Proceedings of the ASME 2022
International Mechanical Engineering Congress and Exposition
IMECE2022
October 30-November 3, 2022, Columbus, Ohio

IMECE2022-97040

IMPROVING SELF-EFFICACY OF FINANCIALLY DISADVANTAGED STUDENTS VIA AUTONOMOUS DESIGN AND BUILD PROJECT

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ABSTRACT

The attrition rate at the undergraduate level for STEM fields is a disappointing 48%, and this is even higher for low-income students. Approximately only 11% of students who identify as low-income earn an undergraduate degree within six years, while 58% of students from higher income backgrounds earn their undergraduate degree within the same timeframe. The high attrition rates coupled with the already existing low enrollment is adversely affecting the country's economy as the supply of degreed professionals is not keeping up with demand. The academic persistence of a student is a critical factor in determining if a student decides to remain in a certain major or not. Researchers have concluded that enhancing the self-efficacy of a student results improves academic persistence which may positively influence retention. This study investigates the effect of autonomous, project-based learning on self-efficacy for 15 financially disadvantaged students. The learning experience was constructed such that all four sources of self-efficacy viz. mastery experience, vicarious experience, social persuasions, and physiological states were incorporated. Results indicate that the experience had a positive effect on the students' perceived self-efficacy. Each student believed that these played a major role in the success of the project and that their success was very much deserved.

Keywords: Self-efficacy, autonomous learning, low-income students, retention, persistence.

1. INTRODUCTION

The Pell Institute's 2018 historical trend report [1] showed that, by the age of 24, students from low-income families are five times less likely to attain their undergraduate degree compared to students from higher income families. The six-year graduation rate for low-income students is 11% as opposed to 58% for students from higher income background [2]. This attrition problem exists in STEM fields as well. Studies have shown that minority and low-income students tend to drop out of these fields at an even greater rate [3,4]. STEM fields drive innovation and global economy. The high attrition rates coupled with low enrollment is adversely affecting the country's economy as the supply of degreed professionals is not keeping up with demand. Moreover, losing low-income and minority students in the STEM fields reduces diverse thinking and participation in the innovation process. The U.S. Bureau of Labor and Statistics has shown that the demand for STEM graduates is outpacing the supply [5].

While data shows that low-income students have significantly higher attrition rates, student retention in general is a national issue that persists. According to the U.S. Department of Education [3], the attrition rate at the undergraduate level for STEM fields between 2003 and 2009 was a disappointing 48%. To make matters worse, at the graduate level, the estimated average attrition rate is 50% [6]. Unfortunately, only 41% of STEM graduate students successfully complete their graduate degree within two years of commencing their Master's program [7]. Student retention is a major issue across the nation for all academic institutions. Beyond the impact on the students this results in a reduction of tuition income, fees, and alumni contributions [8]. A more severe consequence is the resulting lack of diversity among student populations given the higher attrition rate among low-income and minority students. A diverse student population has been shown to immensely benefit the functionality of a heterogenous society [9]. Diversity in academia directly translates to diversity in the workforce, and a diverse workforce drives innovation and sustainability of the society. Louten [10] states that dropping out of college has lasting effects such as lower self-esteem and a higher tendency of not being able to demonstrate upward socioeconomic mobility, i.e. low-income students may continue to remain in the low-income bracket.

To address this ongoing attrition issue, researchers have investigated the various factors that contribute to such high attrition rates. Research shows that financially disadvantaged students have a higher risk of dropout given their tendency to persist less [11,12]. The academic persistence of a student is a critical factor in determining if a student decides to remain in a certain major or not. Several researchers have conducted both qualitative and quantitative studies to improve the academic persistence of a student. A popular psychological perspective is the social cognitive theory that investigates how environmental and cognitive factors influence one's learning and behavior [13]. Central to this scheme is a construct known as self-efficacy, which has been shown to have a strong influence on academic performance and retention. Self-efficacy is defined as the belief in one's capability to produce given levels of attainment.

Researchers have concluded that academic self-efficacy influences choices, effort expended on a given task, and how long one persists in a challenge [14-17]. More specifically, academic self-efficacy has been linked to student achievement and retention in STEM fields. A study conducted in mathematics has shown that children with higher self-efficacy outperformed those with lower self-efficacy in terms of novel problem solving, putting forth more effort, and persisting longer in reworking incorrect problems [18]. Improving one's academic self-efficacy improves persistence which can in turn reduce the attrition rate both at the undergraduate and graduate level. Banudra [13] identifies four sources that influence self-efficacy beliefs, namely: mastery experiences (self-evaluation of performances on prior similar tasks), vicarious experiences (being inspired by similar people achieving success on similar tasks), social persuasions (verbal judgement and appraisal), and physiological states (emotions). Self-efficacy has also been shown to greatly affect female engineering students [14]. Of those students who persist in college, female students have shown to have lower self-efficacy perceptions compared to male students [18]. Besterfield-Sacre et al. [19] found that female engineering students had lower confidence in their basic engineering skills and problem-solving capabilities by the end of their freshman year than their male engineering counterparts. Pajares and Miller [18] state that if self-efficacy is a crucial predictor of academic performance, then efforts to understand and enhance it must be studied.

Various studies have shown that project-based learning (PBL) and a more hands-on approach in engineering elevates learning efficacy. Surveys completed by various employers indicate a strong encouragement of PBL [20]. PBL also serves as a platform for collaborative work and builds critical thinking skills [21-23]. In addition, self-regulated learning, i.e. autonomous learning, has been linked with improved academic success [24,25]. In autonomous learning, students are in charge of their own learning, evaluate their progress by themselves, make critical decisions by themselves, and seek guidance/advise when required. Pintrich [26] states that students who follow this learning method are more motivated, more likely to do well in school, and demonstrate effective learning ability. All of these are essential in improving academic persistence and mitigating attrition. Even though studies have been conducted to assess one's academic self-efficacy, few studies exist on what can be done to enhance self-efficacy belief of students.

While, mastery experience has been shown to have the strongest influence on self-efficacy, social persuasion has been shown to be most beneficial for female students. Women also report being more influenced by vicarious experiences when compared to men [14]. The mastery experience can be strengthened via project-based learning, especially with design and build tasks. The social persuasion and vicarious experience can also be incorporated through PBL for improved effectiveness. Successful completion of a project results in enjoyment and satisfaction, and both boost the physiological state which then elevates self-efficacy. Thus, promoting hands-on learning can potentially result in improved self-efficacy which can in turn improve students' persistence in academia, especially among low-income and minority students. Finally, making the hands-on learning experience more autonomous further improves their chances of academic success.

2. METHOD

In an effort to improve the academic persistence of low-income and minority engineering students to increase their retention rates, this paper investigates the effect of autonomous learning on self-efficacy of financially disadvantaged students via design and build projects. This section highlights the student population, how the projects were formed, description of each project, and general observations by the authors over the course of this experience.

2.1 Student Population

The School of Engineering at Grand Valley State University received a National Science Foundation (NSF) grant (DUE# 2030615) to recruit and support financially disadvantaged students pursuing their Master's degree in engineering. A total of 30 students can be supported through this five-year grant. Each student participates in the combined degree program that awards both the Bachelor and Master's degree simultaneously. In the second year of execution of the grant, a total of 15 sophomore and junior low-income engineering students were recruited to pursue the combined degree program. The student population for this study consists of these 15 students (7 females and 8 males). Cohort 1 is comprised of 6 junior students of which 4 are males and 2 are females, while Cohort 2 is comprised of 9 sophomore students of which 4 are males and 5 are females.

2.2 Project Selection

Each cohort was asked to form two teams (i.e. total of four teams) and develop project ideas within the constraints:

- On time: a target completion date giving them approximately 1.5 semesters
- On budget: a budget of $ 2,000
- Challenging but fun to work on and they should be proud about their product

The teams were given a quick training on brainstorming emphasizing the ground rules of no judgment, encouraging wild ideas, building on other's ideas, quantity over quality, and mechanics of conducting a successful brainstorming session. At the end of the session, the teams deployed a screening method based on the above-mentioned constraints. Interestingly, even without any faculty intervention, each team voted on a project that had a direct consequence on society. Each project was multidisciplinary and carefully thought out to ensure how engineering can be utilized to have a meaningful social impact. The faculty also noted that the students enjoyed the opportunity to contribute as a group and enjoyed the autonomy of selecting their own project. For convenience of reference, the two teams from Cohort 1 are designated A and B, while the two teams from Cohort 2 are designated C and D.

Team A decided on designing and building a robot that can dig a trench along a predetermined path. The idea was inspired by difficulties faced during forest fires. Wildfires have become exceedingly common and destroy thousands of acres of forest land, structures, and claim the precious lives of civilians and fire fighters. For example, in 2020, there were 9,917 wildfires in California alone, and this resulted in a total cost in excess of 12 billion dollars while also claiming the lives of 33 people and injuring 37 [27]. Discussions and preliminary research by team A showed that there was no standard method to combat wildfires, and they were very interested in developing a scaled down prototype to address this ongoing concern. Team B settled on designing and building a device that is capable of harvesting heat energy that would otherwise be lost. Their motivation stemmed from kitchen appliances. For example, after an oven is turned off, the excess heat energy is simply lost to the surroundings. Similarly, once a kettle boils water, heat energy is lost in the cooling down process. The team's intention was to not let this excess heat energy go to waste and be able to recover a portion of it to be utilized for useful work. Ideally, they were aiming for a universal device that can be scaled based on the situation.

For Cohort 2, teams C and D surprisingly went the same route; they focused on environmental sustainability. Both teams decided to focus on recycling. While most people are pro-recycling, there is nothing stopping students and faculty/staff from throwing their pop cans into the trash instead of the recycling bin. The idea here was to incentivize recycling and make it fun for all people irrespective of age. Team C decided to go the unconventional route and build an arcade machine that uses the pop can as the token to play, while team D opted to build a device that relies solely on luck. Both teams initially had intentions of using social media to grow their reach and incentivize more people to recycle their pop cans.

All teams commenced their work in July 2021 and had to display their products during the Project Day event hosted by the School of Engineering in early December 2021. Each team also had access to the same three faculty mentors and could arrange for meetings or ask for guidance on as needed basis. It must be noted that Grand Valley State University's engineering students alternate between academic and co-op semesters, therefore, they had to carefully coordinate their work from start to finish. Cohort 1 was on academic semester in Summer 2021 but was on co-op in Fall 2021, while Cohort 2 was on co-op during Summer 2021 and returned to classes in Fall 2021.

2.3 Project Description

<u>Fire Trench Robot</u>

Team A's project was titled "Fire Trench Robot." The objective was to design and build a scaled down version of an automated fire trench digger to contain the fire without exposing the firefighters to the immense risk. The robot followed a line that was created by spray painting the ground. Line tracking sensors were used to follow the desired path. Since this was a small-scale, limited budget effort to prove functionality, the line was spray painted manually. Ideally, for the full-scale version, the robot would be guided by a navigation system or wirelessly controlled by a drone. Two fine brushes were mounted in front of the robot to loosen up the dirt and push away small debris, while tillers were mounted at the back of the robot to dig into the dirt. Rear metal wings attached to the robot were critical in forming the trench. Various concepts were considered but ultimately the team settled with this design concept after taking into consideration time, budget, and motor specifications. Several design iterations were done to ensure the weight of the robot was within a certain range to prevent the device from tipping over during the digging process. The main components include ball bearings, rotary shaft, roller chains, lightweight sprocket, roller chain sprocket, 12 V battery, high torque motors, tiller blades, and H-bridge. The team also spoke with the local fire department to gain insights into current issues and demo the idea to them. The fire fighters were very impressed with the small-scale device and provided good feedback on what can be done to improve it. This project was perhaps the most challenging and time consuming. An image of the robot is shown in Fig. 1.

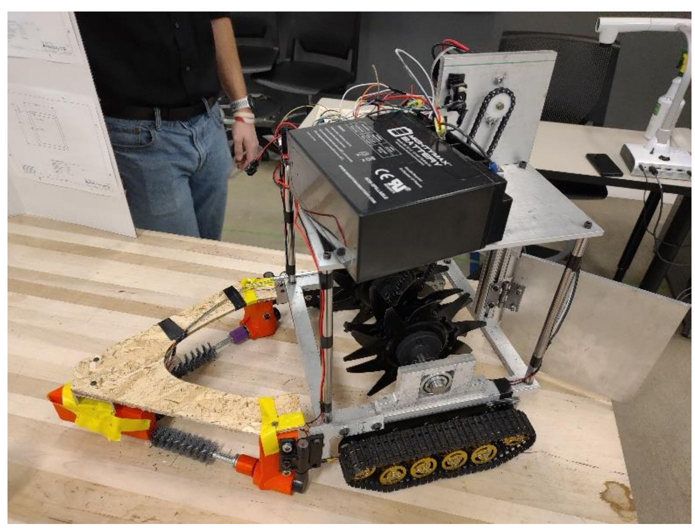

Figure 1: FIRE TRENCH ROBOT DESIGNED BY TEAM A ON DISPLAY DURING THE PROJECT DAY

Figure 2: WASTE ENERGY RECOVERY DESIGNED BY TEAM B ON DISPLAY DURING THE PROJECT DAY

Waste Energy Harvesting

Team B's project was titled "Waste Energy Harvesting." The objective was to design and build a universal device that can be attached to any hot device and harvest the thermal energy that would otherwise have gone to waste. After some preliminary research, the team decided to proceed with the use of thermoelectrics. Thermoelectrics are solid-state semiconductors that generate voltage from experiencing temperature difference (i.e. Seebeck effect). From the get go, the team decided on making a coaster on which a hot kettle could be placed primarily for two reasons. First, working with a hot kettle was much easier than working with an oven. Next, the team had a vision to develop a universal coaster that was modular so that it can be scaled to any scenario. Once a hot kettle was placed on the coaster, the heat drawn from the kettle would then be converted to electrical energy and can either be stored or used for any purpose. For this project, the students decided to use the extracted heat energy to light up an array of LEDs that took the shape of the school's initials (GV) as shown in Fig. 2. One of the major challenges was to ensure that sufficient energy was being captured to power the lights for the desired duration with the intended intensity. To achieve this, a layer of cork was used as an insulator to direct most of the heat towards the sensors and avoid heat loss from the lateral sides. The team also faced difficulty in packaging the product. Due to the large number of LEDs, care had to be taken to avoid short circuiting against the Aluminum heat sink.

Pop Drop

Team C's project was titled "Pop Drop." The intention here was to build a device that would attract audience from all ages and incentivize them to recycle their pop cans. The team wanted to incorporate luck into their design so that the audience will always be unsure of the outcome. The final product was a PLINKO-style game with a recycling motivation theme as illustrated in Fig. 3. The user places a pop can in one of the six pockets located on the top. The can then falls while colliding with pins and can land either in a try again slot or a slot which has a candy reward. If the user lands in a candy reward slot, they must first answer a recycling question before they can proceed to obtain candy from a dispenser than has motion sensors. Based on which slot the can fell into, sensors dispensed the correct candy. An Arduino Mega was used to control all of the senders, motors, and LEDs. The most challenging part of this project was debugging the code for the senders, motors, and LEDs during functional issues. Once the pop can drops to the bottom, it is then collected in a bin and recycled accordingly.

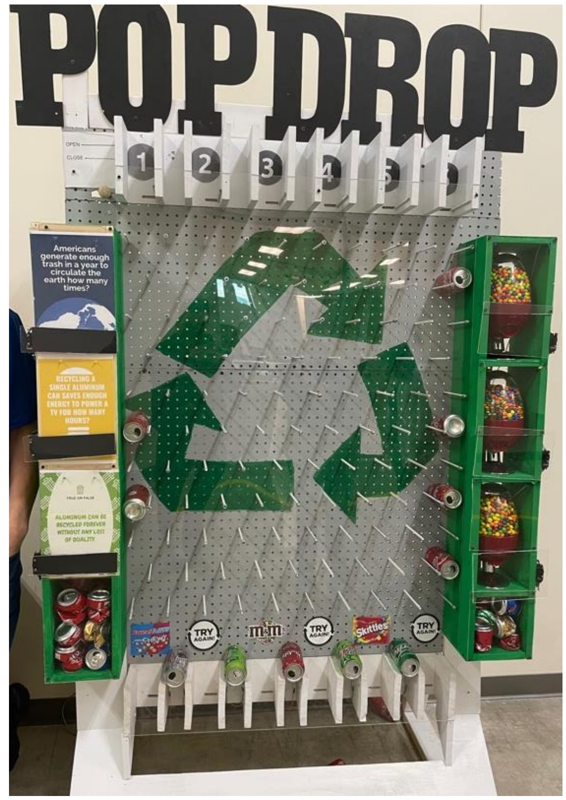

Figure 3: POP DROP DESIGNED BY TEAM C ON DISPLAY DURING THE PROJECT DAY

Crush Rush

Team D's project was titled "Crush Rush." The students opted to build an arcade device to take students back to the 1980s when games such as Pac-man, Space Invaders, Pinball, etc. were big. This retro idea was then blended with recycling motivation. Since pinball was easily coupled with recycling, the team chose a pinball machine where the ball was the crushed pop can. The frame was constructed from wood and calculations were done to ensure the correct angle of inclination was achieved to facilitate the movement of the pop can. The team also interviewed multiple students from the Arts department who specialized in illustration to hand-pick a student to help them paint the device frame. The art was nature themed symbolizing the importance of caring for our environment and making it sustainable. In addition, the students decided to use a bicycle handlebar to actuate the flippers that strike the pop can. This was a subtle way of encouraging users to ride their bikes more often to reduce carbon emissions. The device is shown in Fig. 4.

When the user is ready to play the game, they use a can crusher that is attached to the pinball machine to create the puck. Following this, they insert the can into the side slot and press a button which subsequently activates compressed air to shoot the can into the playing field. Rubber bands are used to bounce the can around while also relaying information using a sensor to account for points scored. The score is displayed on a screen that is embedded in the inclined frame. If the user is unable to strike the can back into the main field using the flippers, the can falls down and is collected for subsequent recycling. After the game concludes, the user inputs their initials and is also able to see the highest score. The main components include solenoids, audio shields, speakers, Arduino Mega microcontroller, LED Matrix, display, diodes and transistors, buttons/switches, flipper bearings, lever cables, bicycle handle, and spacers. The biggest challenge for this project was to ensure the correct angles at which the rebounds were placed. Frequently, the can would enter the playing field, strike a rebound, and simply fall into the slot below between the two flippers.

Figure 4: CRUSH RUSH DESIGNED BY TEAM D ON DISPLAY DURING THE PROJECT DAY

2.4 Faculty Observations

Over the course of the projects, each team reached out to faculty mentors on an as needed basis. Each team opted to arrange for a group meeting with all mentors to demonstrate their progress midway through the projects. If there were any questions on mechanics, electronics, or coding, they sought help from associated faculty. Based on faculty observations, all teams were equally motivated to complete this project on time and under budget so that it could be displayed during Project Day. While there was an appointed leader for each team, all students appeared to take ownership of their respective tasks despite there being no grades assigned. Since the projects assigned had nothing to do with any academic courses, it was possible to make it completely voluntary. This alleviated the grade pressure associated with in-class projects. When speaking with the students, the authors noticed that it ultimately came down to wanting to prove to themselves that they can get this done despite their busy schedules.

While working on the projects boosted their mastery experience, the faculty were genuinely impressed with all projects and kept continuously encouraging the students, i.e. social persuasion. All students were from similar socioeconomic backgrounds and were extremely supportive of their peers. In addition, during our Cohort group meetings (held separately as part of the scholarship program), each group was inspired by other groups on their success. All of these contribute to vicarious experiences. The physiological state was mixed wherein the students seemed stressed near the project deadline as they had to balance exams/work and ensure the project came together as envisioned. However, once they completed the projects, they were very relieved and happy that it was completed on time and within budget. The biggest achievement was them proudly displaying their fully functional devices on Project Day. Project Day saw over 70 projects on display with hundreds of high school students attending the event. The public also voted for the best project on display.

The intended goal was to make the students feel proud of their achievement and improve their self-worth. Both teams (C and D) from Cohort 2 that focused on sustainability jointly won the first place for the People's Choice Award. The students were extremely pleased, and winning the first place gave them immense self-belief; a positive physiological state that enhances self-efficacy. While the project was able to positively impact all four sources of self-efficacy (based on faculty observations), we needed to collect quantitative evidence that this appeared to be the case from the students' perception.

3. SURVEY AND DATA COLLECTION

At the culmination of the project, the students were invited to complete a survey to assess the impact of this autonomous, project-based learning experience on self-efficacy. Participation in the anonymous survey was completely voluntary. All students completed the survey, and this occurred before the results for the Project Day were announced. In hindsight, the survey could have been deployed after the results were announced since two teams jointly won first place. Hutchinson et al. [28] surveyed freshman engineering students enrolled in a problem-solving and computer tools class and have presented nine prominent factors that affect a student's confidence and self-efficacy. From these, the factors that closely relate to this experience are extracted, viz: motivation toward success; teaming; problem-solving abilities; ability to seek help; and enjoyment/satisfaction. Based on these factors, eight questions were developed to assess the impact of this experience on self-efficacy. The questions are given below.

1. I was motivated to take ownership of this project even in the absence of grading.
2. I am happy with my contribution to this project and believe that I played a significant role in its success.

3. I feel more confident in my ability to work effectively on a team because of this project.
4. The experience of working on this project has given me more confidence to challenge ideas and take a firm stance when I believe I am correct about something.
5. Throughout the project, I was comfortable reaching out to the faculty mentors for help or advice regarding the project.
6. This project helped me feel more confident in my hands-on engineering skills.
7. I enjoyed working on this project and would recommend that future students work on a project like this to improve their professional and engineering skills.
8. I believe that my team deserves the success that we achieved through this project, and I am happy with the outcome.

Questions 1 and 2 capture the motivation toward success, while question 3 assesses the project's impact on teamwork. Question 4 was specifically geared towards female students. O'Connell et al. [29] conducted a survey during a workshop held specifically for female STEM professionals and found that several women lack the confidence in challenging ideas or taking a firm stance even when they know they are right. Questions 5 and 6 were developed to address the ability to seek help and problem-solving capabilities, respectively. The final two questions relate to the enjoyment/satisfaction factor. The results are discussed in the subsequent section and data are also analyzed by gender.

4. RESULTS AND DISCUSSION

Each question in the self-efficacy survey was ranked on a Likert scale of 1 – 5 where each number corresponds to the following statement: 1 = Not true at all; 2 = Rarely; 3 = Sometimes; 4 = Often; and 5 = Very true. The cohort average of each question is given below in Table 1.

Overall, it was evident that the autonomous project experience had a positive effect on the students' perceived self-efficacy. For questions 2 and 8, the responses were overwhelmingly positive indicating that their individual contributions were very valuable in the success of the project and that they are very pleased with the outcome. Cohort 2 was more motivated to work on the project despite it not being graded or part of a course requirement (Question 1); the authors expected Cohort 1 to be more motivated. Cohort 1 students (juniors) were all on co-op and were able to meet frequently after work since they had no classes during the Fall 21 semester. Cohort 2 students (sophomores) had a full academic course load, and since it was a multidisciplinary team, arranging for a common time to meet was challenging. Despite this, they met each week late in the night and were very enthusiastic when interacting with the faculty mentors. The juniors felt more comfortable in their ability to seek help from faculty mentors when required and also felt more confident in their team skills. This could be attributed to the fact that they have known both the faculty mentors and their peers for a longer period of time. The sophomores felt that the project was more instrumental in boosting their confidence in their hands-on skills. Through student-faculty interactions, the authors also observed that near the tail end of the project, the students were cramped for time and found it challenging to balance their workload. The students recommended moving the project earlier for future cohorts, and this could be the reason for the relatively lower score for question 7.

Table 1: AVERAGE SELF-EFFICACY SURVEY SCORE OF EACH QUESTION FOR COHORTS 1 AND 2

Question	Cohort 1 Avg	Cohort 2 Avg
1	3.67	4.29
2	4.50	4.57
3	4.00	3.86
4	3.33	3.57
5	4.33	3.71
6	3.83	4.14
7	3.33	3.86
8	4.50	4.71

The lowest scores for both cohorts were for question 4 which assessed the students' confidence in challenging ideas proposed by their teammates. Cohort 1 had a much lower score relative to Cohort 2. To understand this further, the results need to be analyzed by gender, and Table 2 provides this information. The average score for this question among the female students in Cohort 1 was a mere 2.5 indicating that the female respondents agreed with this statement either *rarely* or *sometimes*. For Cohort 2, the response from the female students was between *sometimes* and *often*. While this is an improvement over Cohort 1, it still remains a concern that the female engineering students shy away from challenging ideas proposed by their peers or taking a firm stance even when they know that they are correct. This aligns with the observations from O'Connell et al. [29].

Other findings include female respondents in both Cohort 1 and 2 feeling less confident to work in teams when compared to their male counterparts. Interestingly, while female students in Cohort 1 felt overall less confident in their hands-on engineering skills (aligns with conclusions from [19]), those in Cohort 2 felt more confident when compared to their male peers. Finally, on average, when compared to junior female students, the sophomore female students demonstrated a higher perceived self-efficacy. This is an interesting observation as one would expect that junior students would demonstrate higher self-efficacy given their advanced academic standing and improved maturity. However, the student population is very small and conclusive results cannot be drawn yet.

Based on student data from the survey, the project appeared to have enhanced the students' perceived self-efficacy, and each student believed that they played a major role in the success of the project and that their success was much deserved. This is extremely beneficial as the more the students believe that their success is deserved and not achieved through sheer luck, i.e. impostor syndrome, the more confident they become and the longer they persist. To maintain the autonomy in learning, the faculty mentors only provided advise when required. The authors recommend incorporating more social persuasions and vicarious experiences via active mentoring to benefit the female students [14]. This can be achieved via targeted student-faculty mentoring and peer mentoring where the current students in Cohorts 1 and 2 peer mentor the future cohorts. In addition, the recommendation was to advance the project and have students work on it more during the summer semester where the workload is less demanding.

Table 2: GENDER-BASED AVERAGE SELF-EFFICACY SURVEY SCORE OF EACH QUESTION FOR COHORTS 1 AND 2

	Cohort 1		Cohort 2	
Question	Male Avg.	Female Avg.	Male Avg.	Female Avg.
1	3.67	3.50	4.33	4.25
2	4.33	4.50	4.67	4.50
3	4.00	3.50	4.00	3.75
4	3.67	2.50	4.00	3.25
5	4.33	4.00	3.33	4.00
6	4.00	3.50	3.67	4.50
7	3.33	3.00	4.00	3.75
8	4.33	4.50	5.00	4.50

5. CONCLUSION

Fifteen financially disadvantaged engineering students were placed into two cohorts and exposed to autonomous design and build projects to investigate the effect of this learning experience on their perceived self-efficacy. Overall, both cohorts demonstrated improved self-efficacy by showing improvements in critical factors such as motivation toward success; teaming; problem-solving abilities; ability to seek help; and enjoyment/satisfaction. Even though the female engineering students showed improved self-efficacy in most factors, they still lagged behind their male peers for confidence in challenging ideas and team skills. However, caution has to be exercised in interpreting the results as the sample size is very small.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant No. DUE# 2030615

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