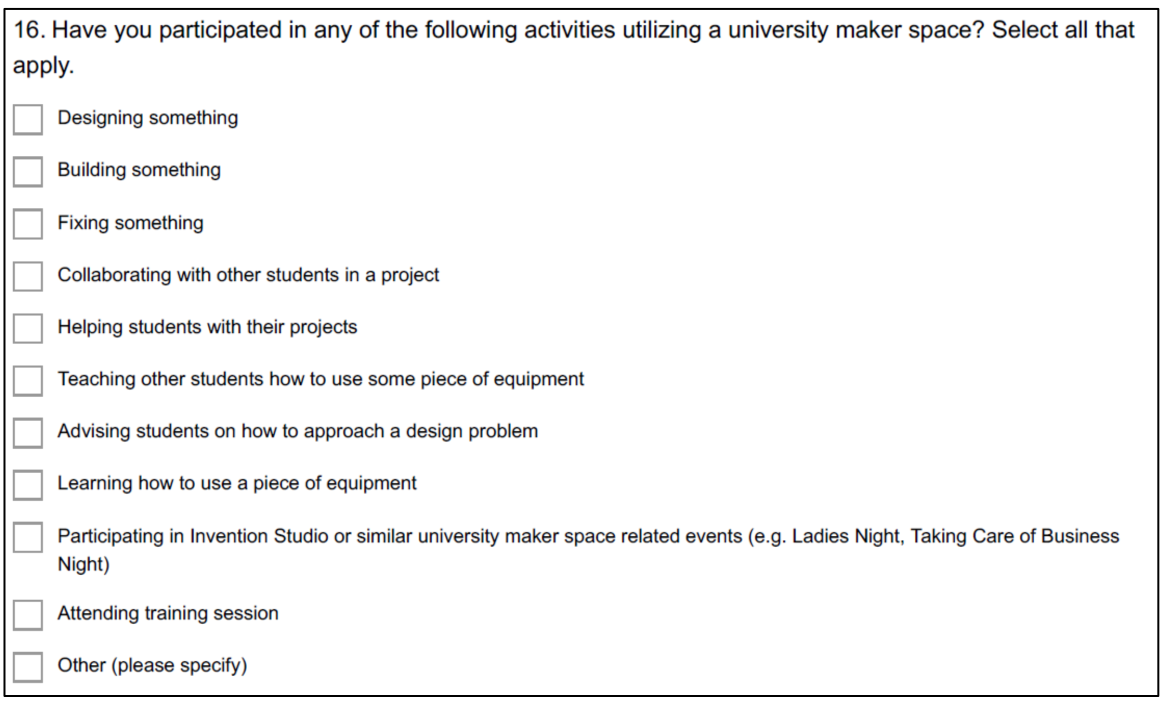
In the second version of the survey, two participation questions were introduced. The first question required the respondent to identify the purpose behind the use of the equipment and resources available at the maker space (Figure 10). The list of projects was developed based on the university maker space related experience of the author of this thesis. The five categories were selected since they are the main and most common purposes for using the equipment and tools available in the maker space. These five different types of projects were discussed and later selected through the collaboration of the author and another graduate student with the same background experience.


12. Have you ever used a university maker space to work on any of the following types of projects? Select all that apply.

- [ ] Class projects
- [ ] Personal projects
- [ ] Research projects
- [ ] Entrepreneurial projects
- [ ] Club or organization projects
- [ ] Other (please specify)

Figure 10: Question designed to capture the types of projects behind the respondent's participation

The second question in this section was included to capture respondent's participation in different types of university maker space related activities (Figure 11). As explained in Chapter 2, university maker spaces are the community of practice for makers. Users can become part of this community of practice by participating in the activities that the community considers to be important. The list, shown in Figure 11, was developed collaboratively by the author and another graduate student with extensive knowledge and experience as users and prototyping instructors. The activities in this list were selected because they are considered to be important for the community of makers of the Invention Studio.


16. Have you participated in any of the following activities utilizing a university maker space? Select all that apply.

- [ ] Designing something
- [ ] Building something
- [ ] Fixing something
- [ ] Collaborating with other students in a project
- [ ] Helping students with their projects
- [ ] Teaching other students how to use some piece of equipment
- [ ] Advising students on how to approach a design problem
- [ ] Learning how to use a piece of equipment
- [ ] Participating in Invention Studio or similar university maker space related events (e.g. Ladies Night, Taking Care of Business Night)
- [ ] Attending training session
- [ ] Other (please specify)

Figure 11: Question designed to determine if the respondent has participated in different type of university maker space related activities

Table 2 shows the hypotheses behind the questions included in participation section of the final version of the survey, as well as the rational for their inclusion.

Table 2: Relationship between hypotheses, survey questions and inclusion rationale for the questions in the participation section

Question Hypothesis	Survey Question	Construct	Rationale for Inclusion
Students with a high levels of participation use university maker spaces in a higher variety of projects	Have you used a university maker space to work on any of the following types of projects?	Type and variety of projects	To determine the relationship between the type and variety of projects and other metrics (e.g., design self-efficacy, GPA, etc.)
Students with a high levels of participation use university maker spaces in a higher variety of related activities	Have you participated in any of the following activities utilizing a university maker space?	Variety of related activities	To determine the relationship between the variety of related activities and other metrics (e.g., design self-efficacy, GPA, etc.)

Other Questions Included in the Survey

There were two additional sets of questions that were included in the survey. The first question had an open-ended format and required the respondent to estimate the total number of different projects they have worked on during the semester (Figure 12). This question allows for differentiation of users in terms of the total number of projects they have worked on. This question was included because it is believed that students with high levels of participation and involvement work on a higher number or more complex projects using the resources available in maker spaces.

Since projects can have different degrees of complexity, the answer to this question needs to be combined with the frequency of use and number of hours spent using university maker spaces. Combining these questions allows for differentiation between multiple small projects and fewer big projects. Since this question needs to be combined with the involvement questions, it was considered to be outside of the scope of this thesis and was not analyzed.

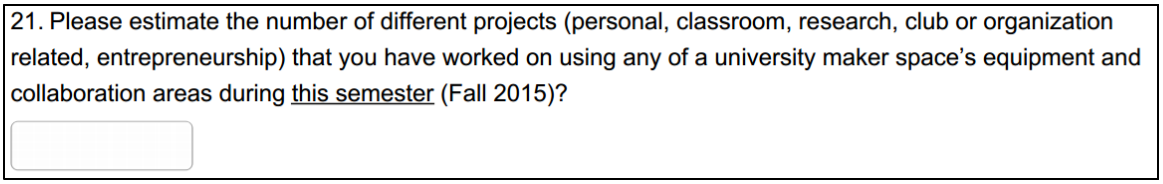
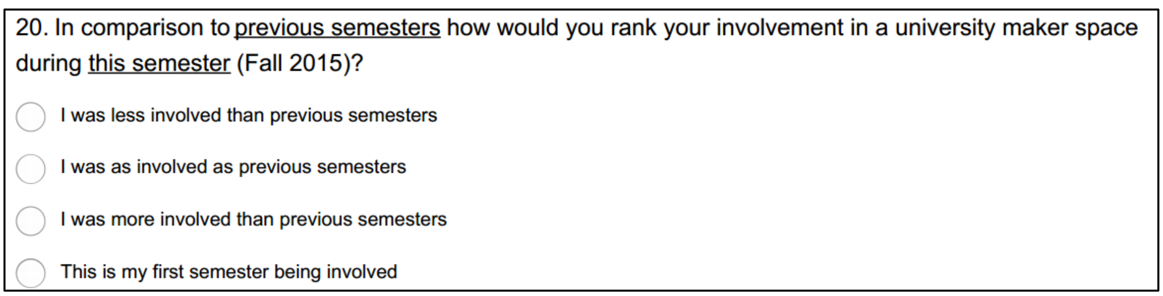

21. Please estimate the number of different projects (personal, classroom, research, club or organization related, entrepreneurship) that you have worked on using any of a university maker space's equipment and collaboration areas during this semester (Fall 2015)?

Figure 12: Question designed to determine the number of different projects the respondent has worked on using the resources available at the Invention Studio

The second set of questions was asked after each involvement question because it required the respondents to rate their response for the current semester with respect to the previous semester. This question was included in the survey to gather data from participants that were not approached or were missed during the previous semester. Through this question, it is possible to determine the progression of university maker space use by the student in a span of two semesters. An example of this question can be seen in Figure 13, as it corresponds to the frequency of use question.


20. In comparison to previous semesters how would you rank your involvement in a university maker space during this semester (Fall 2015)?

- I was less involved than previous semesters
- I was as involved as previous semesters
- I was more involved than previous semesters
- This is my first semester being involved

Figure 13: Question designed to indirectly determine the frequency of use during the previous semester

Criteria for Determining Levels of Participation

Due to the variations in the involvement questions from semester to semester, this thesis will limit its focus on the relation between levels of participation and engineering design self-efficacy. To classify students based on their level of participation, a criterion for participation was defined. For the remainder of this thesis, low participation students are defined as the students that have never used a university maker space, while high participation students are defined as having the following two characteristics: 1) they have used the university maker space for multiple types of activities, and 2) the purpose of their participation is not limited to class related projects. Participating in multiple types of meaningful activities is important for students to become part of the community of practice. The second requirement was included to differentiate between the students that self-select to use the maker space and those that are instructed to use it, since many courses at Georgia Tech require the use of the maker space as part of the learning objectives.

CHAPTER 4

CHARACTERIZING MAKER SPACE USERS

The study presented in this chapter has three main objectives: 1) To design, implement, and analyze the involvement and participation survey instrument described in Chapter 3; 2) To ensure that all the data required for the four-year multi-university longitudinal study is being accurately and methodically collected; and 3) to correlate levels of student participation to engineering design self-efficacy scores with the purpose of characterizing university maker space users and non-users. As mentioned in Chapter 1, maker spaces have the potential to become valuable supplemental tools to improve engineering education. This chapter focuses on the classification and characterization of the students using the Invention Studio, a well-developed university maker space. By determining who is using these environments, it will be possible to identify the barriers that prevent other students from participating. The involvement and participation survey was implemented and allowed for the classification of students in terms of their maker space participation. Both surveys from Chapter 3 were distributed in three engineering design courses in Spring and again in Fall of 2015, allowing for the capture of valuable data from two cohorts of freshman, sophomore, and senior students. Once the students were classified in terms of level of participation, high and low participation students were compared in terms of their engineering design self-efficacy. The data from the two cohorts of students registered in the freshman level course were compared and later combined. Since the data collected for this thesis forms part of a four-year longitudinal study, the results presented in this chapter were used to improve the data collection methodology, and the survey instruments as explained in Chapter 3. Certain user characteristics were identified through the data analysis. These characteristics show that students with high levels of participation are more motivated and less anxious about performing engineering design related tasks than the more typical low participation student.

Data Collection

Data was collected from undergraduate students taking one of three different courses (Introduction to Engineering Graphics (ME1770), Creative Decisions and Design (ME2110), and Capstone Design) during the Spring semester in 2015, and once again during Fall of 2015. These courses were selected due to the following reasons: 1) the courses have an emphasis on engineering design and promote the use of university maker spaces as part of the curriculum, and 2) ME1770, ME2110, and Capstone are tailored to students from the freshmen, sophomore, and senior year, respectively. This will allow the research team to capture the same students as they progress in their college career. The method for collecting the data will change when they approach junior year, as there are no engineering design courses that are taken by all juniors. Therefore, participants will have to be tracked via email. A table identifying the student cohorts that will be tracked throughout the four-year longitudinal study can be found in Figure 1. A fully-detailed version of Figure 1 can be seen in Appendix D. In this thesis, the results from the P, Po, and A cohorts are presented. This method for collecting data will ensure repeated measures from the majority of students enrolled in the school of mechanical engineering, meeting the longitudinal study's data collection goals.

Table 3: Four-year longitudinal study data collection plan with target population cohorts. The cohorts identified by P and Po represent the pilot data for the longitudinal study.

Target Population	Spring 15	Fall 15	Spring 16	Fall 16	Spring 17	Fall 17	Spring 18	Fall 18	Spring 19
ME1770	P	A	A	B	B	-	-	-	-
ME2110	Po	P	A	A	A/B	B	B	-	-
Junior	-	-	P	A	A	A/B	B	B	-
Capstone	Po	Po	Po	P	A	A	A/B	B	B

Methodology

As the data collected was analyzed, errors and limitations in the surveys were found. The survey was reviewed and taken through three iterations to address these issues. Table 4 shows the version of the survey distributed, recruitment methodology, location for the survey distribution, and survey format used in each of the three courses during Spring and Fall of 2015. Three different versions of the involvement and participation survey were distributed. The changes in each of the three versions can be seen in Chapter 3, and the complete surveys can be seen in Appendix A, B, C. There were two different recruitment procedures, "in person" recruitment and email recruitment. The "in person" recruitment required the researchers to show up at the beginning of class and use a script approved by the IRB to recruit participants. The script can be found in Appendix E. For the email recruitment procedure, the researchers sent an IRB approved email to the students for recruitment purposes. The recruitment email can be seen in Appendix F. There were two scenarios that defined how we distributed the survey. If the professor of the course allowed us at least 10 minutes to collect data during scheduled class time, the survey was either distributed as a paper or as an online link to complete right away. On the other hand, if the professor could not spare at least 10 minutes, the survey was administered via a link in the recruitment email or at the beginning of an extracurricular time in which the students could show up and participate in the study. Finally, there were two kinds of survey formats. The online format was developed and distributed through Survey Monkey, while the paper format was developed in Microsoft Word, printed, and distributed during the first ten minutes of class time or at the beginning of the extracurricular scheduled time.

Table 4: Participant responses to the questions about demography in the freshmen level course

Semester/Courses	Number of Participants	Survey Version	Recruitment Procedure	Survey Distribution	Survey Format
Spring 2015					
ME1770	146	2	In Person	Link in Class	Online
ME2110	211	1	In Person	In Class	Paper
Capstone	47	1	In Person	Scheduled	Paper
Fall 2015					
ME1770	372	3 (final)	In Person	Link in Class	Online
ME2110	18	3 (final)	Email	Link in Email	Online
Capstone	16	3 (final)	Email	Link in Email	Online

When the survey data was collected online via Survey Monkey, the responses were downloaded directly into a spreadsheet that was saved on a secure server. When the paper version of the survey was used, the data was transcribed into a spreadsheet by an undergraduate student, twice into two different spreadsheets. Then, the spreadsheets were compared to identify and correct transcription errors. The paper copies of the survey were locked in cabinets in case they need to be accessed by the researchers later on, and the spreadsheets were saved on a secure server. As seen in Table 4, in-class recruitment and survey distribution resulted in the highest response rate of all recruitment procedures.

Results

Population Size

The data was collected from the students taking one of the three courses (ME1770, ME2110, and Capstone) at the end of the Spring and Fall semesters in 2015. This allowed capturing the group of students that take the class during their first fall semester and those that wait until spring to take it. Between the six groups of participants, data was collected from a total of 810 participants, 404 participants in Spring, and 406 in the Fall of 2015.

Demographics

One of the main focuses of the longitudinal study is to understand the impact of university maker spaces on the female and underrepresented minority population. To do this, it is necessary that researchers are capturing diversity in terms of gender, race, and ethnicity. Table 5 shows the population distribution in terms of the participant's self-reported demographics in every course. The demographic results presented in this table show that the sample size of the female students and Black or African American students are lower than the total percentage of these groups in the undergraduate student body at 33.1% and 6.8% respectively [59]. But the percentages of these groups are similar to the percentages enrolled in mechanical engineering with 19.9% female students and 5.5% Black or African American [60]. Similarly, the sample collected from the Hispanic population is about the same as the total percentage of Hispanic or Latino at Georgia Tech at 6.4% [59], and enrolled in the college of mechanical engineering at 6.5% [60]. While the demographic characteristics of the recruited students is similar to the percentage enrolled in mechanical engineering, new initiatives should take place to increase the recruitment and retention of students with these demographic characteristics, to ensure that these populations are captured throughout the four-year longitudinal study.

Table 5: Demographic distribution of the respondents. The number within the parenthesis represent the percentage with respect to the population n.

Demographics	Spring 2015 ME1770 (n=146)	Spring 2015 ME2110 (n=211)	Spring 2015 Capstone (n=47)	Fall 2015 ME1770 (n=372)	Fall 2015 ME2110 (n=18)	Fall 2015 Capstone (n=16)
Gender						
Male	113 (0.77)	165 (0.78)	37 (0.79)	290 (0.79)	15 (0.83)	11 (0.69)
Female	26 (0.18)	42 (0.20)	9 (0.19)	80 (0.22)	2 (0.11)	4 (0.25)
Prefer not to disclose or No response	7 (0.05)	4 (0.02)	1 (0.02)	2 (0.01)	1 (0.06)	1 (0.06)
Race/Ethnicity (Select all that apply)						
White/Caucasian	86 (0.59)	147 (0.70)	36 (0.77)	249 (0.67)	9 (0.50)	11 (0.69)
Black or African American	7 (0.05)	8 (0.04)	2 (0.04)	16 (0.04)	0 (0.00)	0 (0.00)
American Indian or Alaskan Native	1 (0.01)	0 (0.00)	1 (0.02)	3 (0.01)	0 (0.00)	0 (0.00)
Native Hawaiian or Other Pacific Islander	0 (0.00)	0 (0.00)	0 (0.00)	2 (0.01)	1 (0.06)	0 (0.00)
Middle Eastern	3 (0.02)	0 (0.00)	0 (0.00)	3 (0.01)	1 (0.06)	0 (0.00)
Asian	39 (0.26)	42 (0.20)	6 (0.13)	109 (0.29)	8 (0.44)	4 (0.25)
Prefer not to disclose or No response	11 (0.08)	14 (0.07)	2 (0.04)	11 (0.03)	2 (0.11)	1 (0.06)
Hispanic or Latino						
Yes	9 (0.06)	11 (0.05)	3 (0.06)	37 (0.10)	4 (0.22)	1 (0.06)
No	124 (0.85)	194 (0.92)	43 (0.91)	330 (0.89)	14 (0.78)	15 (0.94)
Prefer not to disclose or No response	13 (0.09)	6 (0.03)	1 (0.02)	5 (0.01)	0 (0.00)	1 (0.06)

Participant Exclusion Criteria

There were several reasons for excluding participants from the data analysis and the reported results. If participants failed to complete all components of the design self-efficacy questionnaire, their data was not analyzed. Participants were also excluded if they answered every item of the instrument with the same score, disregarding the expected flip when reporting their anxiety to perform engineering design. This criterion was included to reject the data from the participants that tried to finish the survey as fast as possible without reading the actual questions. For all six courses, a total of 54 participants were excluded from the final results. The distribution of participant exclusion can be seen in Table 6.

Participation Level

Participants from every course were separated into high and low participation groups according to the participation criteria explained in Chapter 3; Students are considered to have low participation level if they have never used any of the equipment or resources available in the university maker space. Students are considered to have high participation if the following two requirements are met: 1) the students have used the university maker space for multiple types of activities, and 2) the purpose of their participation is not limited to class related projects. Table 6 presents an overview of the participant population and classification according to their participation level.

Table 6: Student classification in terms of their level of participation

Courses	Number of Participants	Excluded Participants	Participation Level		
			High	Medium	Low
Spring 2015					
ME 1770	146	8	43	36	59
ME 2110	211	24	66	59	62
Senior Capstone	47	4	20	19	4
Fall 2015					
ME 1770	372	16	77	68	211
ME2110	18	2	6	5	5
Senior Capstone	16	0	7	2	7

Pearson Correlation

As previously stated, the engineering design self-efficacy instrument is divided into four areas: self-confidence (CONF), motivation (MOT), expectancy of success (SUCC), and anxiety (ANX). Through their validation process, Carberry et al. found a correlation between ED and EDP scores of 0.890 for confidence (self-efficacy), 0.882 for motivation, 0.888 for expectancy of success, and 0.791 for anxiety [16]. As a validation mechanism and to ensure the correct behavior of the instrument a Pearson Correlation between ED and EDP, scores were calculated for the four self-concepts and the values were compared to the results from Carberry's correlation. While the correlations values found in this study were slightly lower than the ones found by Carberry et al., the results from the Pearson Correlation test still show high correlation between the ED and EDP scores for both semesters, validating the use of the instrument. The values can be seen in Table 7.

Table 7: Pearson Correlation between ED and EDP scores for all courses. The number of participants N represents both high and low participation groups.
** Correlations are significant at the 0.01 level.
* Correlation significant at the 0.05 level.

		ED and EDP Pearson R			
Courses	N	CONF	MOT	SUCC	ANX
Spring 2015					
ME 1770	102	.809**	.829**	.835**	.847**
ME 2110	128	.728**	.661**	.840**	.825**
Senior Capstone	24	.859**	.737**	.820**	.488*
Fall 2015					
ME 1770	288	.843**	.800**	.891**	.881**
ME 2110	11	.901**	.949**	.905**	.727*
Senior Capstone	14	.758**	.713**	.716**	.889**

Comparison between High and Low Participation Groups

The participants were separated into groups according to their level of participation in the university maker space according to the criteria described in Chapter 3. The distribution of these groups can also be seen in Table 6. The data was analyzed for normality (Shapiro-Wilk's test for normality) and equality of variance (Levene's Test for Equality of Variances) between the two groups. Two tests were used to compare the distributions of the engineering design self-efficacy scores from both groups: 1) the Independent Samples T-Test, a parametric statistical test that is robust against non-normality; and 2) the Mann-Whitney U test, a non-parametric test that does not require normality or equivariance to determine statical significance [61].

The differences between the two participation groups will be presented both in both graphical and tabular formats. When the distributions of the ED and EDP scores of the groups are equivariant, the results from both the Independent Samples T-Test and the Mann-Whitney U test are presented. Both tests are shown because the Independent Samples T-Test compares means of the populations, while the Mann-Whitney U test compares the medians. If the distribution fails Levene's Test for Equality of Variances, then only the results from the Mann-Whitney U are shown.

<u>Freshman - ME 1770 Spring 2015</u>

The Shapiro-Wilk’s Test of Normality showed that most of the self-concepts for the high and low involvement students were not normally distributed, and the Levene's Test showed that only the EDP score for anxiety was non-equivariant. The ED and EDP scores were compared in terms of participation (Figure 14). For this course, the involvement and participation survey (version 2) was implemented. In terms of ED scores, the results show that the high participation students are more confident, more motivated, have higher expectancy of success and are less anxious than the students that were considered low involvement. There is a statistically significant difference in all four self-concepts for the ED scores: self-confidence (Independent Samples T-Test, t= -2.65, df= 100 , p=0.009) (Mann-Whitney U, U=853, p=0.004), motivation (Independent Samples T-Test, t= -3.15, df= 100 , p=0.002) (Mann-Whitney U, U=809, p=0.002), expectancy of success (Independent Samples T-Test, t= -2.15, df= 100 , p=0.034) (Mann-Whitney U, U=879, p=0.007), and anxiety (Independent Samples T-Test, t= 2.05, df= 100 , p=0.043) (Mann-Whitney U, U=894, p=0.010). The results from the EDP scores show the same trend as in the ED scores, but only motivation was found to have astatistically significant difference between the two levels of involvement (Independent Samples T-Test, t= -2.74, df= 100, p=0.007) (Mann-Whitney U, U=833, p=0.003). A summary of the data analysis is presented in Table 8.

Table 8: Summary of the Spring 2015 ME 1770 data

Self-Concept		Participation Levels				Statistical Analysis Results				
		High (n=43)		Low (n=59)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	77.2	2.67	67.8	2.33	-2.65	100	0.009	853	0.004
	EDP	76.4	2.55	71.2	1.85	-1.71	100	0.090	944	0.028
Motivation (MOT)	ED	84.2	2.54	72.9	2.44	-3.15	100	0.002	809	0.002
	EDP	82.6	2.30	74.0	2.09	-2.74	100	0.007	833	0.003
Expectancy of Success (SUCC)	ED	76.5	3.10	68.8	2.05	-2.15	100	0.034	879	0.007
	EDP	76.1	2.48	71.0	1.77	-1.71	100	0.090	975	0.046
Anxiety (ANX)	ED	31.4	4.77	43.2	3.47	2.05	100	0.043	894	0.010
	EDP	36.1	4.40	39.7	2.90	-	-	-	1095	0.238

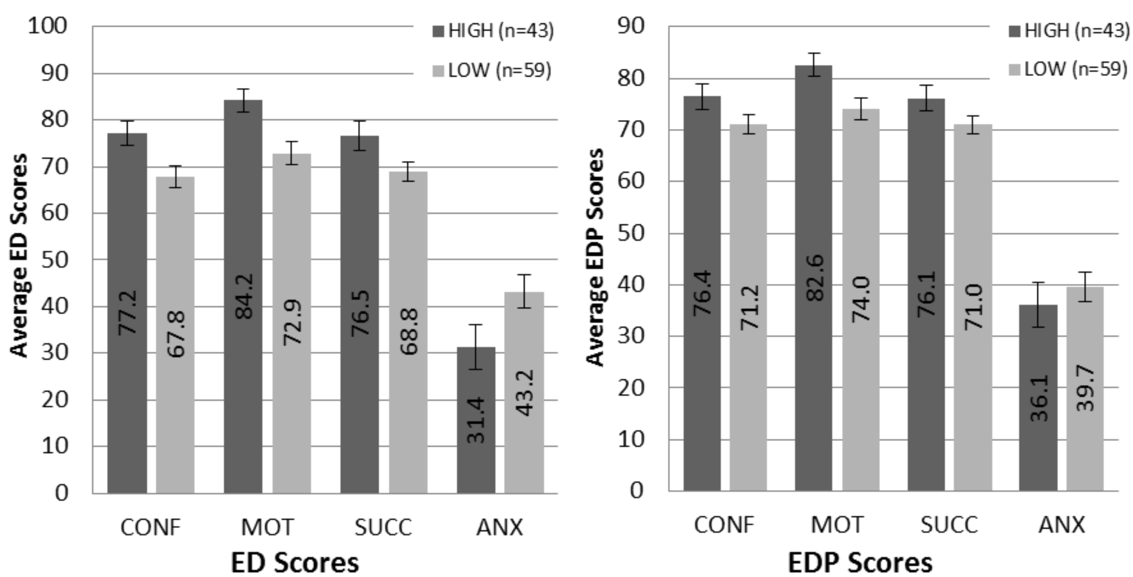


Figure 14: Comparison between high and low participation students in ME 1770 Spring 2015. The error bars represent ±1 S.E.

<u>Freshman - ME 1770 Fall 2015</u>

The Shapiro-Wilk's Test of Normality showed that the data was not normal, and through the Levene's Test for Equality of Variances only the ED scores for motivation showed non-equivariance. The ED and EDP scores were compared in terms of participation (Figure 15). The participation data was collected with the involvement and participation survey (version 3). Statistical significant differences were found for the ED scores: motivation (Mann-Whitney U, U=6866.0, p=0.040), and anxiety (Independent Samples T-Test, t= 2.406, df= 286, p=0.017) (Mann-Whitney U, U=6615.5, p=0.015). The results from the EDP scores show the same trend as in the ED scores, but only anxiety was found to have a statistically significant difference between the two levels of participation (Independent Samples T-Test, t= 1.849, df= 286, p=0.066) (Mann-Whitney U, U=6870.0, p=0.045). A summary of the data analysis is presented in Table 9.

Table 9: Summary of the Fall 2015 ME 1770 data

Self-Concept		Participation Levels				Statistical Analysis Results				
		High (n=77)		Low (n=211)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	76.2	2.28	75.3	1.23	-0.40	286	0.692	7569	0.365
	EDP	78.0	1.95	76.4	1.07	-0.72	286	0.474	7239	0.157
Motivation (MOT)	ED	85.2	1.76	78.9	1.46	-	-	-	6866	0.040
	EDP	82.2	1.63	77.8	1.25	-1.93	286	0.054	7080	0.095
Expectancy of Success (SUCC)	ED	75.2	2.29	73.6	1.39	-0.59	286	0.553	7718	0.509
	EDP	76.1	1.86	74.2	1.23	-0.81	286	0.418	7565	0.371
Anxiety (ANX)	ED	35.6	3.25	45.2	2.09	2.41	286	0.017	6616	0.015
	EDP	36.4	2.99	42.9	1.83	1.85	286	0.066	6870	0.045

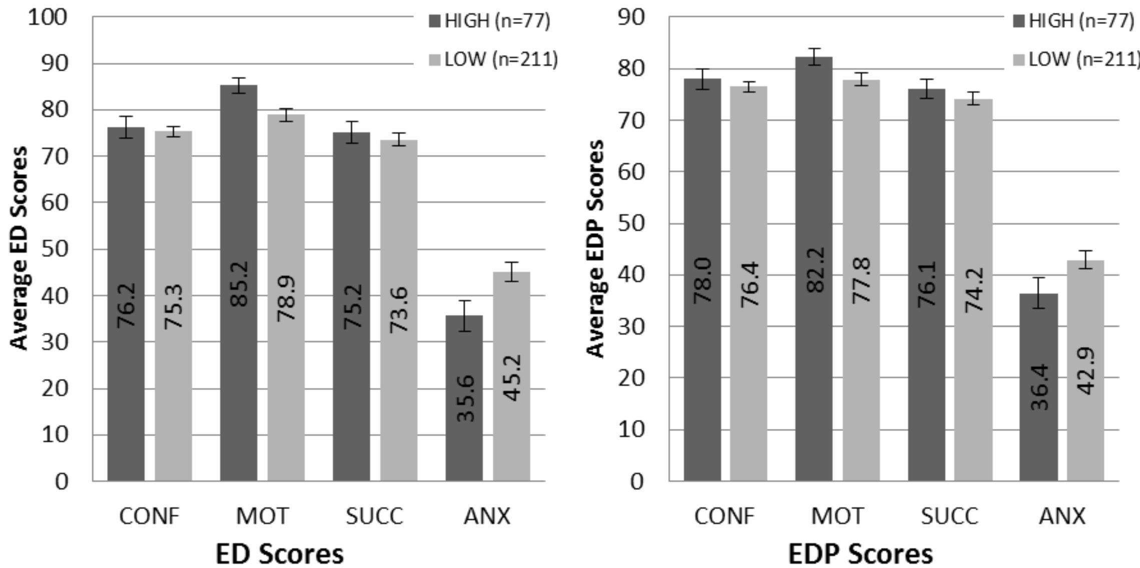


Figure 15: Comparison between high and low participation students in ME 1770 Fall 2015. The error bars represent ±1 S.E.

Semester Differences between ME 1770 participants

To further analyze the data from the students enrolled in the freshmen level course, the overall student population from the Spring and Fall semesters were compared in terms of their engineering design self-efficacy scores. The statistical similarities between the two semesters were determined by implementing the Independent Samples T-Test and the Mann-Whitney U Test. The engineering design self-efficacy score distributions for both groups were found to be non-normal but equivariant. The ED and EDP scores were compared between Spring and Fall semesters (Figure 16). Only the difference in the ED confidence score was found to be statistically significant (Independent Samples T-Test, $t= -2.89$, $df= 492$, $p=0.004$) (Mann-Whitney U, $U=20271$, $p=0.002$). However, the differences for motivation and expectancy were statistically inconclusive and thus require further investigation. The results from the EDP scores show the same trend as the ED scores. Only the difference in confidence was found to be statistically significant (Independent Samples T-Test, $t= -2.93$, $df= 492$, $p=0.004$) (Mann-Whitney U, $U=19919$, $p=0.001$). A summary of the data analysis is presented in Table 10. The differences found might be due to students enrolled in the fall semester being more confident than the students that wait until the spring semester to take ME 1770. However, future studies are required to validate this relationship.

Table 10: Summary of the comparison between Spring and Fall of 2015 cohorts from ME1770

Self-Concept		Semester				Statistical Analysis Results				
		Spring (n=138)		Fall (n=356)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	70.7	1.57	75.8	0.93	2.89	492	0.004	20271	0.002
	EDP	72.4	1.37	77.0	0.81	2.93	492	0.004	19919	0.001
Motivation (MOT)	ED	77.8	1.58	80.2	1.04	1.22	492	0.221	22170	0.086
	EDP	77.3	1.36	78.7	0.90	0.81	492	0.417	22755	0.203
Expectancy of Success (SUCC)	ED	71.3	1.56	74.2	1.05	1.49	492	0.137	21618	0.035
	EDP	72.2	1.38	74.7	0.90	1.49	492	0.136	21716	0.045
Anxiety (ANX)	ED	39.6	2.54	42.2	1.56	0.85	492	0.394	23284	0.365
	EDP	39.8	2.19	40.9	1.37	0.42	492	0.673	24027	0.706

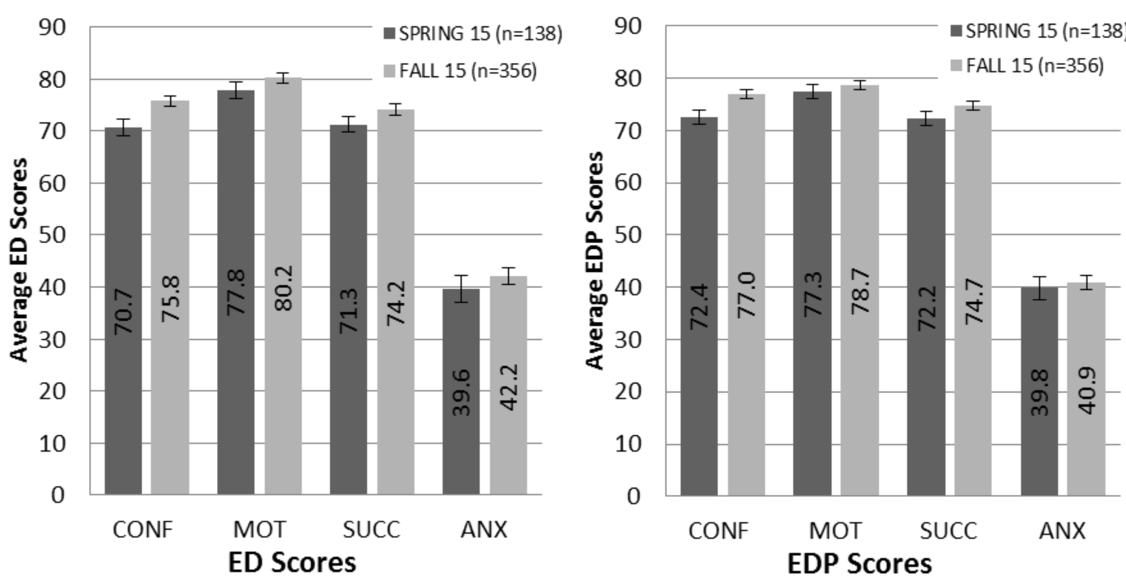


Figure 16: Comparison between students spring and fall semesters for the freshman level course. The error bars represent ±1 S.E.

While the results from the previous comparison showed that the two groups might be different with respect to their self-efficacy scores, a larger sample of semesters are needed to further investigate the differences and similarities. Since only the confidence score was found to be clearly statistically different, both ME1770 cohorts were combined for further analysis. Once again, the ED and EDP scores were compared in terms of participation (*Figure 17*). Students were classified in terms of participation levels, and their engineering design self-efficacy scores were compared. The results showed that there was a statistically significant difference in two self-concepts for the ED scores: motivation (Mann-Whitney U, U=13010, p=0.002), and anxiety (Independent Samples T-Test, t= 3.29, df= 388, p=0.001) (Mann-Whitney U, U=12636, p<0.001). The result from the EDP scores show the same trend as in the ED scores: motivation (Independent Samples T-Test, t= -2.92, df= 388, p=0.004) (Mann-Whitney U, U=13271, p=0.004), and anxiety (Independent Samples T-Test, t= 2.06, df= 388, p=0.04) (Mann-Whitney U, U=13804, p=0.02). A summary of the data analysis is presented in Table 11. According to these results, students that have a higher level of participation are more motivated and less anxious than students with low levels of participation. One possible explanation is that anxiety and lack of motivation might create barriers that prevent students from participating in university maker spaces. Capturing participation and self-efficacy data at the beginning and end of the freshman level course might help to discover if participation is due to being self-efficacious or if students that participate in maker spaces become more motivated and less anxious about performing engineering design tasks.

Table 11: Summary of the ME 1770 combined cohorts data

Self-Concept		Participation Levels				Statistical Analysis Results				
		High (n=120)		Low (n=270)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	76.6	1.74	73.6	1.10	1.46	388	0.144	14216	0.049
	EDP	77.4	1.54	75.3	0.94	1.22	388	0.223	14148	0.046
Motivation (MOT)	ED	84.8	1.44	77.6	1.27	-	-	-	13010	0.002
	EDP	82.4	1.32	77.0	1.08	-	-	-	13271	0.004
Expectancy of Success (SUCC)	ED	75.7	1.84	72.6	1.18	1.45	388	0.149	14297	0.059
	EDP	76.1	1.48	73.5	1.04	1.40	388	0.161	14492	0.096
Anxiety (ANX)	ED	34.1	2.69	44.7	1.80	-3.29	388	0.001	12636	<0.001
	EDP	36.3	2.47	42.2	1.56	-2.06	388	0.040	13804	0.020

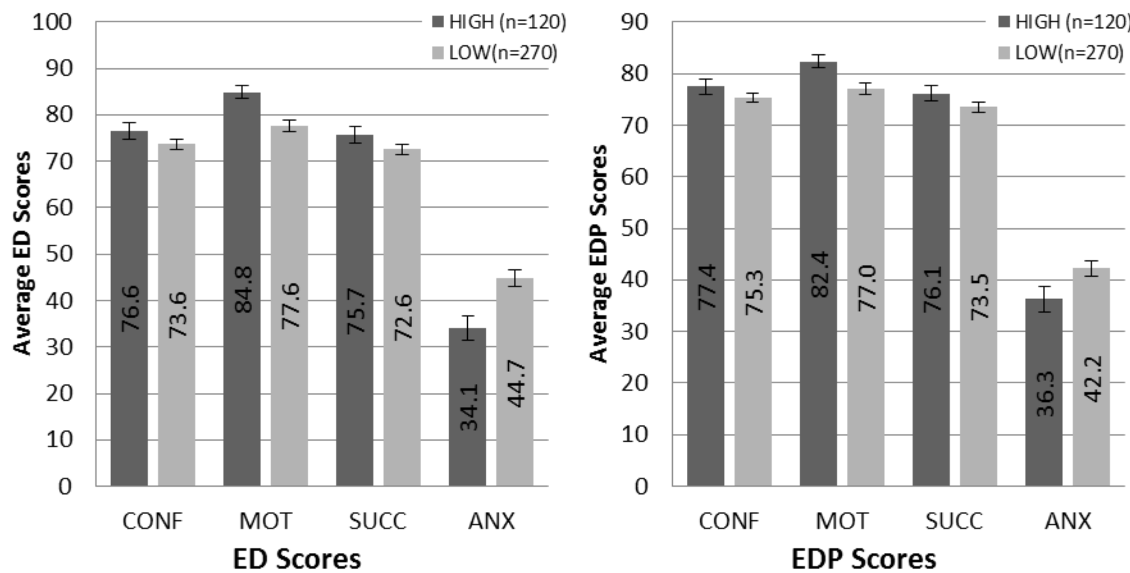


Figure 17: Comparison between high and low participation from the combined ME1770 data. The error bars represent ±1 S.E.

<u>Refining Semester Differences – ME 1770</u>

To identify the reason for the semester differences, the high participation students from Spring semester to the high participation group from Fall were compared. Both the Independent Samples T-Test and the Mann-Whitney U revealed that there was no statistically significant difference for any of the four self-concepts. *Figure 18* shows the ED and EDP scores for the high participation groups in Spring and Fall. A summary of the data analysis is presented in Table 12.

Table 12: Summary of the comparison between high participation Students from Spring and Fall

Self-Concept		Semester				Statistical Analysis Results				
		Spring (n=43)		Fall (n=77)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	77.2	2.67	76.2	2.28	-0.27	118	0.789	1651	0.978
	EDP	76.4	2.55	78.0	1.95	0.48	118	0.633	1522	0.463
Motivation (MOT)	ED	84.2	2.54	85.2	1.76	0.33	118	0.739	1607	0.781
	EDP	82.6	2.30	82.2	1.63	-0.13	118	0.901	1612	0.809
Expectancy of Success (SUCC)	ED	76.5	3.10	75.2	2.29	-0.34	118	0.733	1550	0.553
	EDP	76.1	2.48	76.1	1.86	-0.02	118	0.987	1648	0.967
Anxiety (ANX)	ED	31.4	4.77	35.6	3.25	0.75	118	0.457	1472	0.309
	EDP	36.1	4.40	36.4	2.99	0.05	118	0.960	1595	0.740

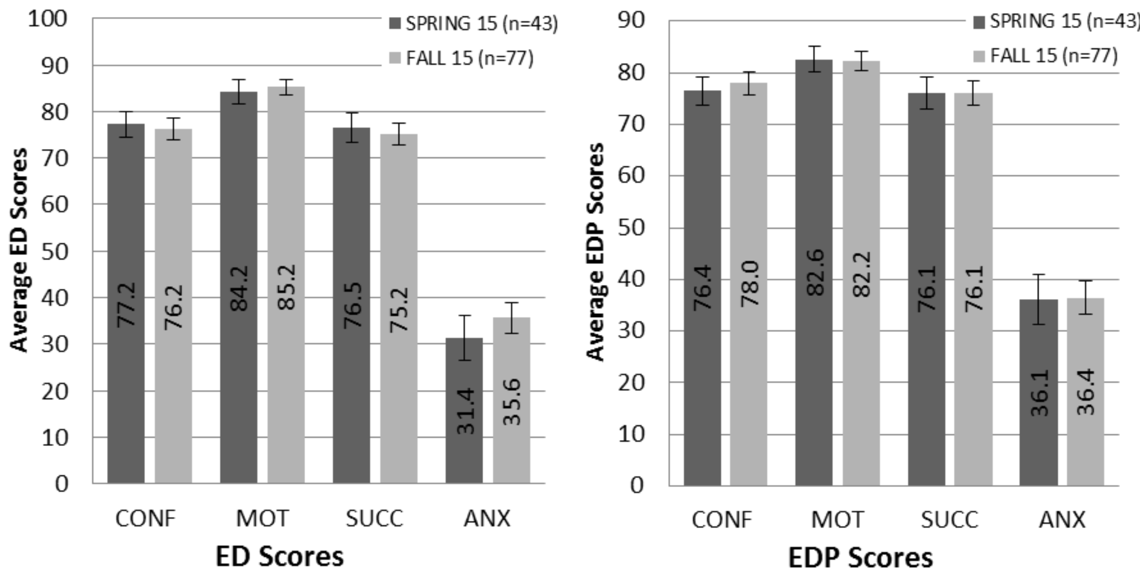


Figure 18: Comparison of high participation students between the two cohorts of ME 1770 students. The error bars represent ±1 S.E.

On the other hand, when the low participation groups from Spring and Fall semesters were compared, a statistically significant difference between the two was discovered. Figure 19 shows the ED and EDP scores for the high participation groups in Spring and Fall. Statistically significant differences between the semesters were found in two self-concepts for the ED scores: confidence (Independent Samples T-Test, t= -2.84, df= 268, p=0.005)(Mann-Whitney U, U=4599, p=0.002), and motivation (Independent Samples T-Test, t= -1.96, df= 268, p=0.05)(Mann-Whitney U, U=4826, p=0.007). The results from the EDP scores show the same trend as in the ED scores, but only the difference in confidence was found to be statistically significant (Independent Samples T-Test, t= -2.35, df= 268, p=0.02) (Mann-Whitney U, U=4717, p=0.004). A summary of the data analysis is presented in Table 13.

Table 13: Summary of the comparison between low participation Students from Spring and Fall

Self-Concept		Semester				Statistical Analysis Results				
		Spring (n=59)		Fall (n=211)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	67.8	2.33	75.3	1.23	2.84	268	0.005	4599	0.002
	EDP	71.2	1.85	76.4	1.07	2.35	268	0.020	4717	0.004
Motivation (MOT)	ED	72.9	2.44	78.9	1.46	1.96	268	0.051	4826	0.007
	EDP	74.0	2.09	77.8	1.25	1.46	268	0.146	5120	0.037
Expectancy of Success (SUCC)	ED	68.8	2.05	73.6	1.39	1.69	268	0.093	4911	0.012
	EDP	71.0	1.77	74.2	1.23	1.25	268	0.213	5095	0.033
Anxiety (ANX)	ED	43.2	3.47	45.2	2.09	0.45	268	0.656	6091	0.800
	EDP	39.7	2.90	42.9	1.83	-	-	-	5842	0.471

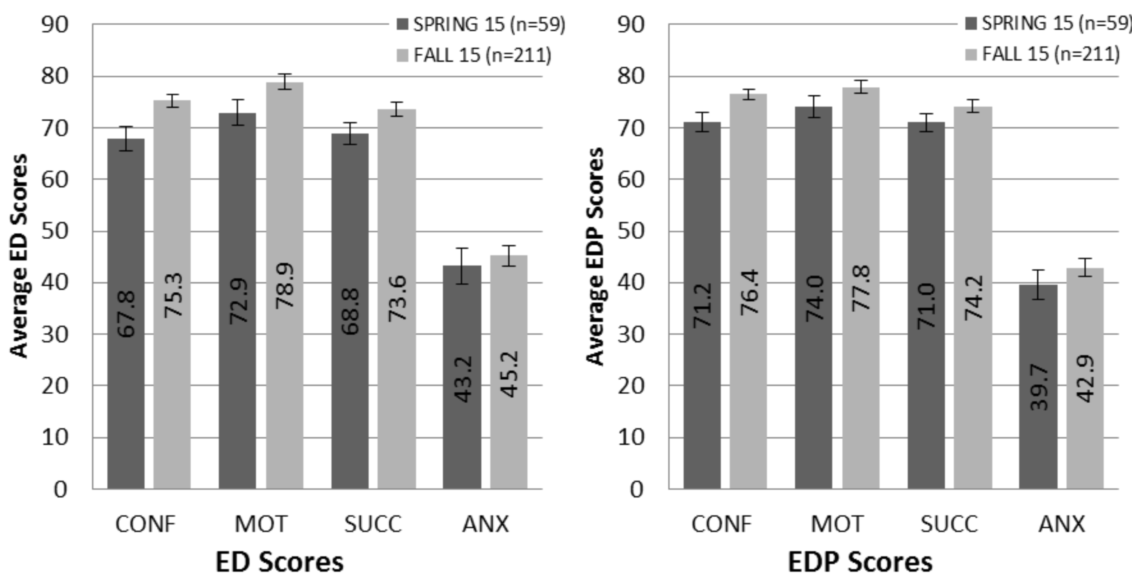


Figure 19: Comparison of low participation students between the two cohorts of ME 1770 students. The error bars represent ±1 S.E.

Due to the design self-efficacy differences between the low participation students from both semesters, it can be argued that the low participation students in Spring and Fall semesters might come from two distinct populations. It is possible that during the Fall semester, highly confident freshman students have not had the opportunity to participate in the university maker space. This theory can be supported through the results seen in Figure 20. This graph shows that there is a higher percentage of high participation students and a lower percentage of low participation students in the Spring semester when compared to the Fall semester. Throughout the Spring semester, highly confident students will have more opportunities to participate in university maker space related activities. By the end of Spring semester, originally low participation students will be considered to be part of the high participation group. The migration from low to high participation might be the cause of the differences between the low participation group from Spring and Fall. This also indicates that there are existing processes in place that help students make this transition from low participator to high participator.

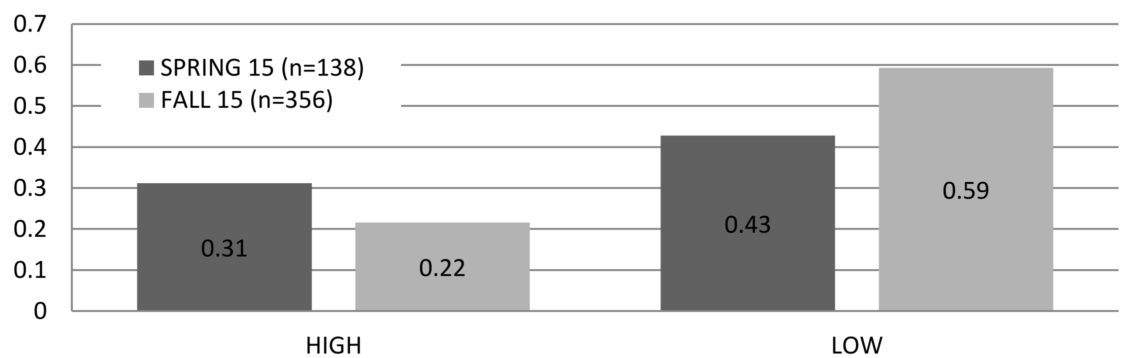


Figure 20: Percentage of high and low participation students in both of the two freshman level courses

Differences between genders were also explored by comparing the percentages of high and low participation students during both semesters as shown in Figure 21. The percentages of female and male students that were considered to be high and low participation were compared over spring and fall. The graph shows that the male population behaves similarly to the trends seen in Figure 20. The percentage of high participation males in the spring semester is higher than in the fall, and the percentage of low participation males is lower in the spring than in the fall semester. Conversely, the female population does not show the same behavior. Figure 21 shows that there is no semester variation between the percentages of female students in the high and low participation groups. This may indicate that the process of migrating from low to high participation does not affect the female population the same way it affects the male population. One possible explanation is through the existence of gender based barriers that affect the female population to a different degree than the male population. Further studies are required to have a better understanding of this behavior.

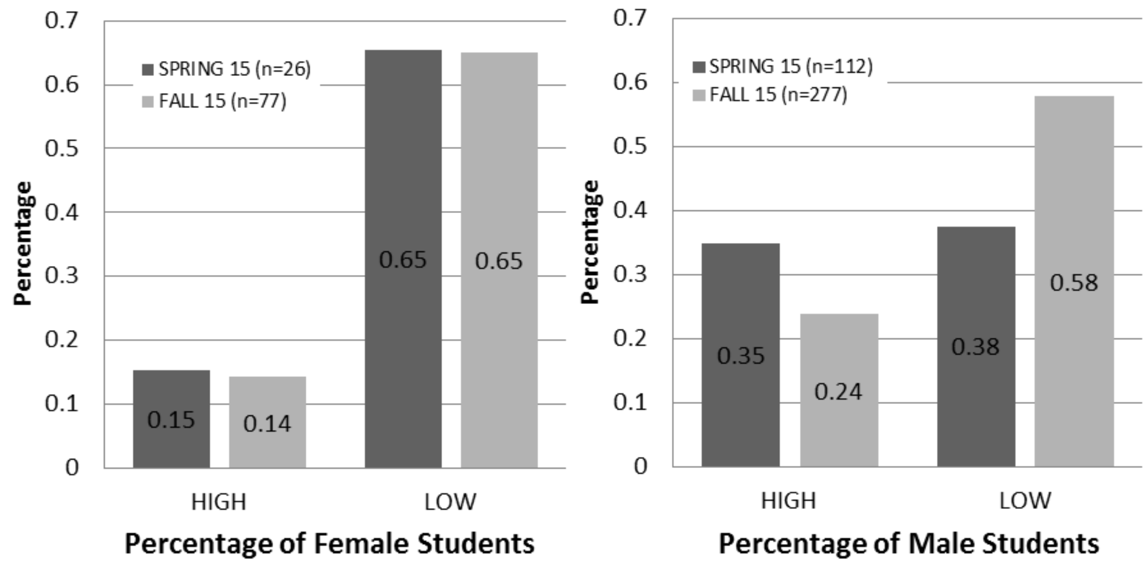


Figure 21: Gender based percentage of high and low participation students in both of the two freshman level courses

Exploring Gender Differences – ME 1770

The gender difference previously found was further studied by comparing female and male students in terms of their design self-efficacy scores. The Shapiro-Wilk’s Test of Normality showed that most of the self-concepts for the high and low involvement students were not normally distributed, and the Levene's Test showed that only the EDP score for motivation was non-equivariant. The ED and EDP scores were compared in terms of participation (Figure 22). In terms of ED scores, the results show that the male students have higher expectancy of success and are less anxious than the female students. There is statistical significant difference in two self-concepts for the ED scores: expectancy of success (Independent Samples T-Test, t= -1.94, df= 490 , p=0.053) (Mann-Whitney U, U=17370, p=0.034), and anxiety (Independent Samples T-Test, t= 3.43, df= 490 , p=0.001) (Mann-Whitney U, U=15816, p=0.001). The results from the EDP scores show that only anxiety was found to have statistical significant difference between male and female students (Independent Samples T-Test, t= 3.32, df= 490, p=0.001) (Mann-Whitney U, U=15615, p=0.001). A summary of the data analysis is presented in Table 14. The data shows that in general, male students are less anxious about performing engineering design related tasks than female students. Future studies will investigate the gender difference while taking into consideration level of participation. This will allow identifying if there are gender based self-efficacy differences between high and low participation groups.

Table 14: Summary of the gender differences in ME 1770

Self-Concept		Participation Levels				Statistical Analysis Results				
		Female (n=103)		Male (n=389)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	72.9	1.62	74.8	0.92	-0.96	490	0.337	18423	0.201
	EDP	75.9	1.41	75.7	0.81	0.12	490	0.905	19854	0.889
Motivation (MOT)	ED	78.6	1.84	79.9	0.98	-0.58	490	0.562	18989	0.406
	EDP	79.3	1.34	78.1	0.88	-	-	-	19953	0.950
Expectancy of Success (SUCC)	ED	70.1	1.90	74.3	0.99	-1.94	490	0.053	17370	0.34
	EDP	72.2	1.65	74.5	0.85	-1.21	490	0.228	18280	0.172
Anxiety (ANX)	ED	50.3	3.00	39.2	3.98	3.43	490	0.001	15816	0.001
	EDP	48.1	2.46	42.7	38.7	3.32	490	0.001	15615	0.001

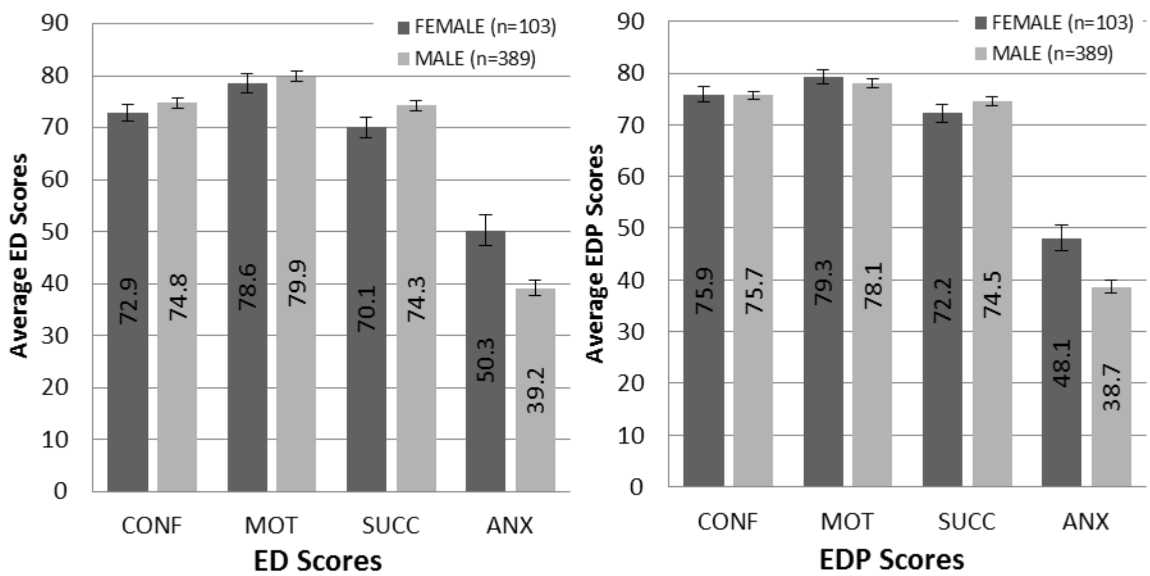


Figure 22: Comparison of female and male students in terms of engineering design self-efficacy scores. The error bars represent ±1 S.E.

<u>Sophomore - ME 2110 Spring 2015</u>

On the contrary, when comparing the ED and EDP scores of the sophomore level design course (Figure 23), there was no discernible trend between high and low participation students. Moreover, there was no statistically significant difference between the two groups for ED and EDP. There might be multiple reasons for the lack of difference between participation levels and their design self-efficacy scores in this group. For this study, the first version of the involvement and participation survey was used. As explained in Chapter 3, this survey suffered from questions that limited the classification of students in terms of their participation levels. The survey implemented in the freshman class allowed researchers to be more selective when classifying individuals according to their participation level, which resulted in differences between the two groups. Collecting data from the sophomore level course with the final version of the survey will clarify if high and low participation groups are in fact equal in terms of their engineering design self-efficacy scores. The lack of difference could also mean that there is simply no difference in terms of design self-efficacy between these two groups once they reach their second semester in engineering. However, given the results from the freshman level courses, further studies are required. A summary of the data analysis is presented in Table 15Table 15.

Table 15: Summary of the Spring of 2015 ME 2110

Self-Concept		Participation Levels				Statistical Analysis Results				
		High (n=66)		Low (n=62)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	73.5	2.05	69.8	2.59	-1.13	126	0.259	1858	0.362
	EDP	77.1	1.50	75.2	1.87	-0.78	126	0.440	1914	0.529
Motivation (MOT)	ED	76.7	2.39	77.3	2.47	0.20	126	0.845	1989	0.783
	EDP	77.7	1.91	76.0	1.77	-0.65	126	0.519	1844	0.334
Expectancy of Success (SUCC)	ED	74.8	1.87	73.0	2.50	-0.60	126	0.549	2020	0.900
	EDP	77.6	1.62	74.3	1.99	-1.30	126	0.197	1791	0.224
Anxiety (ANX)	ED	40.9	3.68	42.6	3.98	0.31	126	0.758	1982	0.759
	EDP	37.6	2.76	42.7	3.29	1.20	126	0.234	1828	0.297

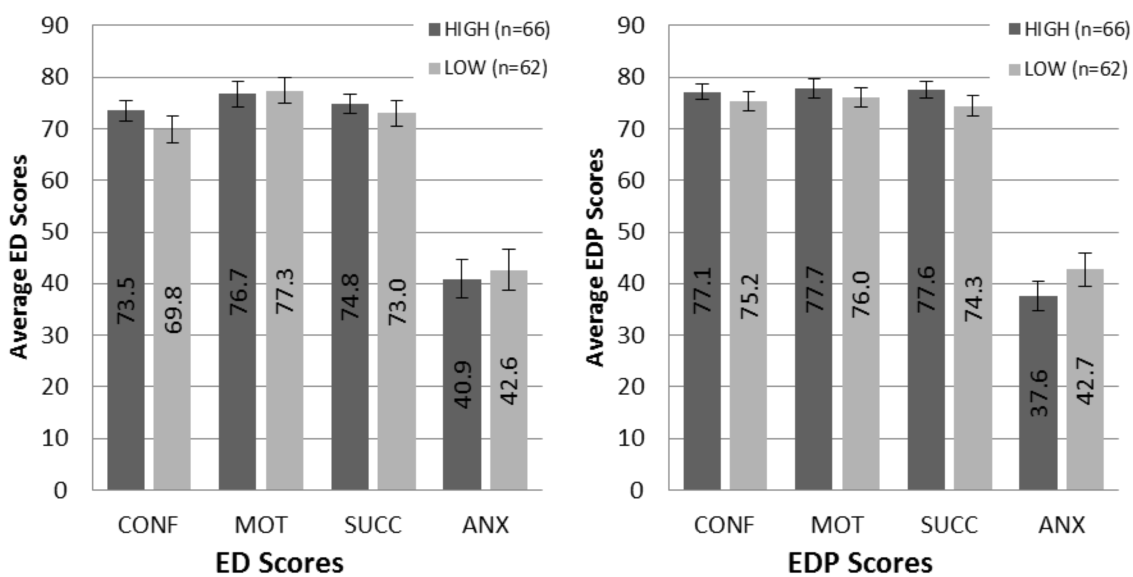


Figure 23: Comparison between high and low participation students in ME 2110 Spring 2015. The error bars represent ±1 S.E.

<u>Sophomore - ME 2110 Fall 2015</u>

When comparing the ED and EDP scores of the sophomore level design course (Figure 24), the trends show that the high participation students are more confident, more motivated, have higher expectancy of success and are less anxious than the students that were considered low involvement. Given the low number of participants, it is necessary that a bigger sample is collected to have more conclusive results. The low number of participants from this course was due to the recruitment methodology implemented. The students in this course were approached and recruited uniquely via email. Since emails are easily ignored, in-class recruitment could result in higher response rates. Through this recruitment process, researchers were able to have good response rates for other classes, so there is reason to believe that the same process could result in a higher response rate for this course. Recruiting during class time will help to ensure that the data necessary for the longitudinal study is collected. A summary of the data analysis is presented in Table 16.

Table 16: Summary of the Fall of 2015 ME 2110 data

Self-Concept		Participation Levels				Statistical Analysis Results				
		High (n=6)		Low (n=5)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	81.7	12.49	64.0	6.78	-1.17	9	0.272	5	0.064
	EDP	81.3	7.90	65.0	4.45	-1.69	9	0.125	5	0.067
Motivation (MOT)	ED	93.3	6.67	64.0	12.9	-2.13	9	0.062	6	0.059
	EDP	87.5	5.66	64.3	6.91	-2.63	9	0.027	4	0.044
Expectancy of Success (SUCC)	ED	78.3	10.14	66.0	6.78	-0.97	9	0.359	7	0.133
	EDP	82.7	6.13	64.8	5.62	-2.12	9	0.063	4	0.035
Anxiety (ANX)	ED	15.0	5.63	36.0	11.7	1.72	9	0.120	8	0.164
	EDP	26.9	6.10	35.0	9.18	0.76	9	0.466	11	0.409

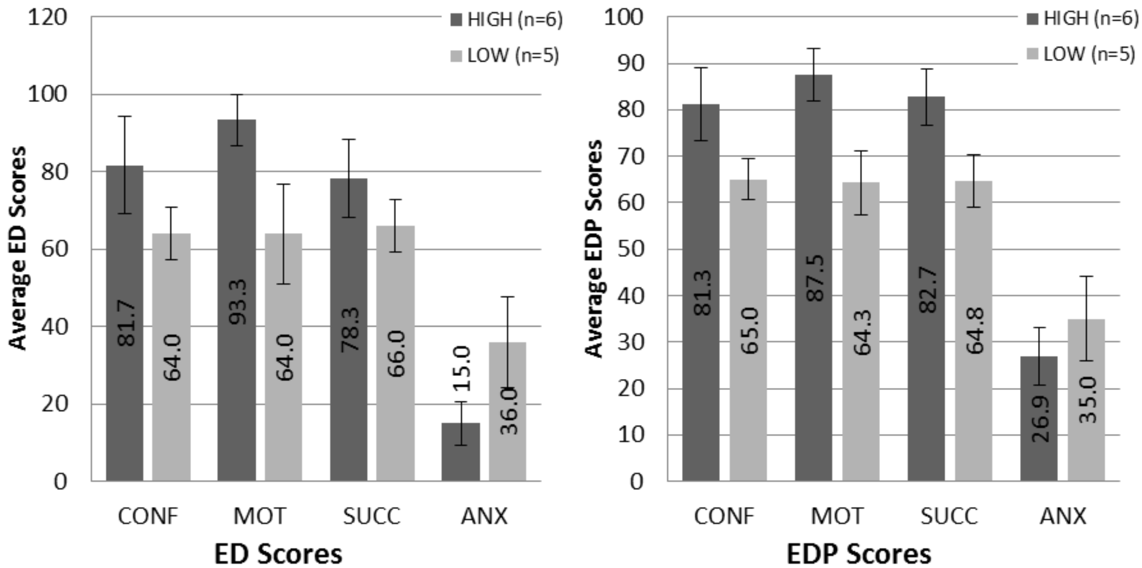


Figure 24: Comparison between high and low participation students in ME 2110 Fall 2015. The error bars represent ±1 S.E.

<u>Capstone Spring 2015</u>

Similar to the results found in the sophomore level course, there is no easily identifiable trend when comparing the ED and EDP scores, with the exception of EDP anxiety scores (Figure 25). Another issue with the data collected from the capstone course is that from the 55 total participants, only 4 were identified as having low participation. The small sample of low participation students could mean that Georgia Tech is doing a good job in exposing students to the Invention Studio. If the sample size for low participation students continues to be this small, it might be necessary to create a new criteria for participation to compare students once they are enrolled in capstone. To get more conclusive results, it is necessary to collect data from a bigger sample. A summary of the data analysis is presented in Table 17.

Table 17: Summary of the Spring of 2015 Capstone data

Self-Concept		Participation Levels				Statistical Analysis Results				
		High (n=20)		Low (n=4)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	71.0	4.35	72.5	7.50	0.15	22	0.886	40	0.968
	EDP	77.1	3.09	74.1	5.96	-0.41	22	0.684	33	0.561
Motivation (MOT)	ED	68.5	5.63	77.5	10.3	0.67	22	0.511	32	0.530
	EDP	74.2	3.59	75.3	5.24	0.13	22	0.895	38	0.846
Expectancy of Success (SUCC)	ED	66.0	5.30	70.0	7.07	0.32	22	0.750	39	0.937
	EDP	74.4	3.49	75.9	4.72	0.19	22	0.850	40	1.000
Anxiety (ANX)	ED	40.0	6.24	67.5	6.29	-	-	-	19	0.092
	EDP	34.8	4.07	66.6	4.93	3.35	22	0.003	5	0.007

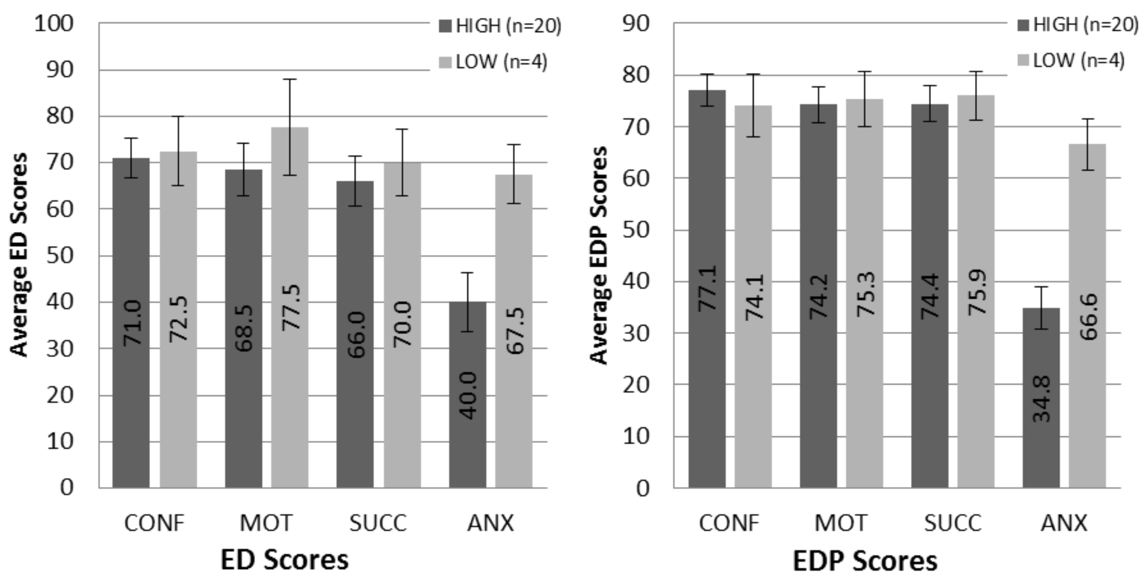


Figure 25: Comparison between high and low participation students in Capstone Spring 2015. The error bars represent ±1 S.E.

Capstone Fall 2015

When comparing the ED and EDP scores of the senior level design course (Figure 26), there is no easily identifiable trend between the high and low participation students. The low number of participants from this course was due to the recruitment methodology implemented. As described earlier in the chapter, the students in this course were approached and recruited uniquely via email. Since emails are easily ignored, researchers need to recruit students, and if possible, gather the survey data during their class time.

Through this recruitment process, researchers were able to have good response rates for other classes, so there is reason to believe that the same process could result in a higher response rate for this course. Recruiting during class time will help to ensure that the data necessary for the longitudinal study is collected. A summary of the data analysis is presented in Table 18.

Table 18: Summary of the Fall of 2015 Capstone data

Self-Concept		Participation Levels				Statistical Analysis Results				
		High (n=7)		Low (n=7)		Independent Samples T-Test			Mann-Whitney U	
		Mean	SE	Mean	SE	t	df	p-value	U	p-value
Confidence (CONF)	ED	77.1	4.21	78.6	5.95	0.20	12	0.848	22	0.742
	EDP	76.3	3.35	75.7	3.06	-0.12	12	0.908	21	0.654
Motivation (MOT)	ED	78.6	5.53	75.7	5.28	-0.37	12	0.715	19.5	0.508
	EDP	77.5	3.86	73.6	4.68	-0.65	12	0.529	18	0.406
Expectancy of Success (SUCC)	ED	74.3	6.85	70.0	4.36	-0.53	12	0.607	17.5	0.358
	EDP	78.0	2.67	68.4	3.75	-2.10	12	0.058	10.5	0.073
Anxiety (ANX)	ED	57.1	11.07	60.0	10.7	0.19	12	0.856	23.5	0.897
	EDP	42.1	5.83	57.0	8.25	1.47	12	0.168	13.5	0.159

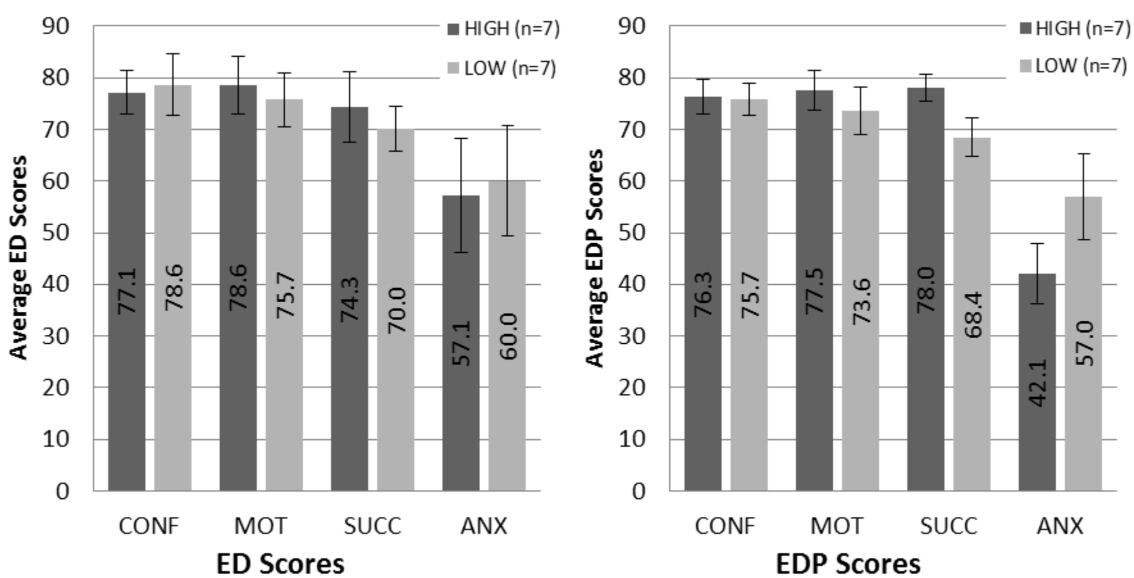


Figure 26: Comparison between high and low participation students in Capstone Fall 2015. The error bars represent ±1 S.E.

Limitations

One of the main limitations of this study was the small sample sizes associated with some of the courses in which the data was collected. The small sample sizes might be associated with the different data collection and survey distribution methods that were used. Variations in the time of the day and day of the week when data was collected could also have an impact on the survey responses. Data was also collected during different weeks throughout the semester, which could have an unwanted effect on the responses based on the different levels of maker space exposure or the motivation to participate in the study.

This study had some limitations associated with the survey instrument implemented. Since the students were not required to participate in the study, there might be an impact on the accuracy of the student's responses based on the lack of motivation to take the survey. While measures were taken to aid the students with the memory recall, the responses might also be affected by the inability of some students to accurately remember their involvement in maker spaces. Finally, there might be limitations associated with the students electing not to disclose certain information on the survey

Conclusion

The data collection methodology presented in this chapter allowed for the classification and characterization of university maker space users and non-users. Survey theory was used to design and validate the survey instrument capable of effectively differentiating between degrees of university maker space usage in terms of involvement and participation. A criterion for classifying students in terms of their participation was developed and successfully implemented. The survey created empowered researchers with the ability to accurately capture different levels of maker space usage. The survey's design and implementation was the first step to standardize the process of comparing maker space usage and impact across academic institutions.

The data collection methodology was studied to identify issues that could negatively affect the success of the longitudinal study. To do this, the impact of recruitment and survey distribution methodologies on the overall sample size and demographical characteristics was identified. By comparing the sample size from multiple different methods of recruitment and survey distribution, it was found that recruiting and distributing the survey during class time resulted in the highest response rates. Thus whenever possible, it is recommended that researchers follow these data collection methods. By identifying the demographic characteristics of the students that were recruited, it was found that the current data collection methodology is capturing a representative sample of students with different demographic characteristics with respect to the percentage of these groups enrolled in the school of mechanical engineering. These findings and recommendations will ensure that the longitudinal study is able to answer the question about the impact of maker spaces on the female and underrepresented minorities' retention in engineering.

Finally, by combining the involvement and participation survey with Carberry's engineering design self-efficacy, it was possible to differentiate the students that self-select to participate in university maker spaces from the more common low participation students with respect to confidence when performing engineering design related tasks. The results presented in this chapter showed a positive correlation between levels of participation in university maker spaces during freshman year and two engineering design self-concepts, motivation and anxiety. Students that participate in university maker spaces tend to be more motivated and less anxious about performing engineering design tasks. This result, while not surprising, provides an indicator that perhaps those students with a natural inclination to use the space have a propensity to seek out opportunities to engage in the maker space. This result suggests that anxiety might be a significant barrier for students to start participating in university maker spaces. Finding approaches to reduce student anxiety surrounding design activities may also lead to greater participation in maker spaces where students have the opportunity to build knowledge, skills, and self-efficacy.

Another interesting finding from this study was the migration of self-efficacious students from low to high levels of participation. The design self-efficacy scores from the low participation students in the Fall semester were better than the scores from the students enrolled during the Spring. This difference was further investigated by comparing the percentage of high and low levels of participation with respect to the entire sample population. This comparison showed that there was a higher percentage of high participation students and a lower percentage of low participation students in the spring semester. It is thought that students that originally take the freshmen level course during the fall semester have not had the opportunity to get involved and participate in the activities related to the university maker space. But the students that wait to take the course during the spring semester had more opportunities to participate, hence the higher percentage of high participation. This finding drives the belief that there might be some processes that help self-efficacious students to migrate from the low to high levels of participation, and should be further evaluated in future studies.

Since this study focused on the first two semesters of a four-year multi-university longitudinal study, the current results only demonstrate correlation between student participation in maker spaces and the four self-concepts associated with engineering design self-efficacy. The longitudinal results should be able to start to discern if students with more motivation and less anxiety about design tend to join maker spaces, demonstrating causality and impact of these learning environments. These two factors in combination could indicate that university maker spaces must be very easy for students to engage with and minimize many barriers in order to be successful. If only the students with very high levels of motivation to do design related activity participate, these spaces may be under-utilized.

CHAPTER 5

NON-OBTRUSIVE METHOD FOR COUNTING MAKER SPACE USERS

Accurately counting the number of students using university maker spaces could be a valuable method to identify characteristics that differentiate users and non-users and to understand the overall impact of these environments in engineering education. In some studies, researchers report the number of people using university maker spaces as a measure of success [4], while in others, it is used to emphasize the importance and impact of maker spaces in higher education [17, 18]. However, the method to find this number is not often reported, and it is often a crude estimate of the real quantity. The more open and less restrictive university maker spaces are, the more difficult it is to track the number of users. Developing an effective and accurate way to measure the number of users attending university maker spaces could further increase the value for additional reasons, including: 1) Predicting material and equipment needs throughout the year for increased efficiency, 2) Understanding traffic data to determine the optimal periods for maximum availability of equipment and resources, 3) Quantifying the impact of layout changes within the university maker spaces, 4) Determining peaks and off seasons based on daily usage data, and 5) Leveraging data to emphasize the importance of the space, given the number of users and to raise capital. Current methods of traffic analysis use Automatic People Counters (APCs). Due to their intrinsic benefits, APCs could help university maker spaces, like the Invention Studio, to determine user traffic in a non-obtrusive way. This could be extremely valuable to minimize the number of entry barriers preventing students from using university maker spaces and at the same time collect data that will allow us to characterize student makers.

In this chapter, the advantages of implementing an APC system in a well-developed university maker space are evaluated. For the pilot study, the APC camera was installed in the Invention Studio's 3D Printing room. To validate the accuracy of the technology, the APC data was compared to the manually collected data via a camera located in the room. Due to the open access nature of the 3D Printing room and 3D printer technology, users tend to walk in and out of the room multiple times a day, as they wait for their prints to complete. Since the APC technology cannot identify if the same individual entered multiple times a day, the pre-existing camera was employed to determine the ratio between count data and the number of individuals that use the room each day. This ratio will allows to use the APC's automatically collected count data to determine the total number of unique individual users for any day throughout the year.

Background

ClearCount Active IR PC-VAIR-5

After looking at multiple different types of APC technologies, the ClearCount Active IR was selected for multiple reasons. 1) The counter's infrared technology works under poorly lighted conditions, and even in total darkness. 2) The counter captures the heat signature of the people and tracks their movement to determine bidirectional (differentiating people walking in and out of the room) count data with a minimum of 95% accuracy. 3) The software provided by SenSource allows for live monitoring of the count data. 4) The entire system had a one-time payment of $995 with free installation and customer service.

The ClearCount Active IR developed by SenSource Inc. uses an infrared camera technology to provide count data with a minimum of 95% accuracy [62]. This counter comes bundled with two software packages: the ClearCount Active IR software and the Vea Software. The ClearCount Active IR software can be accessed online and is primarily used to configure the counters settings and to incorporate multiple counters under the same network. This software is also used to calibrate the counters and modified the counting lines for specific applications. The counting lines are the boundaries that are used by the counter to determine if a person is walking in or out of the room (Figure 27). Finally, this software provides people counting information in five minute intervals.

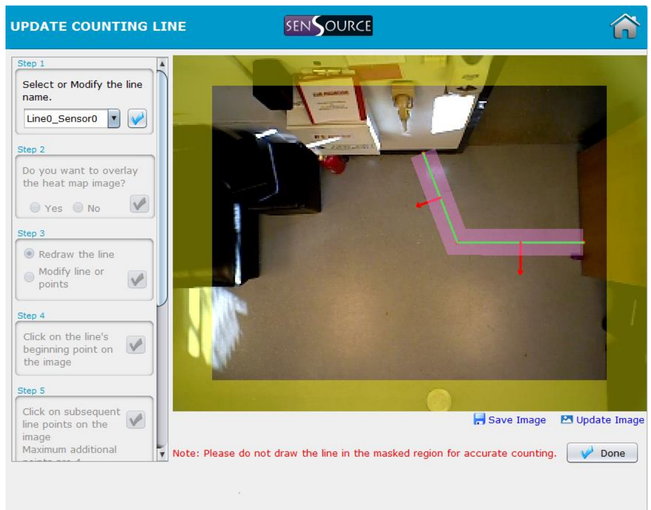


Figure 27: Screenshot of the ClearCount Active IR software to modify the counting line

The downloadable Vea Software provides customizable analysis reports of the non-identifiable count data and allows forwarding the reports via email to multiple individuals, so they can actively track the traffic flow.

The ClearCount Active IR could provide an autonomous and reliable system to capture user traffic in the Invention Studio. In order to test this, an experiment and pilot study were designed to validate the APC for university maker space applications.

Data Collection

The traffic flow in the 3D Printing room has a particular pattern that prevents the direct use of the ClearCount Active IR APC to determine the number of individual users in any given day. While SenSource ensures that the APC has an accuracy of at least 95% and has the ability to distinguish between a person entering and leaving the room, the

APC is unable to account for repeat entries by a single person. It is common for users to enter and leave the room several times in a day. Thus, there is a need to determine the ratio between person counts and actual individuals to avoid any skewing effects. The driving objective in this experiment is to determine a ratio between the APC count data and the actual number of individuals using the equipment and resources available in the 3D Printing room any given day. This will allow reasonable estimation of the population of members of the Georgia Tech community who utilize the 3D printing facilities inside the Invention Studio. An IRB protocol was created to gather data from the security cameras available in the room. The protocol stated that the security camera video footage will be assessed to collect non-identifiable data like count data, gender, people movement within the space, gathering patterns, as well as common activities being performed, like equipment usage.

This pilot study is divided in two parts: 1) validating the accuracy of the APC and 2) determining the ratio between APC counts and number of individual users for any given day. To validate the accuracy of the APC for our particular application, the APC data was compared to the manually collected data via the security camera available in the room. For this pilot study, data was collected from five days throughout the months of January and February. Also, data was collected during open hours, from 10 A.M. to 6 P.M. Mondays through Fridays. To take into consideration the possible variation between the different days of the week in terms of traffic, one of each day of the week from January 25th and February 29th was randomly selected and are highlighted in Table 19.

Table 19: Randomly selected days for data collection

Monday	Tuesday	Wednesday	Thursday	Friday
25-Jan	26-Jan	27-Jan	28-Jan	29-Jan
1-Feb	2-Feb	3-Feb	4-Feb	5-Feb
8-Feb	9-Feb	10-Feb	11-Feb	12-Feb
15-Feb	16-Feb	17-Feb	18-Feb	19-Feb
22-Feb	23-Feb	24-Feb	25-Feb	26-Feb
29-Feb				

Finally, the security camera footage was used to count the number of unique users entering and exiting the room each day. This was achieved by identifying the individuals that repeatedly enter and leave the room. Once the number of unique users is determined, linear regression will be used to determine the relationship between automatically collected count data and the number of daily users.

Experimental Setup

APC

Figure 28 shows the location of the APC and security camera in the 3D Printing room. The APC was installed in this room because it is one of the areas with the most traffic throughout the year, and the room has a security camera that points directly at the sole entrance of the room. Researchers can use the video footage from the security camera to validate the accuracy of the APC. This room would directly benefit from the count data due to the high demand of ABS filament used in the 3D printers. With the count data, PIs will be able to estimate material use, and equipment needs. Determining traffic patterns in this room throughout the semester could be used to ensure availability of resources and equipment during high usage periods. If the APC technology is proved to be effective and accurate under the high traffic conditions in this room, it is believed that the technology will work in any other area of the Invention Studio and other university maker spaces.

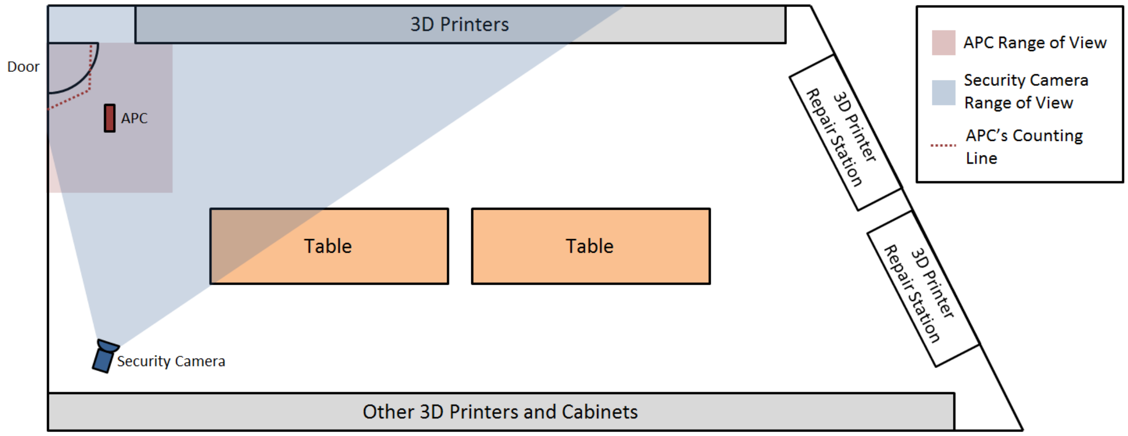


Figure 28: Layout of the 3D Printing room and the location of the APC technology and security camera

Security Camera

The security camera is located in the bottom left corner of the 3D Printing room as shown in Figure 28. The camera was installed for security purposes and it continuously records the activity in the room. The video footage is saved on a secure server for 32 days. Through the security video application, the researchers are able to view the video footage of any day in the past 32 days to collect data. Also, the application allows to rewind and fast forward the video footage to ensure accuracy and speed up the data collection process. Figure 29 shows a screenshot of the web application that was used to observed users entering the 3D Printing room. The door to the room can be seen in the top left side of the screen.

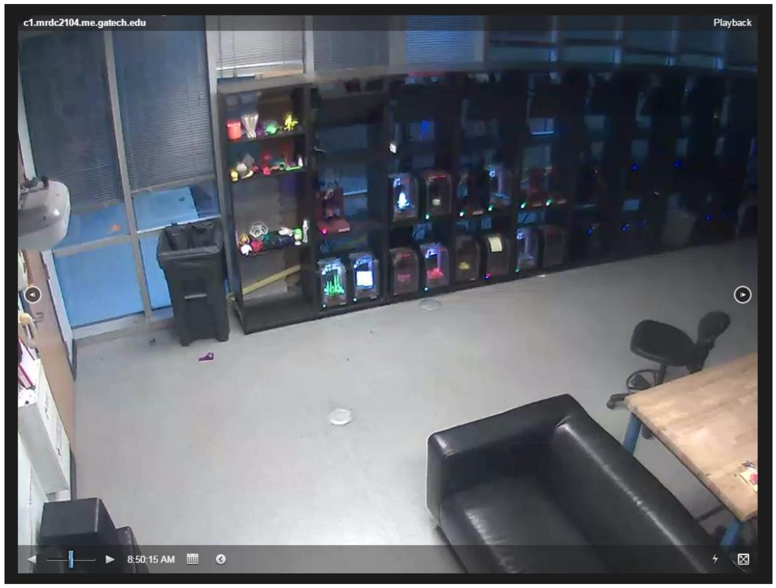


Figure 29: Screenshot of the video footage from the 3D Printing room's security camera

Methodology

<u>APC Data Collection</u>

Once the SenSource support team installed the APC software, the researchers had access to the ClearCount Active IR online application. Through this application the APC can be calibrated, and the researchers can change the APC settings and have access to the count data. The software has the capability of saving and downloading the data as a CSV file. The data can be downloaded in two ways: 1) the daily (24 hours) count value and 2) the count value for each individual day in five minute intervals. Figure 30 shows the data format as it is saved by the ClearCount Active IR software. For this pilot study, the daily count data in five-minute intervals was downloaded for the five days that were previously selected. Then, the five-minute interval count data was added in 30-minute intervals during the Invention Studio's open hours from 10 A.M. to 6 P.M.

	A	B	C	D	E	F	G
1	Date:01/28/2016						
2							
3	Door Report For The Day						
4							
5	Time		DoorName		In		Out
6	0:05		AutoDoor		0		0
7	0:10		AutoDoor		0		0
8	0:15		AutoDoor		0		0
9	0:20		AutoDoor		0		0
10	0:25		AutoDoor		0		0
11	0:30		AutoDoor		0		0
12	0:35		AutoDoor		0		0

Figure 30: Format of the count data available from the ClearCount Active IR software

Data Collection through Video Observation

Data was collected from the security video footage to validate the accuracy and precision of the APC. The video footage was observed and analyzed for five specific days during the months of January and February highlighted in Table 19.

There are a few definitions that must be made when collecting the manual count data. Since the view of the room is limited to the actions taking place within the room through the security camera, a user was defined as a person that takes at least three steps inside the room. As defined, a user can be using the 3D printing machines, talking to someone inside of the 3D Printing room, using the room to do school or personal work, observing the 3D printed artifacts, or taking a tour of the 3D printing room. Anyone who does not cross the three-step threshold is not counted in the observation data. Figure 31 shows an example of a student that walks inside the 3D Printing room but does not cross the threshold to be counted. An "out" was defined as when the majority of a person's body crosses the doorway to exit the room. If a person crosses the doorway and then returns into the room (more than 3 steps), this person is counted as another "in".

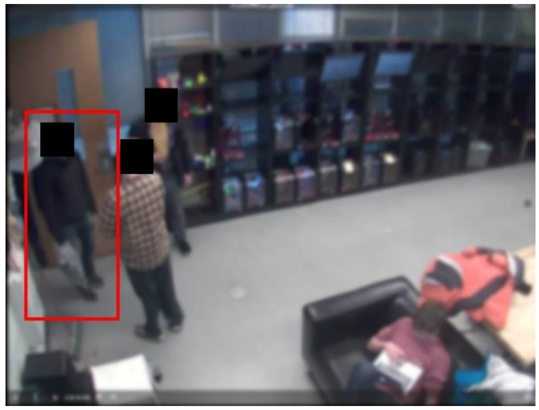


Figure 31: Screenshot of a student that entered the 3D Printing room but did not cross the threshold necessary to be counted as an user. (Images are intentionally blurred and covered to protect the identity of the users)

As previously mentioned, the manual count data collected by observing the video footage has two purposes: 1) to validate the accuracy of the APC, and 2) to determine the actual number of individual users. A spreadsheet was used for the pilot data collection as shown in Figure 32. The images shown in this thesis were intentionally blurred to protect the identity of the user. The data points were collected in photographs that were clipped from recordings of the room's security camera feed. These photographs are used to validate the data collected by the APC. To achieve this, a researcher would watch the eight hours of camera footage from a predetermined day. Each time someone walked into the room and was identified as a user, the person was clipped using the Microsoft Snipping Tool and pasted into an Excel spreadsheet. The spreadsheet was divided into thirty-minute intervals to make it easier to collect the data and a note was added in the spreadsheet every five minutes. These notes help to localize any significant discrepancies between the APC and manually collected count data. After all eight hours of footage had been examined, the researcher would count the number of entries. Once the count data and gender data was collected, the spreadsheets were deleted. This number was then compared to the APC counts for the same eight hour time interval to determine the accuracy of the APC technology.

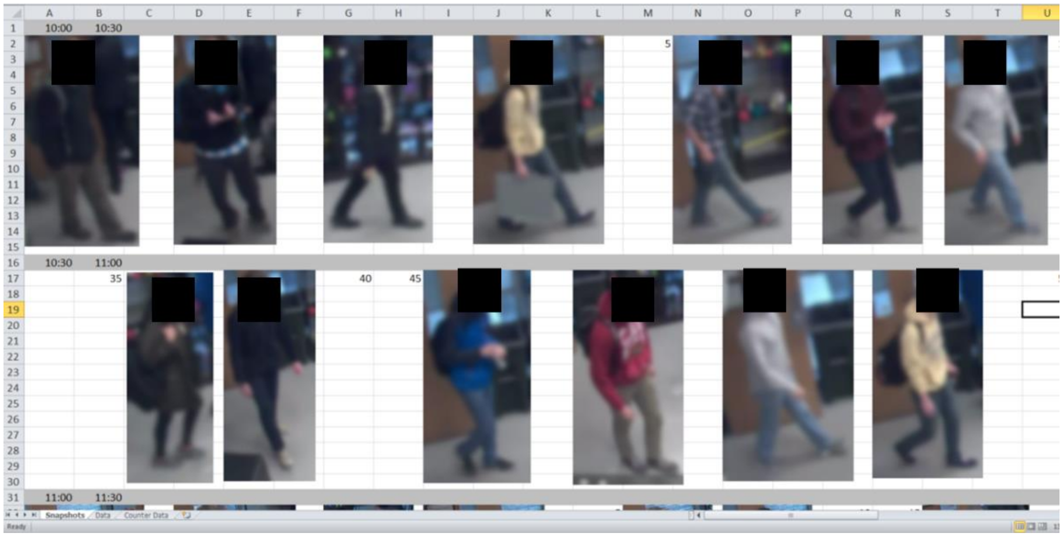


Figure 32: Example of the Excel table and methodology used to gather count data manually via video footage observation. (Images are intentionally blurred and covered to protect the identity of the users)

Duplicated entries (caused by people entering and leaving the room more than once a day) were accounted for in a separate spreadsheet as shown in Figure 33. If a student came into the 3D print room seven times, there would be one row with seven photos of the student. If a student only came into the 3D print room one time, there would be a row with only one photo of them. Certain identifiers were used to determine which individuals returned to the 3D print room. These identifiers may refer to characteristics such as, but not limited to, facial characteristics, clothing type, backpack color, shoe type and color, and hair color. In total, the data collection process took about eight hours of research time to collect the eight hours of data. It then took an additional two hours to parse the photos and analyze the reoccurrence information. As soon as the count and gender data was collected the spreadsheets containing the pictures were deleted.

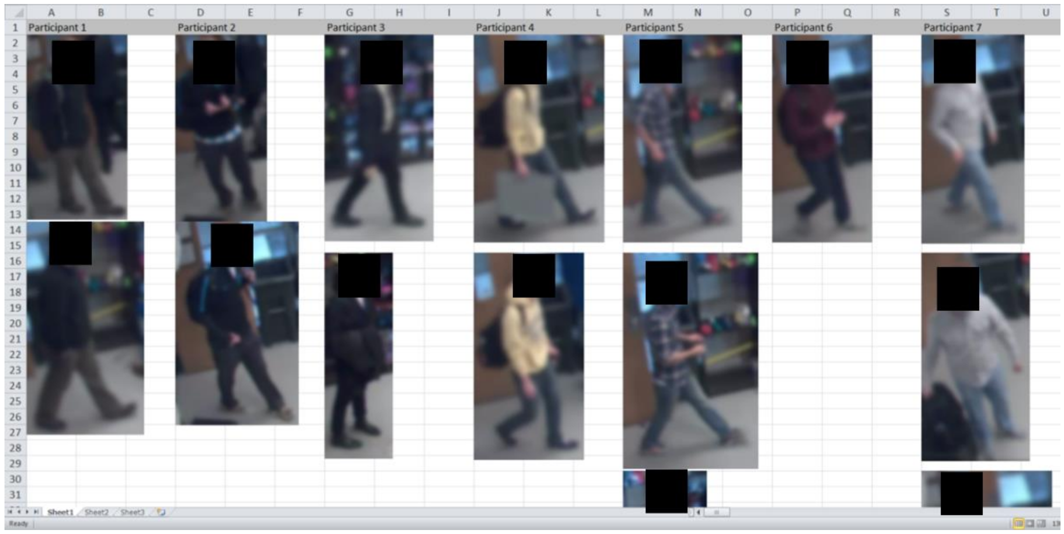


Figure 33: Example of the Excel table and methodology used to identify user reoccurrences and count the actual number of individual users. (Images are intentionally blurred and covered to protect the identity of the users)

Identifying students can be difficult since appearances can change over the course of a day. Sometimes, students remove articles of clothing that were previously used as identifiers (shoes, etc.), or even change outfits entirely. Often times the change in identifiers makes it very difficult to determine if a person is coming in for the first time or is a repeat entry, thus serving as potential source of error in the data. When there were doubts about the similarities between people in two photos, the researcher went back to the video footage to gather a better and more conclusive picture.

Despite these challenges, the methodology presented was created to reduce the risk for such error and attempts to collect the most accurate data possible. To ensure data validity and account for confirmation bias among researchers, two researchers viewed one full day of camera feeds separately. The security footage for Thursday January 28th was analyzed by two researchers in order to validate the data collection methodology and ensure the accuracy of the manually collected data. Table 20 shows the comparison between the data collected by both researchers as well as the identification of individual users and reoccurrences. The total daily count data was found to be identical for both researchers and the percent difference for the individual user count was 1.2%. Based on these values, the data collection methodology previously described can be assumed to be accurate.

Table 20: Inter-rater agreement when using the data collection methodology using the video footage from the security camera

	Total Daily Count	Individual User Count
Researcher 1	171	83
Researcher 2	171	82
Average	171	82.5
Percent Difference	0.00%	1.21%

Data Analysis and Results

APC Validation

The APC technology was validated by comparing the automatically collected count data to the data collected manually. As previously stated in the background, APC accuracy is measured by calculating the confidence interval (C.I.) of the difference between the automatic and manual data with a confidence level of 95%. If the value zero (meaning no difference) falls within the C.I., the APC is deemed accurate. Equation 1 found in Chapter 2 was used to find C.I. of the difference between APC count data (APC_{IN}) and manually collected count data (OBS_{IN}). Table 21 shows the values used to calculate the C.I. for the five sample days. The C.I. was found to be -13.5 to 9.55 counts. Since the value zero falls within the C.I., the APC can be considered to be accurate for this specific application. Next the average precision of the counter for any given day was calculated. To do this the standard error of the sample was divided by the average APC_{IN}, and a precision of ±6.04% was found. As the sample size increases, it is expected that the C.I. and the precision percentage will decrease.

Table 21: Comparison between APC entry counts and observed entry counts

Sample Day	APC_{IN}	OBS_{IN}	Difference ($APC_{IN} - OBS_{IN}$)
25-Jan	185	184	1
28-Jan	179	171	8
10-Feb	210	216	-6
16-Feb	154	151	3
26-Feb	227	243	-16
Total	955	965	-10

Relating APC Counts to Individual Users

Given the previous validation results, it can be assumed that the APC provides a high level of accuracy and precision for this application. Next, the count data was used to estimate the number of individual users in any given day. The relationship between individual users and count data was found by counting the number of unique users for the five sample days using the video footage from the security camera. The user ratio is calculated by dividing the number of individual users by the APC counts as shown in Table 22. Linear regression was then used to find the relationship between APC counts and individual users that can be used for any day throughout the year (Figure 34). While a larger sample is required to ensure the validity of this pilot study, the results show that the user ratio is about 0.52 with a 95% confidence interval of ±5.2%. This means that in average, users enter the 3D printing room twice per day. This ratio is consistent to the activities of the room, since users tend to initiate a 3D print job, leave the room and come back to pick up the print later in the day. The user ratios found in this study were sensitive to large tours and the unpredictable behavior of prototyping instructors. This can be seen in the variability of the user ratios found for each one of the sample days. It is recommended that future studies classify users to determine the actual impact of tours and prototyping instructors on the user ratio.

Table 22: Relationship between APC entry counts, individual users count, and user's gender.
[a] Ratio was affected by a prototyping instructor entering the room 20 times in one day
[b] Ratio was affected by a large amount of tours happening that day

Sample Day	APC_{IN}	OBS_{IN}	Individual Users	Female Users	Male Users	% of Female Users	User Ratio (Individual User/APC_{IN})
25-Jan	185	184	85	11	74	0.13	0.46
28-Jan	179	171	83	12	71	0.14	0.46
10-Feb	210	216	84	25	59	0.30	0.40[a]
16-Feb	154	151	107	34	73	0.32	0.69[b]
26-Feb	227	243	128	30	98	0.23	0.56

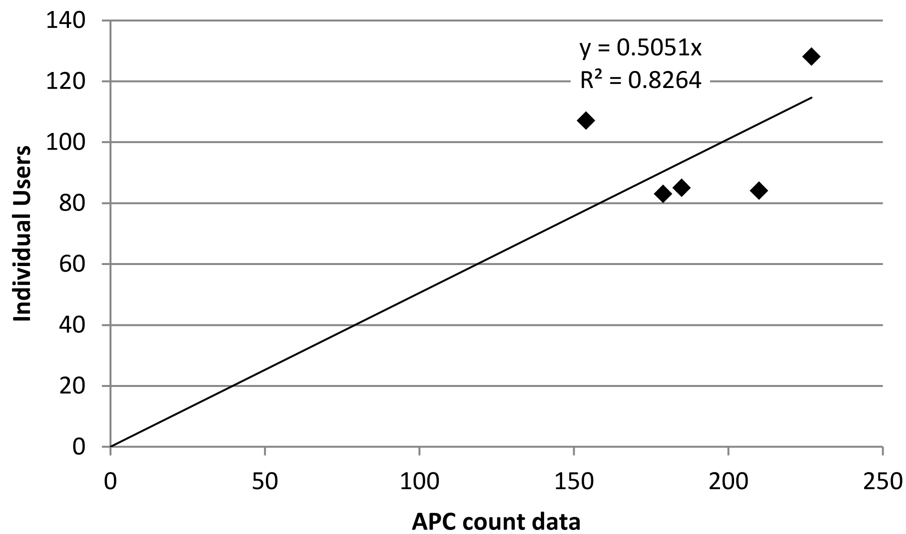


Figure 34: Linear regression of the user ratios

The methodology to identify individual users was also leveraged to characterize them in terms of their gender. Gender was determined based on certain characteristics such as, but not limited to, facial characteristics, body characteristics, clothing type, and hair type. It is important to note that there are clear limitations with this methodology since there might be female students who do not fall within the characteristics used. For this study, gender was identified as an example of all the possible uses of automatically collected count data. The results presented in Table 22 show that the average percentage of female users was 22.5% with a 95% confidence interval of ±10.7%. The large variability between each sample day shows conflicting results. In the first two days, the percentage of female users was lower than both the percentage of female in the student body at Georgia Tech (33%) [63], as well as the percentage of female students enrolled in school of mechanical engineering (19.9%) [60]. On the other hand, the following days show an average closer the total percentage of students at Georgia Tech. In order to understand this phenomenon, a larger sample will be necessary.

Using the Relationship

While a bigger sample is needed to ensure the validity of the relationship between APC counts and individual users, the individual to APC count ratio could be used to estimate the actual user traffic throughout the year. By implementing the ratio, it was found that there was an average of 214 users per day for the months of October through December of 2015, with a high of 316 on November 23rd and a low of 74 users on December 4th. Figure 35 shows the user distribution from the day the counter was implemented (October 1st) until the end of the semester. An average of 97 users per day was found for the months of January through February of 2016, with a high of 209 on February 12th and a low of 34 on January 13th. Figure 36 shows the daily traffic for the 3D Printing room since the beginning of the Spring semester of 2016 until February 29th. This data could be useful to determine the periods of high usage, allowing the students and faculty in charge of the maker spaces to ensure availability of equipment and resources during those periods. Also, this data could be leverage to plan changes to the space during low traffic periods.

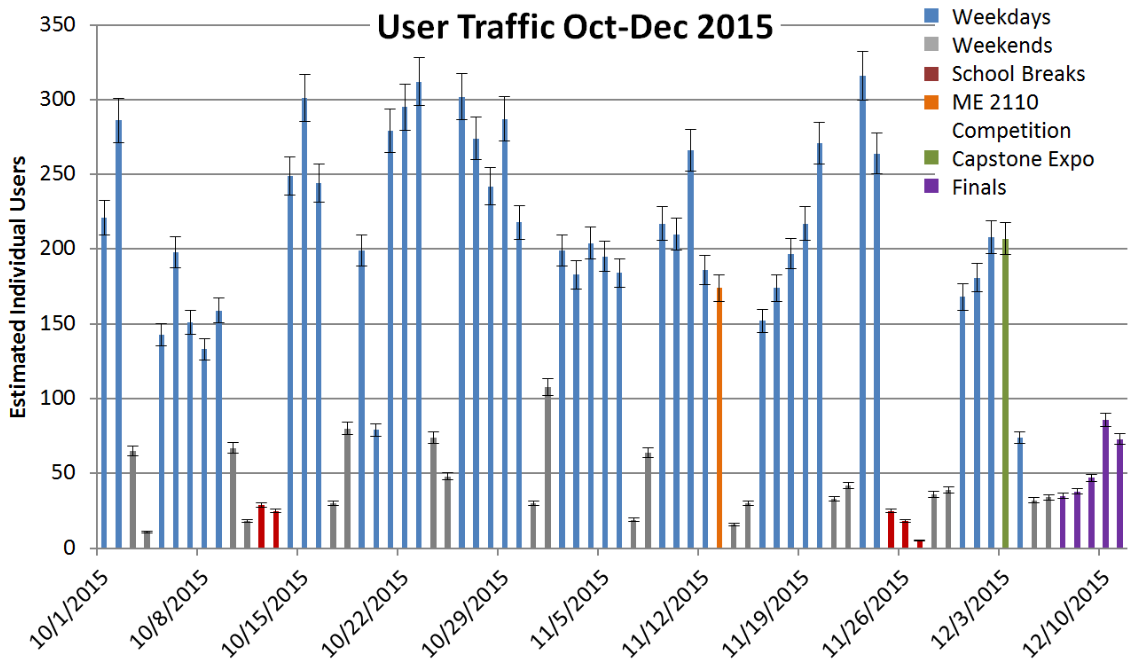


Figure 35: Fall of 2015 user traffic flow in the 3D Printing room. The error bars represent ±1 S.E.

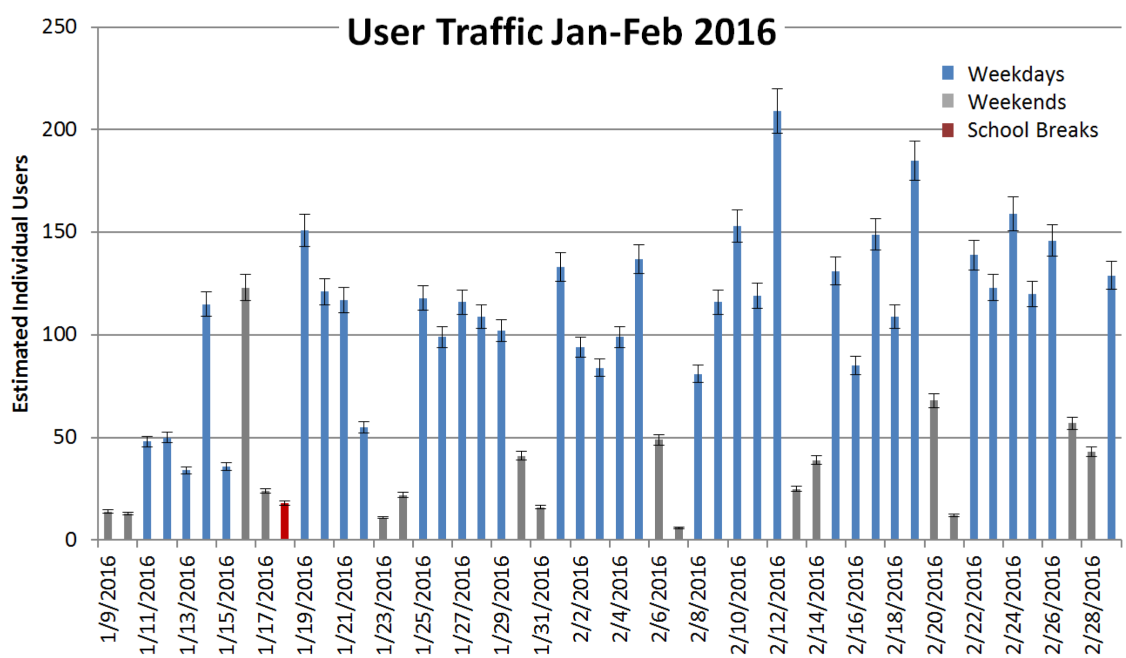


Figure 36: Spring of 2015 user traffic flow in the 3D Printing room. The error bars represent ±1 S.E.

Limitations

The main limitation of this study was the small sample size of five days and that the five sample days were collected over the span of two months. Because of this, the user to count ratio might not be representative of the overall ratio for everyday throughout the year. There were also limitations on the methodology used to determine the user's gender from the video footage. As previously mentioned, the identification of gender was based on specific characteristics like facial characteristics, body characteristics, clothing type, and hair type. The methodology described does not allow determining the gender of individuals who do not fall within this set of characteristics. Future work should use a better method for accurately determining gender.

The identification of unique individuals was also limited due to the effect of the user changing clothing throughout the day, since clothing was one of the main characteristics used for this purpose. While in some cases the other characteristics such as facial characteristics allow to unequivocally identify a person as the same even if they changed their attire, in other cases this was not possible and it affected our individual to count ratio. Finally, the traffic pattern from tours and prototyping instructors were not taken into consideration in this study but future work should track these characteristics to have a better understanding of how these groups are affecting the user to count ratio.

Conclusion

The methodology described in this chapter allowed validating the accuracy and precision of the APC technology selected. The methodology took advantage of video cameras located in the Invention Studio to compare observational count data to the automatic data collected via the APC. The pilot study used the methodology described to confirm the accuracy and precision of the APC technology for this application. The data collected from the video cameras was then analyzed to determine the actual number of individuals using the university maker space, and to classify them according to their gender.

While further studies are required to collect a larger sample of observational data, the process developed can be easily replicated to estimate the relationship between count data and individual users, effectively quantifying the user traffic in the university maker space. This data was used to calculate the user ratio by dividing the number of individual users by the count data from the APC. For the pilot study, this ratio was found to be about 0.52. This means that on average, users tend to enter the 3D Printing room twice a day. This ratio was consistent with the expected user behavior of the 3D Printing room, since users print parts and come back to the room once the print is completed. Moreover, the data collection methodology was implemented to identify the percentage of female users during any given day.

Through this approach, maker spaces can quantify the number of people using the equipment and resources in a non-obtrusive manner, limiting the barriers imposed on the users. The methodology can be implemented to enhance the understanding of university maker space usage by classifying users according to certain characteristics. This would allow measurement of the impact of university maker spaces with respect to user characteristics like demographics once a method is developed and implemented to accurately capture these characteristics without introducing barriers in the space. This traffic data could also be combined with other dynamic metrics such as material consumption and equipment usage, to further improve accessibility and availabilities of resources. Due to the success from this pilot study, the combination between the technology and methodology previously presented can be applied to other rooms in the Invention Studio and other maker spaces around the country.

CHAPTER 6: CONCLUSION

To solve the future challenges that our society will encounter, it is important that academic institutions nurture engineering students with the creativity and innovative skills necessary to imagine and create the solutions for these problems. Given their rapid expansion and integration in academic environments, maker spaces could play a key role in complementing the engineering curriculum with activities that require the students to be creative, innovative, and capable of excelling in collaborative and multidisciplinary settings. Since university maker spaces have the potential to benefit students around the world, there is a need to quantify the benefits associated with these environments and understand how they are impacting the students and engineering education as a whole.

The first step in understanding and measuring the impact of university maker spaces is to identify what type of students are taking advantage of the resources and equipment available, and to what extent these users are participating in these environments. This thesis presented the results from two studies that described the methodology to classify maker space users and non-users, and then compared these two groups according to specific characteristics.

Both involvement and participation were considered to be an important part of university maker space usage. Involvement is theoretically defined as the amount of time and effort one spends on a particular activity, and theory of communities of practice states that individuals can become part of the community by participating in the activities that are considered to be important by its members. In this case university maker space participation can be defined as whether students are participating in the activities that are considered to be important by the community of users or not. Based on these definitions, the impact associated with maker space usage might be related to these two concepts. The first study presented in this thesis used survey design theory and the two concepts to classify students in terms of their involvement and participation in university maker spaces.

To do so, the author designed a survey instrument by leveraging experience and knowledge gained as a university maker space user and student volunteer. The survey was continuously improved throughout the first two semesters of data collection in two ways: 1) questions were improved by utilizing survey design theory techniques to lower the cognitive burden associated with recalling past events, and 2) the distribution of answers found in the survey were used to design better questions about student involvement. The final version of the survey was reviewed by two survey design experts from Georgia Tech. The final product from this improvement phase was a survey capable of collecting maker space usage information in the form of student involvement and participation.

This survey will be used in a four-year multi-university longitudinal study. With it, researchers can collect repeated measurements of student involvement as they progress through their academic career. Furthermore, the survey was developed to be easily adapted to other institutions so university maker space usage can be compared across different university maker spaces across the country.

The Carberry et al. engineering design self-efficacy instrument [16] was employed as a metric to characterize the students that were identified as high and low participation in university maker spaces in terms of their design self-efficacy scores. Data was collected in the Spring and Fall of 2015 from students enrolled in three mandatory engineering design courses at the freshmen, sophomore and senior levels. The data was analyzed for all six groups, but not much could be concluded from the sophomore and senior level groups due to small sample sizes, changes in the survey instrument, and the data collection procedures during the first two semesters of the longitudinal study. Only the data collected from the students enrolled in the freshman level courses were further evaluated. Both parametric and non-parametric statistical analysis tests were implemented when the required assumptions about normality and equality of variance were met. The results showed a positive correlation between levels of university maker space participation, and for both motivation and anxiety engineering design self-concepts. Since this data is only correlational at this point, there are three possible scenarios to explain such relation: 1) The active use of university maker spaces for hands-on engineering applications increases one's motivation or lowers one's anxiety associated with performing engineering design related tasks; 2) Higher motivation may drive students to seek places that allow them to explore engineering design related activities. Similarly, students with less anxiety may be less susceptible to the risks associated with manufacturing tools, thus increasing their involvement in maker spaces; and finally, 3) there could be a reciprocal effect between positive self-efficacy and participation. High self-efficacy leads to high participation and vice-versa, allowing a continuous growth in both.

While these three are possible, an interesting finding suggests the second scenario to be the most likely: During the Spring semester there was a higher percentage of high participation students and a lower percentage of low participation individuals. It was theorized that, during the Fall semester, some highly self-efficacious students have not had enough time or opportunities to get involved in the university maker spaces. This might have changed once the students had an extra semester to participate. Due to these results, it could be argued that anxiety and lack of motivation in the students is one of the significant barriers preventing them from participating in these environments. Future longitudinal work is needed to understand the causality between university maker space participation and engineering design self-efficacy scores. Furthermore, identifying approaches and initiatives to reduce anxiety and increase motivation in first year engineering students could lead to greater participation in maker spaces, in which students have the opportunity and resources to build valuable skills as future engineers.

As previously mentioned, there might be barriers in place that prevent the use of university maker spaces, so it is important that these environments are studied without introducing new obstacles that might negatively affect student participation and maker space culture. University maker spaces like the Invention Studio are known for their open, free, and inclusive access, so to prevent the introduction of new barriers, it is important that any data collection process is as non-obtrusive as possible. Due to the intrinsic benefits associated with automatic people counter technology, it was predicted that the use of this technology could help the researchers to gather usage data and traffic behavior within these unique learning environments.

Accurately quantifying user traffic can be valuable to understand the usage of university maker spaces. Some ways in which traffic data could be leveraged are to: 1) predict material use and equipment availability, 2) identify the impact of initiatives and changes to the spaces, 3) determine peak and off seasons to ensure availability of resources and equipment, and 4) emphasize the impact and importance of these environments. Moreover, collecting accurate traffic data could be useful to predict the existence of barriers when changes are made to the space and study how these barriers prevent specific groups from using the resources available. Ultimately, this understanding could be used to reduce those barriers and stimulate participation.

To validate the accuracy and precision of the APC technology selected, a data collection methodology was developed to take advantage of video cameras available in the space. The observational data from five randomly selected days was compared to the APC counts, and it was determined that the APC technology was both accurate and precise for this application. Due to the expected user traffic behavior associated with the 3D Printing room, it was important to identify the number of unique individuals using the resources in the room. The data collected via the video camera was further analyzed to identify unique individuals by tracking the number of times the same user entered the room through the day. The ratio of unique individuals versus count data was found to be 0.52, meaning that in average users tend to enter the room two times a day. This finding was consistent to the expected ratio given the activities associated with the 3D Printing room. The ratio was further used to estimate the traffic patterns of individual users in the 3D Printing room of the Invention Studio throughout the year. The data showed that on average, the 3D Printing room hosted about 214 users per day during the months of October through December of 2015. Without including weekends and school holidays, the 3D Printing room had a high of 316 users on November 23rd and a low of 74 users on December 4th. Traffic patterns during January and February of 2016 showed a daily average of 97 users, with a high of 209 on February 12th and a low of 34 on January 13th. The methodology presented also allowed estimating the number of female users based on count data. It was found that the percentage of female users varied throughout the five sample days. A larger sample is required to evaluate the actual usage of the Invention Studio by this demographical group.

Being capable of determining the demographical characteristics of the users of the maker space is highly valuable to discover barriers that prevent certain groups from participating. This information could also be leveraged to create initiatives with the objective of attracting these alienated groups. While a larger sample size is required, the results found in this pilot study are extremely promising. The flexibility of the methodology created allowed for it to be used to validate APC technologies in other rooms within the Invention Studio and other university maker spaces around the country. With the steps outlined in this thesis, researchers will be able to determine the actual number of users from APC counts, characterize these individuals, and combine this data with other metrics to have a better understanding of their maker space.

Future Work

Further Refining the Characterization of Student Makers

The first study presented in this thesis correlates participation in university maker spaces to the individual's engineering design self-efficacy. In future studies, other metrics like GPA, innovation self-efficacy, idea generation ability, and retention will be used to characterize users and non-users. Since the data collection methodology and survey instrument distributed changed over the course of the study, the classification of students was limited to their reported participation. Data analysis in the future studies will take advantage of both the involvement and participation questions to create a better user classification. While the criteria defined in this thesis provided a clear differentiation between users and non-users, multivariate analysis should be employed to identify which question or set of questions are having a stronger impact on the metrics previously described. Also, it is recommended that students are compared not only based on the course they are enrolled but also based on their status as freshman, sophomore, junior, or senior. While the current percentage of captured female, Hispanic or Latino, and Black or African American students is similar to the percentage of these groups enroll at Georgia Tech, it is advised that researchers take extra measures to capture a larger sample size, helping to ensure repeated measurement of these students throughout the longitudinal study. This could be done by targeting extracurricular events sponsored by the Invention Studio, or getting in contact with clubs and organizations created for minorities.

Moving Forward with Automatic People Counters

Through the implementation of automatic people counters and the data collection methodology proposed, maker spaces now have a practical process to quantify the number of people using the equipment and resources in a non-obtrusive manner, limiting the barriers imposed on the students. Researchers, faculty, and university maker space leaders can now make educated decisions for how to operationally improve these environments, and quantify the impact of initiatives to create more accessible and inclusive spaces. As an example, the methodology and technology proposed could be used in combination with dynamic metrics such as material consumption and equipment usage to ensure the availability of these resources, especially during high traffic periods.

While the relationship found between count data and individual users with certain characteristics is promising, it is important that more observational data is collected. A larger sample will confirm the validity of the relationship. It is recommended to gather data from particularly low and high traffic days to identify the behavior of the relationship for these irregularities, allowing to validate the user ratio for any given day. One of the main limitations of this pilot study was selecting all the sample days from the month of January and February. Since the ratio might vary throughout the semester and between semesters, it is important that future sample days are selected randomly over the entire semester and for both Fall and Spring. The behavior of tours and prototyping instructors impacted the ratio of APC counts and unique users. Future studies in this area should further classify the observational counts to identify these two groups. This will allow understanding of their behaviors, and impact on the students using the equipment and resources available. Future studies should also install and validate the APC in other locations. Since the Invention Studio is divided into multiple rooms with specific purposes, installing APCs in other rooms will create a clearer picture of the traffic and usage of the maker space as a whole.

Once data is collected and analyzed from a more representative sample size, the relationship between individual users and APC counts can be used to estimate the entire user population. In public transportation this data is leveraged to determine the sample size required to characterize the overall population. This will allow researchers to random sample the population without the need to capture data from every single user. By having an accurate estimate of the traffic it would be possible characterize users in terms of the major, race, ethnicity, and many other traits in a way that is representative of the overall user population. Understanding the use of maker spaces by groups with certain characteristics will help to make these environments more attractive and inclusive for all students.

APPENDIX A

VERSION 1: INVOLVEMENT SURVEY INSTRUMENT

Name: ___________________________

Email: ___________________________

GTID# (90XXXXXXX): ___________________________

Capstone Professor: ___________________________

Survey

1. What is your current major?
   Select one
   - Mechanical Engineering
   - Aerospace Engineering
   - Industrial Engineering
   - Computer Engineering
   - Electrical Engineering
   - Nuclear Engineering
   - Chemical Engineering
   - Biomedical Engineering
   - Undeclared or Undecided Engineering
   - Undeclared or Undecided
   - Other: ___________________________

2. Have you ever used the Invention Studio or other Maker Spaces?
   - Yes
   - No

3. Are you or have you ever been a University Lab Instructor (ULI) at the Invention Studio? If yes which school year(s)? (Select all that apply)
   - 2009-2010
   - 2010-2011
   - 2011-2012
   - 2012-2013
   - 2013-2014
   - 2014-2015
   - N/A

4. Are you taking or have you ever taken ME2110? If yes which school year?
   - 2009-2010
   - 2010-2011
   - 2011-2012
   - 2012-2013
   - 2013-2014
   - 2014-2015
   - N/A

5. Are you taking or have you ever taken Capstone Design? If yes which school year?
   - 2009-2010
   - 2010-2011
   - 2011-2012
   - 2012-2013
   - 2013-2014

- 2014-2015
- N/A

6. Please fill in the table to the best of your knowledge. Indicate your use of the Invention Studio during your college career

Year	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015
Average amount of hours per week						
Please estimate how your time was distributed in the Invention Studio per year						
Classwork Use (2110, Capstone, other)						
Personal Use						
University Lab Instructor (ULI)						
Research						

Rate your degree of confidence that you can do each of the activities listed below on a scale from 0 (not at all confident) to 100 (extremely confident) by circling your answer.

	0	10	20	30	40	50	60	70	80	90	100
Understand the needs of people by listening to their stories											
Find connections between different fields of knowledge											
Seek out information from other disciplines to inform my own											
Identify opportunities for new products and/or processes											
Question practices that others think are satisfactory											
Come up with imaginative solutions											
Make risky choices to explore a new idea											
Consider the viewpoints of others/stakeholders											
Evaluate the success of a new idea											
Apply lessons from similar situations to a current problem of interest											
Envision how things can be better											
Do things in an original way											
Set clear goals for a project											
Troubleshoot problems											
Keep informed about new ideas (products, services, processes, etc.) in my field											
Communicate ideas clearly to others											
Provide compelling stories to share ideas											
Learn by observing how things in the world work											

	0	10	20	30	40	50	60	70	80	90	100
Solve most problems if I invest the necessary effort											
Be resourceful when handling an unforeseen situation											
Suggest new ways to achieve goals or objectives											
Test new ideas and approaches to a problem											
Share what I have learned in an engaging and realistic way											
Make a decision based on available evidence and opinions											
Relate seemingly unrelated ideas to each other											
Think of new and creative ideas											
Model a new idea or solution											
Find new uses for existing methods or tools											
Explore and visualize how things work											

DIRECTIONS: Please answer all of the following questions fully by selecting the answer that best represents your beliefs and judgment of your current abilities. Answer each question in terms of who you are and what you know today about the given tasks.

1. Rate your degree of CONFIDENCE (i.e. belief in your current ability) to perform the following tasks by recording a number from 0 to 100.
   (0 = cannot do at all; 50 = moderately can do; 100 = highly certain can do)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
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											
redesign											

2. Rate how MOTIVATED you would be to perform the following tasks by recording a number from 0 to 100.
   (0 = not motivated; 50 = moderately motivated; 100 = highly motivated)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
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											
redesign											

3. Rate how SUCCESSFUL you would be in performing the following tasks by recording a number from 0 to 100.
   (0 = cannot expect success at all; 50 = moderately expect success; 100 = highly certain of success)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
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											
redesign											

4. Rate your degree of ANXIETY (how apprehensive you would be) in performing the following tasks by recording a number from 0 to 100.
(0 = not anxious at all; 50 = moderately anxious; 100 = highly anxious)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
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											
redesign											

7. I identify my gender as…
   - o Female
   - o Male
   - o Prefer not to disclose
   - o Other: ______________________

8. I identify my race as…
   - o American Indian or Alaska Native
   - o Asian
   - o Black or African American
   - o Native Hawaiian or Other Pacific Islander
   - o White/Caucasian
   - o Prefer not to disclose
   - o Other: ______________________

9. Are you Hispanic or Latino?
   - o Yes
   - o No
   - o Prefer not to disclose

Thank you for your time.

Any additional comments:

APPENDIX B

VERSION 2: INVOLVEMENT SURVEY INSTRUMENT

2. Name:

3. GTID# (90XXXXXXX)

4. Email:

5. Are you interested in participating in future studies for extra credit or payment?

- Yes
- No

6. Name your ME 1770 Professor

7. What is your current major?
Select one

- Mechanical Engineering
- Aerospace Engineering
- Industrial Engineering
- Computer Engineering
- Electrical Engineering
- Nuclear Engineering
- Chemical Engineering
- Biomedical Engineering
- Undeclared or Undecided Engineering
- Undeclared or Undecided
- Other (please specify)

8. Have you ever heard of the Invention Studio?

- ◯ Yes
- ◯ No

9. Have you ever used any of the Invention Studio's equipment?

- ◯ Yes
- ◯ No

10. Please select the semester in which you started using the Invention Studio's equipment

11. Have you ever been a University Lab Instructor (ULI) or a Prototype Instructor (PI) at the Invention Studio?

- ◯ Yes
- ◯ No

12. If yes, please indicate the number of semesters you have been a ULI or PI

13. Please select all the Invention Studio related activities you have participated in

- ☐ Designing something
- ☐ Building something
- ☐ Collaborating with other students in a project
- ☐ Helping student with their projects
- ☐ Learning how to use a piece of equipment
- ☐ Participating in Invention Studio related events (e.g. Ladies Night, Taking Care of Business Night)
- ☐ Attending workshops
- ☐ Attending training session
- ☐ Other (please specify)

14. Have you used the Invention Studio to work on any of the following types of projects? Select all that apply.

- [ ] classroom project
- [ ] personal project
- [ ] research project
- [ ] entrepreneurial project
- [ ] project for a club or organization
- [ ] Other (please specify)

15. Please estimate frequency in which you have been involved in Invention Studio related activities in Spring 2015

- ○ Daily
- ○ 2-3 times a week
- ○ Once a week
- ○ 2-3 times a month
- ○ Once a month
- ○ Less than once a month
- ○ Once a semester
- ○ Did not participate in any of the activities this past semester

16. Please estimate the number of different projects (personal, classroom, research, club or organization related, entrepreneurship) that you have worked on using any of the Invention Studio's equipment and collaboration areas in Spring 2015?

17. In comparison to previous semesters how would you rank your involvement in the Invention Studio in Spring 2015?

- ○ I was less involved than previous semesters
- ○ I was as involved as previous semesters
- ○ I was more involved than previous semesters
- ○ This is my first semester being involved

18. In comparison to previous semesters how would you rank the number of projects you have worked on using any of the Invention Studio's equipment and collaboration areas in Spring 2015?

- I have worked on fewer projects
- I have worked on about the same number of projects
- I have worked on more projects
- This is my first semester being involved

19. What type of projects have you been working on in Spring 2015? Select all that apply.

- ME1770
- ME2110
- Capstone
- Research
- Personal
- Entrepreneurship
- Club or Organization related
- Other (please specify)

20. If you have been working on personal or entrepreneurial projects in Spring of 2015, please describe the project(s) that you consider most important in a few sentences:

DIRECTIONS: Please answer all of the following questions fully by selecting the answer that best represents your beliefs and judgment of your current abilities. Answer each question in terms of who you are and what you know today about the given tasks.

21. Rate your degree of CONFIDENCE (i.e. belief in your current ability) to perform the following tasks by recording a number from 0 to 100.
(0 = cannot do at all; 50 = moderately can do; 100 = highly certain can do)

	0	10	20	30	40	50	60	70	80	90	100
Conduct engineering design											
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											
Redesign											

22. Rate how MOTIVATED you would be to perform the following tasks by recording a number from 0 to 100.
(0 = not motivated; 50 = moderately motivated; 100 = highly motivated)

	0	10	20	30	40	50	60	70	80	90	100
Conduct engineering design											
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											
Redesign											

23. Rate how SUCCESSFUL you would be in performing the following tasks by recording a number from 0 to 100.
(0 = cannot expect success at all; 50 = moderately expect success; 100 = highly certain of success)

	0	10	20	30	40	50	60	70	80	90	100
Conduct engineering design											
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											
Redesign											

24. Rate your degree of ANXIETY (how apprehensive you would be) in performing the following tasks by recording a number from 0 to 100.
(0 = not anxious at all; 50 = moderately anxious; 100 = highly anxious)

	0	10	20	30	40	50	60	70	80	90	100
Conduct engineering design	○	○	○	○	○	○	○	○	○	○	○
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	○	○	○	○	○	○	○	○	○	○	○
Redesign	○	○	○	○	○	○	○	○	○	○	○

	0	10	20	30	40	50	60	70	80	90	100
Communicate ideas clearly to others	○	○	○	○	○	○	○	○	○	○	○
Provide compelling stories to share ideas	○	○	○	○	○	○	○	○	○	○	○
Learn by observing how things in the world work	○	○	○	○	○	○	○	○	○	○	○
Solve most problems if I invest the necessary effort	○	○	○	○	○	○	○	○	○	○	○
Be resourceful when handling an unforeseen situation	○	○	○	○	○	○	○	○	○	○	○
Solve most problems if I invest the necessary effort	○	○	○	○	○	○	○	○	○	○	○
Be resourceful when handling an unforeseen situation	○	○	○	○	○	○	○	○	○	○	○
Suggest new ways to achieve goals or objectives	○	○	○	○	○	○	○	○	○	○	○
Test new ideas and approaches to a problem	○	○	○	○	○	○	○	○	○	○	○
Share what I have learned in an engaging and realistic way	○	○	○	○	○	○	○	○	○	○	○
Make a decision based on available evidence and opinions	○	○	○	○	○	○	○	○	○	○	○
Relate seemingly unrelated ideas to each other	○	○	○	○	○	○	○	○	○	○	○
Think of new and creative ideas	○	○	○	○	○	○	○	○	○	○	○
Model a new idea or solution	○	○	○	○	○	○	○	○	○	○	○
Find new uses for existing methods or tools	○	○	○	○	○	○	○	○	○	○	○
Explore and visualize how things work	○	○	○	○	○	○	○	○	○	○	○

26. What is your gender?

- Female
- Male
- Prefer not to disclose
- Other (please specify)

27. I identify my race as...

- American Indian or Alaska Native
- Asian
- Black or African American
- Native Hawaiian or Other Pacific Islander
- White/Caucasian
- Prefer not to disclose
- Other (please specify)

28. Are you of Hispanic or Latino origin or descent?

- Yes, Hispanic or Latino
- No, not Hispanic or Latino
- Prefer not to disclose

29. Any additional comments:

Thank you for your time!

25. Rate your degree of confidence that you can do each of the activities listed below on a scale from 0 (not at all confident) to 100 (extremely confident) by circling your answer.

	0	10	20	30	40	50	60	70	80	90	100
Understand the needs of people by listening to their stories											
Find connections between different fields of knowledge											
Seek out information from other disciplines to inform my own											
Identify opportunities for new products and/or processes											
Question practices that others think are satisfactory											
Come up with imaginative solutions											
Make risky choices to explore a new idea											
Consider the viewpoints of others/stakeholders											
Evaluate the success of a new idea											
Apply lessons from similar situations to a current problem of interest											
Envision how things can be better											
Do things in an original way											
Set clear goals for a project											
Troubleshoot problems											
Keep informed about new ideas (products, services, processes, etc.) in my field											

APPENDIX C

FINAL VERSION: INVOLVEMENT SURVEY INSTRUMENT

Name: ___________________________
Email: ___________________________
GTID# (90XXXXXXX): ___________________________

1. What is your current major?
   Select one
   - ○ Aerospace Engineering
   - ○ Biomedical Engineering
   - ○ Chemical Engineering
   - ○ Computer Engineering
   - ○ Electrical Engineering
   - ○ Industrial Engineering
   - ○ Mechanical Engineering
   - ○ Nuclear Engineering
   - ○ Other (please specify) :______________________

2. Which of the following courses are you currently taking?
   - ☐ ME 2110
   - ☐ ME Capstone
   - ☐ BME 2310
   - ☐ BME Capstone

3. Please Indicate the academic year you started at Georgia Tech
   - ○ 2015-2016
   - ○ 2014-2015
   - ○ 2013-2014
   - ○ 2012-2013
   - ○ 2011-2012
   - ○ 2010-2011
   - ○ Before 2010

For the next section of the survey we are investigating your involvement in university maker spaces. A university maker space is a location associated with your university designed to give prototyping access to students. Maker spaces give students access to prototyping equipment such as 3D printers and CNC machines for personal and/or class projects.

Examples of university maker spaces at Georgia Tech include the Invention Studio and the BME Machine Shop.

4. Select the statement that best describes your familiarity with university maker spaces.

    - I have never heard of any university maker spaces **Please continue to question 20**

    - I have heard of university maker spaces but I have never used any of the equipment and/or resources. **Please continue to question 20**

    - I have used a university maker space's equipment and/or resources. **Please continue to question 5**

5. Which university maker space have you used before? Select all that apply.
   - ☐ Invention Studio
   - ☐ BME Machine Shop
   - ☐ Other (please specify) :______________________

6. Are you or have you ever been a student volunteer or employee of a university maker space?
   - o No, I have never been a student volunteer or employee of a university maker space
   - o No, but I am interested in becoming one
   - o Yes, **I was** a student volunteer or employee of a university maker spaces in a previous semester
   - o Yes, **I am currently** a student volunteer or employee of a university maker space

7. Please indicate the number of semesters you have been a student volunteer or employee of a university maker space (if you have never been a student volunteer or employee, put 0)

   ____

8. Select all the university maker spaces for which you are or have been a student volunteer or employee.
   - ☐ Not Applicable
   - ☐ Invention Studio
   - ☐ BME Machine Shop
   - ☐ Other (please specify) :______________________

9. Have you ever used a university maker space to work on any of the following types of projects?
   Select all that apply.
   - ☐ Class projects
   - ☐ Personal projects
   - ☐ Research projects
   - ☐ Entrepreneurial projects
   - ☐ Club or organization projects
   - ☐ Other (please specify) :______________________

10. During **this semester** (Spring 2016), have you used a university maker space to work on any of the following types of projects?
Select all that apply.
- ☐ Class projects
- ☐ Personal projects
- ☐ Research projects
- ☐ Entrepreneurial projects
- ☐ Club or organization projects
- ☐ Other (please specify): ______________________

11. Selected all the classes for which you have ever used a university maker space's equipment and/or resources.
Select all that apply.
- ☐ ME 1770
- ☐ ME 2110
- ☐ ME Capstone
- ☐ BME 2310
- ☐ BME Capstone
- ☐ Other (list) : ______________________

12. During **this semester** (Spring 2016), for which of the following classes are you actively using a university maker space's equipment and/or resources?
Select all that apply.
- ☐ ME 1770
- ☐ ME 2110
- ☐ ME Capstone
- ☐ BME 2310
- ☐ BME Capstone
- ☐ Other (list) : ______________________

13. Have you participated in any of the following activities utilizing a university maker space?
Select all that apply.
- ☐ Designing something
- ☐ Building something
- ☐ Fixing something
- ☐ Collaborating with other students in a project
- ☐ Helping students with their projects
- ☐ Teaching other students how to use some piece of equipment
- ☐ Advising students on how to approach a design problem
- ☐ Learning how to use a piece of equipment
- ☐ Participating in Invention Studio or similar university maker space related events (e.g. Ladies Night, Taking Care of Business Night)
- ☐ Attending training session
- ☐ Other (please specify): ______________________

14. How much time have you spent **this semester** (Spring 2016), during a typical week, in a university maker spaces related activities?
- o None
- o Less than 1 hour
- o 1-2 hours
- o 3-5 hours
- o 6-10 hours
- o 11-20 hours
- o Over 20 hours

15. In comparison to **previous semesters**, how would you rank the amount of time you have spent during a typical week **this semester** (Spring 2016) in a university maker space?
- o I spent less time than previous semesters
- o I spent as much time as previous semesters
- o I spent more time than previous semesters
- o This is my first semester being involved

16. Please estimate frequency in which you have been involved in a university maker space related activities **this semester** (Spring 2016).
    - Did not participate in any of the activities this past semester
    - Daily
    - 2-3 times a week
    - Once a week
    - 2-3 times a month
    - Once a month
    - Less than once a month
    - Once a semester

17. In comparison to **previous semesters** how would you rank your involvement in a university maker space during **this semester** (Spring 2016)?
    - I was less involved than previous semesters
    - I was as involved as previous semesters
    - I was more involved than previous semesters
    - This is my first semester being involved

18. Please estimate the number of different projects (personal, classroom, research, club or organization related, entrepreneurship) that you have worked on using any of a university maker space's equipment and collaboration areas during **this semester** (Spring 2016)?

    ____

19. In comparison to **previous semesters** how would you rank the number of projects you have worked on during **this semester** (Spring 2016) using any of a university maker space's equipment and/or resources?
    - I have worked on fewer projects
    - I have worked on about the same number of projects
    - I have worked on more projects
    - This is my first semester being involved

20. **DIRECTIONS: Please answer all of the following questions fully by selecting the answer that best represents your beliefs and judgment of your current abilities. Answer each question in terms of who you are and what you know today about the given tasks.**

Rate your degree of CONFIDENCE (i.e. belief in your current ability) to perform the following tasks by recording a number from 0 to 100.
(0 = cannot do at all; 50 = moderately can do; 100 = highly certain can do)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
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											
redesign											

Rate how MOTIVATED you would be to perform the following tasks by recording a number from 0 to 100.
(0 = not motivated; 50 = moderately motivated; 100 = highly motivated)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
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											
redesign											

Rate how SUCCESSFUL you would be in performing the following tasks by recording a number from 0 to 100.
(0 = cannot expect success at all; 50 = moderately expect success; 100 = highly certain of success)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
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											
redesign											

Rate your degree of ANXIETY (how apprehensive you would be) in performing the following tasks by recording a number from 0 to 100.
(0 = not anxious at all; 50 = moderately anxious; 100 = highly anxious)

	0	10	20	30	40	50	60	70	80	90	100
conduct engineering design											
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											
redesign											

21. What is your gender?
    - o Female
    - o Male
    - o Prefer not to disclose
    - o Other (please specify): ______________________

22. What is your race/ethnicity?
    Select all that apply.
    - ☐ White/Caucasian
    - ☐ Black or African American
    - ☐ American Indian or Alaskan Native
    - ☐ Native Hawaiian or Other Pacific Islander
    - ☐ Middle Eastern
    - ☐ Asian
    - ☐ Prefer not to disclose
    - ☐ Other (please specify): ______________________

23. Do you consider yourself to be of Hispanic, Latino, or Spanish origin?
    - o Yes, Hispanic or Latino
    - o No, not Hispanic or Latino
    - o Prefer not to disclose

24. What is the highest level of education completed by either one of your parents or guardians?
    - o Did Not Complete High School
    - o High School/GED
    - o Some College
    - o Bachelor's Degree
    - o Master's Degree
    - o Advanced Graduate work or Ph.D.
    - o Not Sure

25. Any additional comments:

Thank you for your time!

APPENDIX D

FOUR-YEAR LONGITUDINAL STUDY DATA COLLECTION PLAN

Year	Pilot	1		2		3		4	
Target Population	**Spring 15**	**Fall 15**	**Spring 16**	**Fall 16**	**Spring 17**	**Fall 17**	**Spring 18**	**Fall 18**	**Spring 19**
ME1770	**Cohort P**	**Cohort A**	**Cohort A**	**Cohort B**	**Cohort B**				
			Survey (Pre)	Survey (Pre)	Survey (Pre)				
			Design Self-Efficacy (Pre)	Design Self-Efficacy (Pre)	Design Self-Efficacy (Pre)				
	Survey (Post)	Survey (Post)	Survey (Post)	Survey (Post)	Survey (Post)				
	Design Self-Efficacy (Post)	Design Self-Efficacy (Post)	Design Self-Efficacy (Post)	Design Self-Efficacy (Post)	Design Self-Efficacy (Post)				
	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention				
		Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)				
ME2110	**Cohort Po**	**Cohort P**	**Cohort A**	**Cohort A**	**Cohort A/B**	**Cohort B**	**Cohort B**		
	Survey	Survey	Survey	Survey	Survey	Survey	Survey		
	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy		
	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention		
	Idea Generation & Innovation Self-Efficacy (In class)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)		
Junior			**Cohort P**	**Cohort A**	**Cohort A**	**Cohort A/B**	**Cohort B**	**Cohort B**	
			Survey	Survey	Survey	Survey	Survey	Survey	
			Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	
			GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	
			Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	
Capstone	**Cohort Po**	**Cohort Po**	**Cohort Po**	**Cohort P**	**Cohort A**	**Cohort A**	**Cohort A/B**	**Cohort B**	**Cohort B**
	Survey	Survey	Survey	Survey	Survey	Survey	Survey	Survey	Survey
	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy	Design Self-Efficacy
	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention	GPA & Retention
	Idea Generation & Innovation Self-Efficacy (In class)	Idea Generation & Innovation Self-Efficacy (They Schedule Times With US)	Idea Generation & Innovation Self-Efficacy (In class)	Idea Generation & Innovation Self-Efficacy (In class)	Idea Generation & Innovation Self-Efficacy (In class)	Idea Generation & Innovation Self-Efficacy (In class)	Idea Generation & Innovation Self-Efficacy (In class)	Idea Generation & Innovation Self-Efficacy (In class)	Idea Generation & Innovation Self-Efficacy (In class)

APPENDIX E

IN-PERSON RECRUITMENT SCRIPT

Hello,

My name is XXXXX and I represent the iDREEM lab here at Georgia Tech. We are conducting research to better understand the Invention Studio in order to better understand its impacts. As an engineering student at Georgia Tech, you are given the opportunity to participate in this research today.

If you agree to participate, you will fill out some surveys and participate in idea generation activities. The information collected will be used for research purposes only. Your participation is fully voluntary. You can end your participation anytime.

The initial survey will require less than 5 minutes of your time. You will be compensated for further activities associated with this study with extra credit when possible or $20/hour. We hope that what we learn about how the studio affects you will help create a model that can be replicated at other institutions and benefit students at this and other institutions.

If you are interested, please sign up for the study here. You can also sign up by emailing XXXXXXX at XXXXXXXXX@gmail.com.

APPENDIX F

ONLINE RECRUITMENT SCRIPT

Subject: Volunteers needed for a research study about university maker spaces and their impact on students!

Hello,

We are conducting a research study to understand the activities in university maker spaces and how they form a unique learning environment. If you agree to participate you will fill out some short surveys as well as take part in idea generation activities. You will be compensated $20/hour for your time. If you are interested in participating please take the time to read the consent form and take the survey by clicking on the following link.

https://www.surveymonkey.com/XXXXXXXXXXX

If you have any questions about the study, you may reply to this email or contact XXXXXX at XXXXXX@gatech.edu.

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