A Project-based Experiential Learning Approach To Cybersecurity And Biometrics

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Abstract

In this case study of a course on Cybersecurity and Biometrics, we explore the effectiveness of project-based learning using a makerspace combined with the 5E Instructional Model. We describe the course design and its objectives, the project itself, and the makerspace facility where students undertook the project. Using a pre- and post-project student survey, we examine changes in student perceptions over the course of the project. We uncover some interesting insights relative to the use of a project as a learning tool in technical courses such as this, particularly regarding pedagogy, teamwork, incorporation of a makerspace, and online learning.

Section 1 - Introduction

A Cybersecurity course is challenging to teach and learn. Bridging the gap between theory and practice is problematic due to its abstract and highly technical content, and online teaching adds to this complexity. With this in mind, we conducted an experiment using a makerspace for experiential learning in conjunction with a project-based approach and the 5E Instructional Model to bring theoretical concepts in a Cybersecurity Biometrics course to practical implementation.

To study the effectiveness of our experiment, we used a case study approach where 35 students in an online Cybersecurity Biometrics class were grouped into teams for a semester-long project to integrate theory and practice by building a working prototype of an optical fingerprint reader using a Raspberry Pi, an Internet of Things (IoT) camera, a glass prism, the National Institute of Standards and Technology (NIST) Biometric Image Software (NBIS) modules, a database, and a 3D printed case to integrate these components. Each team followed project management processes and designed their own 3D case, database and program interface. The makerspace provided students the opportunity for ideation, prototyping, learning from failure, and creativity. Pre and Post surveys, employing a modified 7-point Likert Scale ranging from Strongly Disagree to Strongly Agree, were used to explore our research questions and assess the effectiveness of a makerspace project-based experiential learning to teach cybersecurity and biometrics concepts through an online modality.

In section 2 of our paper we review principles and related work on the 5E Instructional Model, project-based learning, and the utilization of makerspaces as a learning tool. Section 3 describes the methods and details our approach with 5E, project-based learning and structure, technical specs and biometric concepts of an optical fingerprint scanner, makerspace lab resources, and pre/post-survey sections. Pre and post survey data of key results and analysis is discussed in section 4 and section 5 contains a brief conclusion of our study.

Section 2 - Related Work / Literature Review

Instructional models are effective at helping students learn STEM concepts through inquiry and experimentation (Bybee, et al., 2006). The 5E instructional model consists of Engagement from prior experiences, Exploration through inquiry of past knowledge, Explanation of what the student understands, Elaboration of understanding through new experiences, and Evaluation of the student's own understanding. The BSCS 5E Instructional Model was developed in the late 1980s and have been used broadly and effectively across multidisciplinary STEM curriculums and professional development (Bybee, et al., 2006).

Research and case studies on the utility and implementation of the 5E model have been shown to be effective in many disciplines and settings such as teaching Physics and Newtonian mechanics to over 150 undergraduate students (Bahtaji, 2021); at the elementary and middle school levels to teach STEM, buoyancy force problems (Çepni & Şahin, 2012), mathematical modeling of geometric objects (Tezer & Cumhur, 2017), or exploration of concepts and solutions of STEM problems affecting local communities (Bybee, Using the BSCS 5E Instructional Model to Introduce STEM Disciplines, 2019); online hybrid teaching modality for Special Education Teachers (van Garderen, Decker, Juergensen, & Abdelnaby, 2020); and at the graduate level in a Network Security course (Olimid, 2019). Although the latter represents an example of a successful implementation of the 5E Instructional Model for teaching Cybersecurity, this is a rare case study because the 5E Model has not been widely researched or applied in teaching Cybersecurity shown by the limited published research.

Project-based Learning provides a structure, processes, and workflow for students to gain deeper knowledge through creative and critical thinking, and manage uncertainty with real-world problems through communication and teamwork while learning professional skills (Anazifa & Djukri, 2017; Johnson, 2019). This approach is commonly used in teaching Cybersecurity. It keeps students engaged, focused on specific tasks, and directs the learning process through the development of diverse solutions to real-world problems (Sherman, et al., 2019).

Makerspaces are venues for carrying out do-it-yourself (DIY) activities. They typically are home to various machines and hand tools, including 3-D printers, laser cutters, vinyl cutters, vacu-formers, sewing and embroidery machines, among others, and laptop or desktop computers with design software. In the education realm, they are used to give students the opportunity to engage in ideation and to build prototypes, as part of a project-based learning component of a given course. As of 2020, there were over 2,300 makerspaces globally (hackerspaces.org, 2021).

Makerspaces are the physical manifestation of the maker movement, considered by some to be the most important economic movement since the Industrial Revolution (Anderson, 2012). It represents a migration away from mass production in factory facilities to small-scale manufacturing often by end users. Makerspaces have been found to promote creativity and innovation and makerspace projects frequently lead to new business startup (Halbinger, 2020).

Section 3 - Methods

Section 3.1 - 5E Instructional Model

The 5E instructional model was used an online asynchronous Cybersecurity Biometrics class. Lectures on fundamentals of biometrics were delivered through Zoom sessions. These lectures were used to engage the students through discussions of project management, computer science and cybersecurity topics such as teamwork and communication; the security triad of Confidentiality, Integrity, and Availability (CIA); Authentication vs Authorization; Identification vs Verification; programming languages/libraries; and databases. These discussions also provided an opportunity for the students to explore their understanding of computer science and cybersecurity concepts from previous classes and how these can be applied to the assigned project. At the end of the semester students were required to produce a written report with analysis of their project results and provided a presentation to the class. This process allowed them to explain their understanding of the cybersecurity and biometric concepts and elaborate on their newly acquired insights based on the analysis of the project results. Evaluation of the student's own understanding occurred as other groups presented their report and analysis of their project and the students were able to compare and contrast their personal understanding with that presented by their classmates.

Section 3.2 - Project-based Learning and Teaching

In this case study, students were instructed to form groups of four or five and were provided detailed project instructions to create a structured project approach. Instructions included coming up with a team name, selecting a team leader, identifying student's technical skills, defining roles and responsibilities, creating a schedule of tasks and timelines, and agreeing on a communication plan and meeting frequency.

Defining a team name to help enhanced their perception of identity and belonging to a group. Students approached this project with a competitive spirit; this was an unexpected side effect observed through student comments throughout the semester and during the presentations. They also showed pride in their project solution during the presentation by sharing personal experiences on how they overcame specific challenges.

The selection of a team leader is an important step to define roles and responsibilities and create an organizational structure to manage the project. The team leader managed project tasks schedule and communicated with the team and the stakeholder (instructor). Team members helped define the expected timeline and effort to foster a sense of responsibility and ownership. Team leaders were tasked with identifying each team member's technical skills and defining their roles and responsibilities. This is a critical step in the team formation to ensure everyone in the team understands their contribution and what the team expected of them. This approach was derived from the organizational development literature on team building, and particularly the work of Richard Beckhard (Beckhard, Optimizing team building effects, 1972) (Beckhard & Harris, Organizational transition: Managing complex change, 1987). Beckhard was the co-developer of a model for team building called GRPI (goals, roles, processes, and interpersonal relationships), which he asserted were the keys to successful and high-performing teams. Team leaders met biweekly with the instructor for mentoring on technical challenges, team dynamics, and share ideas and provided a written progress status.

Section 3.3 - Cybersecurity, Biometrics, and Optical Fingerprint Reader

Each team was instructed to design, develop, and implement a Biometric System for an optical fingerprint reader. Students were introduced to the concepts of biometrics and key factors that makes a biometric system functional and secured through a series of online lectures. Students were provided a project description to guide them through a set of requirements and asked to be creative and design a working prototype that is technical, functional, and secured.

The National Institute of Standards and Technology (NIST) Biometric Image Software (NBIS) is an open source biometric software that can be used to analyze scanned fingerprint images for image quality, minutiae detection, classifications, and generate fingerprint matching with a low rate of False Acceptance Rate (FAR) and False Rejection Rate (FRR). This software was developed for the Federal Bureau of Investigation (FBI) and Department of Homeland Security (DHS) (Ko & Salamon, 2010). Students used this open source software to match captured fingerprints and perform their statistical analysis.

Packages containing a CanaKit Raspberry Pi 4 Model B with 4GB of RAM, 32GB MicroSD card, a 250GB USB drive, a 1.25” x 1.25” prism, and an autofocus camera attachment were supplied to each student. Detailed instructions were given on how to assemble and connect the Raspberry Pi to the autofocus camera. The Raspberry Pi OS (32-bit) version was downloaded and installed in the MicroSD card and the 250GB USB drive was used to store the NBIS libraries, programs, and database.

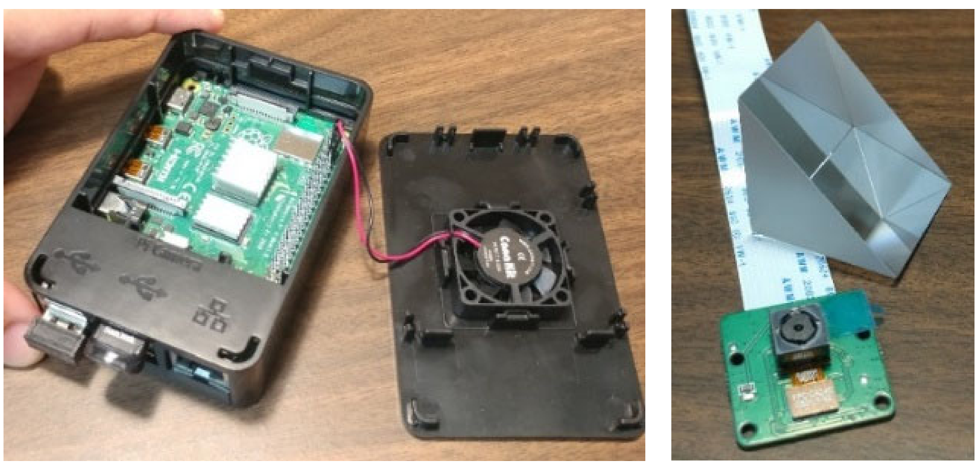


Figure 1 - Assembled Raspberry Pi 4, prism, and autofocus camera

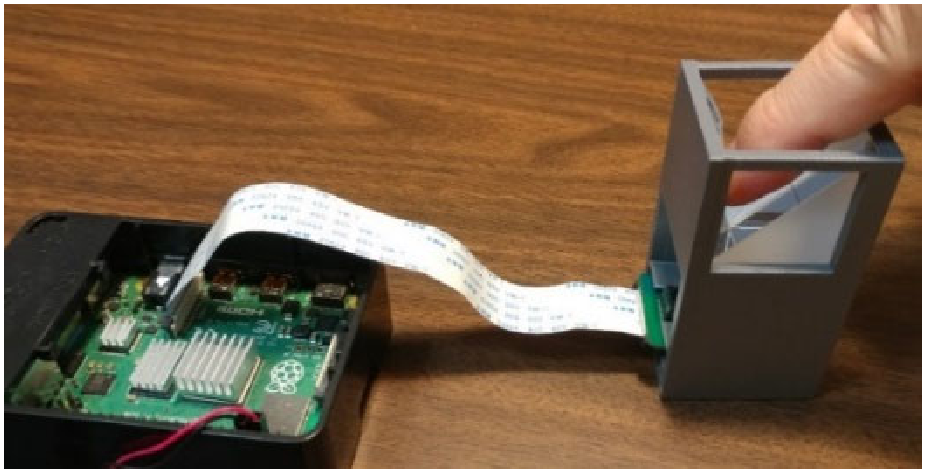


Figure 2 - Raspberry Pi optical fingerprint scanner

Section 3.4 - Makerspace

The Hatch It! Lab makerspace at the Center for Innovation and Entrepreneurship at the University of Tennessee Chattanooga served as an ideal space for prototyping the fingerprint reader. It houses six 3-D printers and the requisite design software for their operation. The makerspace is staffed by trained student workers, called Makerspace Managers, who troubleshoot, provide assistance in using the equipment, and police safety protocols. Students in this course received required training in the safe use of the makerspace.

The makerspace is not merely a place to build a prototype. It is a safe space for experimentation. Students were able to fail in their efforts, reflect on what went wrong, and pivot to test a new approach. In this way, both the principles of the scientific method and the necessity of having an entrepreneurial mindset could be taught simultaneously.

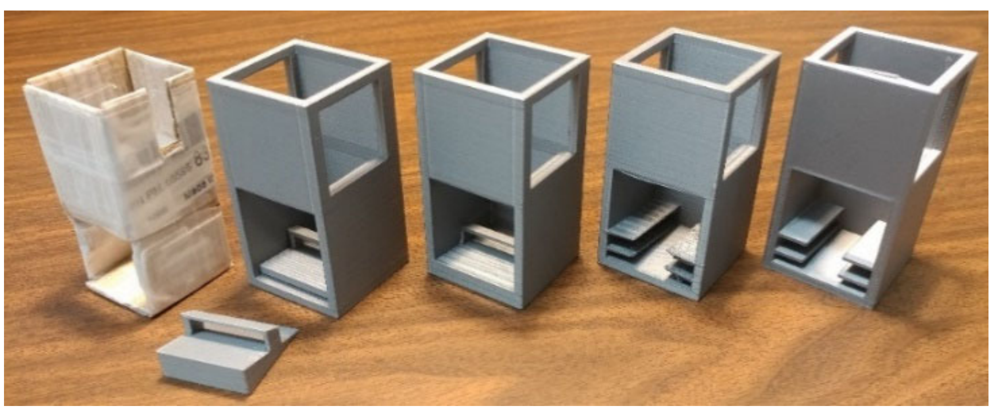


Figure 3 - Prototyping progression from cardboard to final 3D case

Section 3.5 - Online Learning

This course was taught during the spring of 2021 with an online synchronous modality due to the constraints imposed by COVID-19. Weekly class meetings were conducted over Zoom twice a week. Teams often met online to work on their design, presentation, and report. They occasionally met face-to-face on campus at the makerspace lab to print their 3D design and discuss improvements.

This online modality was challenging for the students and instructor. Difficulties included coordination, communication, and meeting to collaborate in the project. A major contributing factor to these challenges was credited to the online component and inability to have impromptu meetings before or after class because students were not physically in the same room.

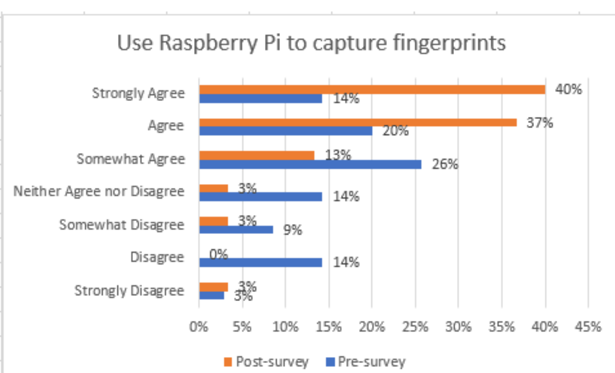
Section 3.6 - Pre and Post-Surveys

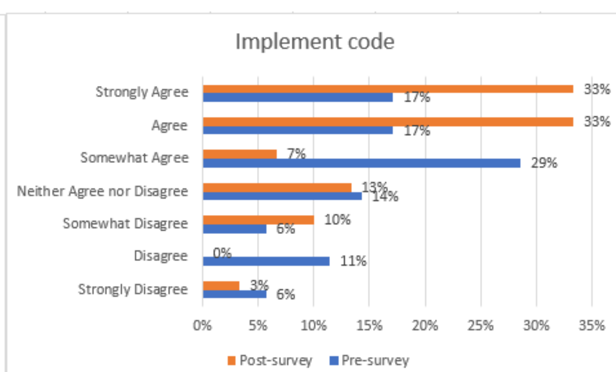
In order to better understand the impact of our approach on learning of the students in this cybersecurity course, an anonymous pre- and post-survey was used to bookend this case study. The pre-survey sought to derive student perspectives on several topics prior to beginning the project. The post-survey had the same set of questions plus several additional sections with a slant on post experience and lessons learned. These additional sections were added to gather data on the student's learning process and perspective on cybersecurity concepts, online learning experience, makerspace experience, and open-ended questions. This method permitted us to gather quantitative and qualitative data on topics such as student's understanding of the learning objectives, teamwork, engagement, and demographics. A seven (7) point Likert scale was used to gather the quantitative data while specific questions and open-ended questions were designed to gather qualitative data. The class consisted of 35 students and 31 responded to the surveys. The pre-survey provided a baseline measurement and the post-survey data allowed for a delta analysis.

Section 4 - Results

Section 4.1 - Learning Objectives

The surveys show that student's confidence in their ability to meet the learning objectives to use the Raspberry Pi and the NBIS libraries to design a biometric system and 3D case to capture and analyze fingerprint images significantly increased by the end of the project. Most notable changes can be seen in the use of Raspberry Pi, code implementation, and use of NBIS libraries where it changed from 34% to 77%, 34% to 66%, and 29% to 74% in the agree/strongly agree ratings respectively. We also saw a shift in the 3D case design response from 11% to 43% in the strongly agree rating and can be attributed to increased confidence on themselves as shown by the changing numbers from pre and post-surveys in the somewhat, neither, and overall disagree ratings.





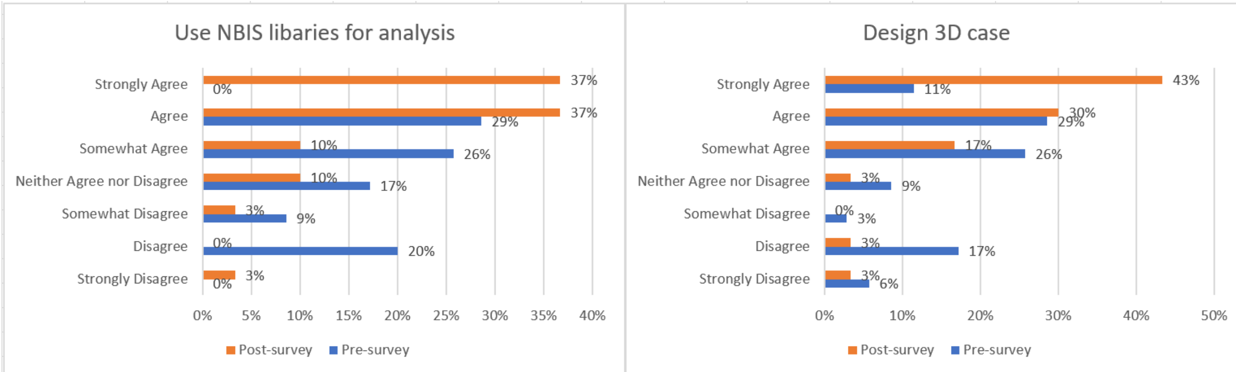


Figure 4 - Pre and post-survey Learning Objectives

Section 4.2 - Teamwork

In the pre-survey, students came into the project with a very strong positive perception of working in teams and their ability to do so effectively. Seventy-seven percent (77%) agreed (somewhat agree, agree or strongly agree) concerning the value of working in teams. The great majority of students saw themselves as potentially strong contributors to a team who would always come prepared and complete tasks on time (97% agreed). Students were almost equally confident in their ability to work well with teammates, understand the importance of team management (specifying roles and responsibilities), and understand the importance of communication in teamwork (94% agreed).

In the post-survey, students largely perceived that they worked well with their teams (70% somewhat agreed, agreed, or strongly agreed), and that team members worked well together (74% agreed); however, in both cases, 20% or more disagreed. Students perceived that they were strong contributors to their teams (83% agreed) and that they completed tasks on time (90% agreed). By smaller majorities, respondents perceived that their attitude toward teamwork had improved (53% agreed) and that their team's attitude had also improved (63% agreed); although, 23% disagreed that the team's attitude had improved. Most students felt that they came prepared (90% agreed) and worked well with their team (83%). Sixty-four percent of respondents reported a positive feeling of accomplishment working with their team.

While still positive, attitudes about teamwork in general, the ability to complete tasks on time, and being prepared all fell. It would seem that reality weakened perceptions of teamwork – its desirability and efficacy – to some extent. Overall, though, students were more positive than negative about teamwork at the end. Expectations for the power of teamwork can be inflated as individuals enter a project. Preparation by teams relative to establishing goals, roles, processes, and relationships may vary from team to team by the quality of the effort put into it. It is encouraging, however, that students concluded the project with a net positive attitude toward teams.

Section 4.3 - Engagement and Learning Experience

Student's views that this was a good learning experience and motivation/interest dropped from 94% to 80% and 88% to 67% in the agree/strongly agree rating respectively. This change could be attributed to their experiences and challenges in teamwork as discussed in the previous section. Another contributing factor could be their technical preparation prior to this course. It changed from 18% to 39% in the overall disagree rating. Despite these changes in the negative, 84% feel motivate to continue learning about biometrics, 73% felt this was a good and effective learning experience, 66% recommend this project, and 76% felt the level of effort is adequate. An 87% of students believe this project improved their theoretical and applied understanding of cybersecurity and biometrics while 93% believe their critical thinking skills improved.

Based on responses to the survey, students felt challenged by the project. For many, it was perceived to overtax their skillset. The anxiety produced by this challenge may have caused the drop off in the number of students who believed the project provided a good learning experience and was motivating for the rest of the course. Nevertheless, a significant majority of the class reported that they were more confident about meeting the course learning objectives after the project than they were before it began. Ultimately, two-thirds of responding students indicated that they would recommend a project like this one as a learning experience.

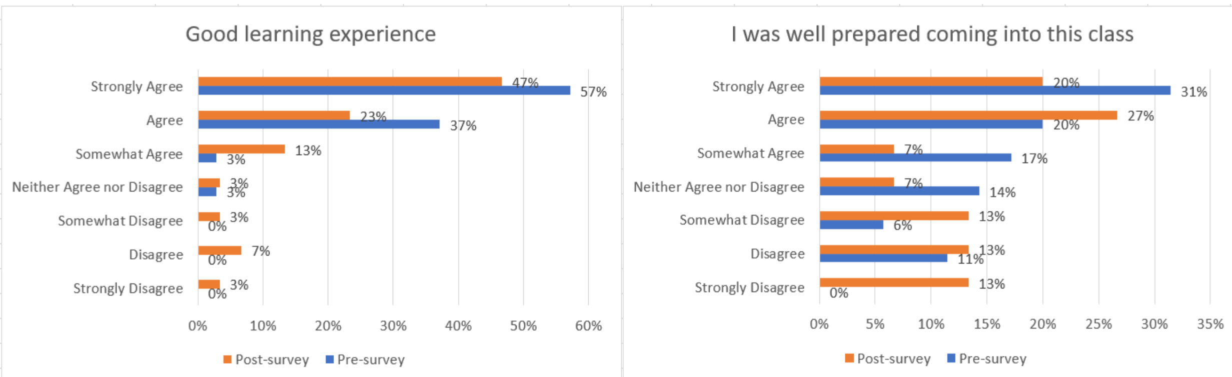
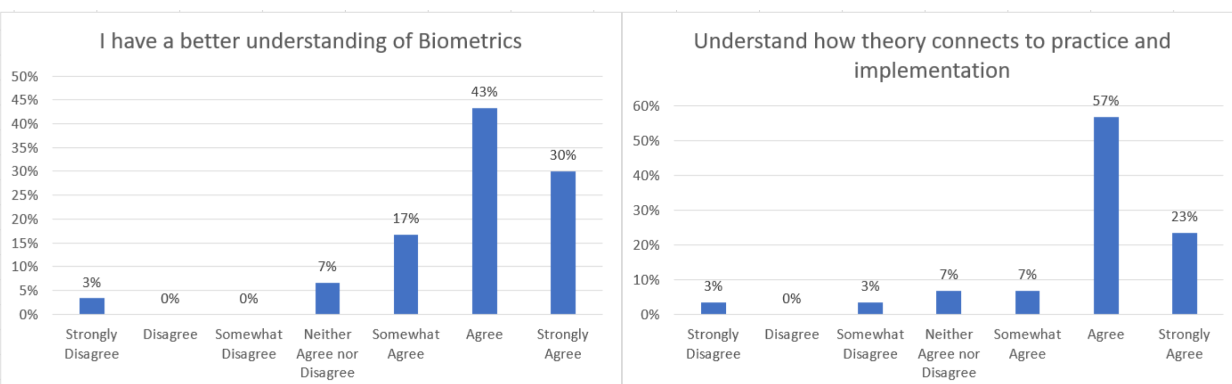


Figure 5 - Pre and post-survey Engagement and Learning Experience

Section 4.4 - Cybersecurity Concepts (Post-Survey Only)

Students were overwhelmingly positive in their responses associated with their understanding of biometrics and cybersecurity concepts after this project with 90% agreeing, 87% agreeing they understand how theory connects to practice and implementation, and approximately 90% agreeing that they understand key biometric concepts of enrollment, verification, identification, false acceptance rate, false rejection rate, and hamming distance. These responses support this type of project-based experiential learning.



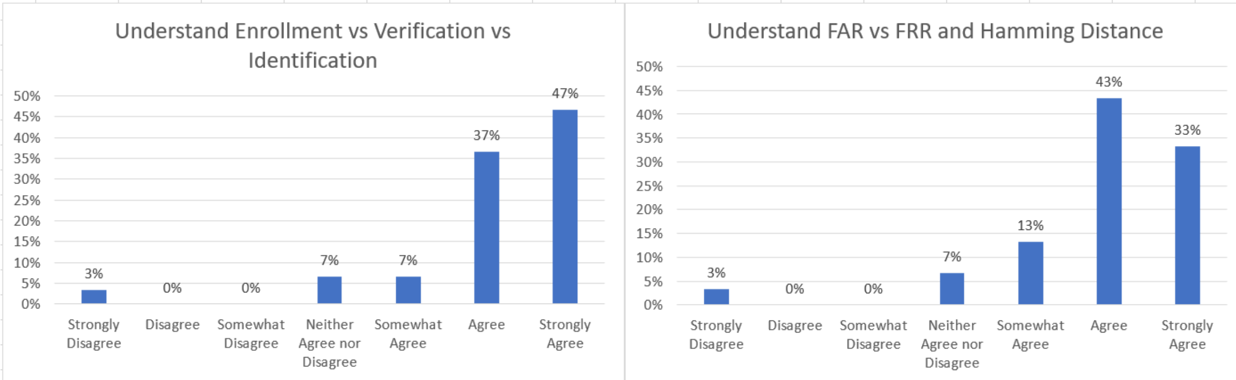


Figure 6 - Pre and post-survey Cybersecurity Concepts

Section 4.5 - Course Online Experience (Post-Survey Only)

Engaging students in online classes has been a challenge throughout the COVID-19 pandemic and 67% of respondents agree that online lectures through Zoom helped them stay connected with classmates, the instructor, and the course content while 77% agree that the project provided an opportunity to be an active participant in the online learning process. This online project-based experiential learning approach motivated 77% of the students to learn and research new cybersecurity topics and is in line with the reported 84% who felt motivate to learn about biometrics in section 4.3. When asked if they preferred this class be taught in a face-to-face modality, a surprising 40% neither agree or disagree while 47% agree. It could be argued that this was a good approach and delivery but further inquiries will help to clarify.

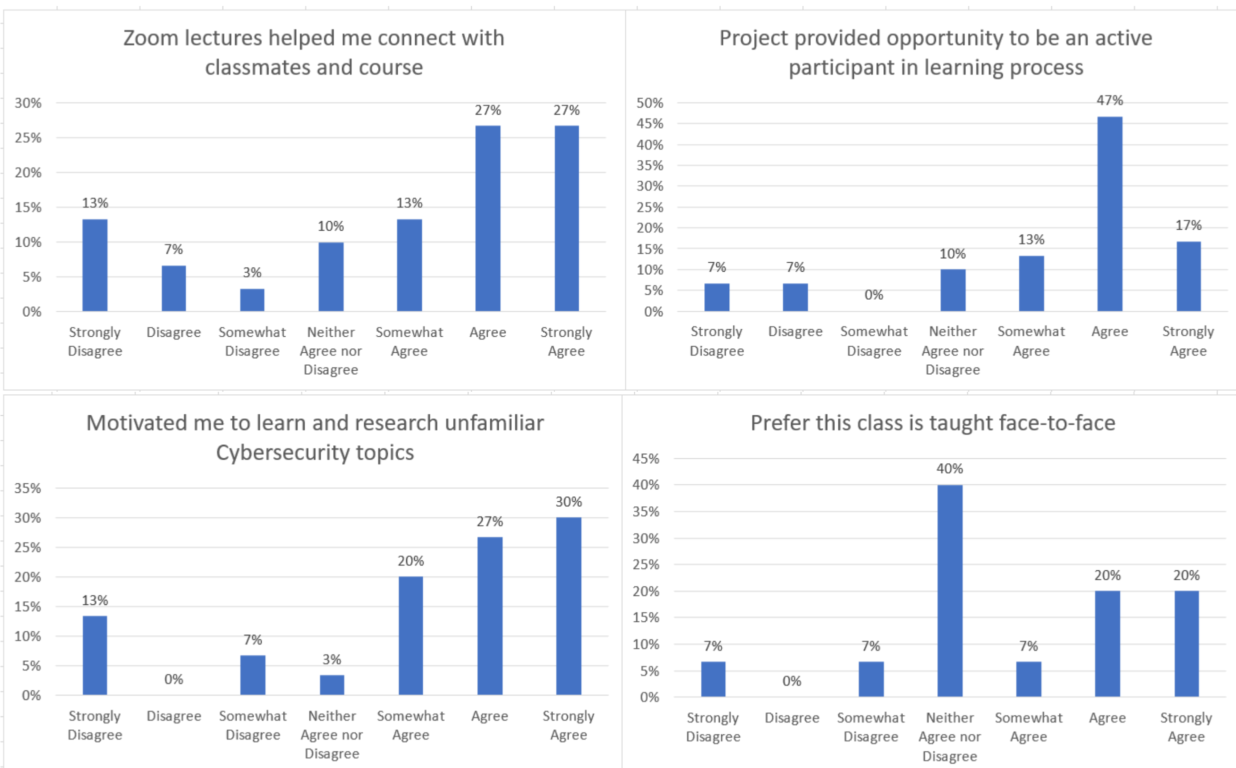


Figure 7 - Pre and post-survey Course Online Experience

Section 4.6 - Makerspace Experience (Post-Survey Only)

After the project, 87% of the responding students felt they understood the tools of the makerspace. Their makerspace experience caused 87% to conclude that they were well-prepared to bring creative ideas to a project, while 89% felt they were able to use resources effectively and efficiently. Seventy-seven percent of students felt that they effectively managed their time and that they were adequately prepared to deal with failure. Students were largely positive about their ability to share what they learned with others (80% agreed).

Over the course of the semester, it is clear from the survey that the students' perception of their understanding of the makerspace tools increased substantially. Most came into the course not having been exposed to a makerspace. Requiring them to spend time in the space, working with the equipment, paid off in increased self-efficacy. Several students indicated that they would actively seek opportunities to use the makerspace again in the future.

Interestingly, students' confidence in their ability to manage time, to be prepared for failure, and to share their learning and offer assistance to others all fell off when they were confronted with the reality of actually using the makerspace. It is likely that these students were not prepared coming into the course for the numerous failed experiments and resulting pivots this kind of work entails. Given their own struggles, it is possible that reaching out to others became a luxury they came to feel they could not afford. These are all useful lessons that engaging in experimentation in a makerspace can teach. It is probable that a second makerspace experience would change this result, as expectations would be adjusted.

Students' perceptions about being prepared to be creative and to use resources to create a project improved somewhat. Because of the challenges presented by working in a makerspace, these students appear to have learned that they are, in fact, creative and resourceful. These are empowering life lessons that extend well beyond the walls of the makerspace.

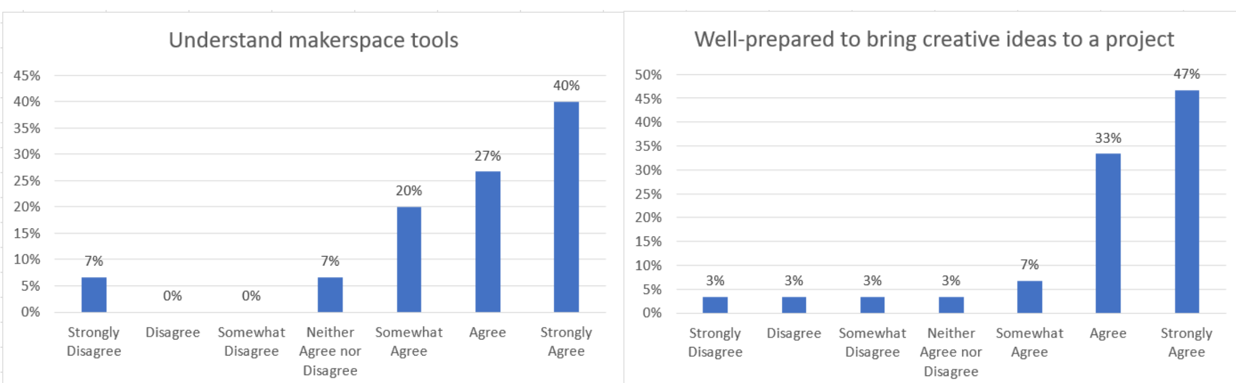


Figure 8 - Pre and post-survey Makerspace Experience

Section 4.7 - Open-ended Questions (Post-Survey Only)

Several open-ended questions were given in the post-survey to give students a chance to freely express their opinions and collect additional qualitative data. When asked on their impressions of this project and its ability to teach Cybersecurity and Biometric concepts, most responses were extremely positive and indicated that the project provided an excellent learning experience, helped them learn the material, and challenge their skills.

The responses were mixed when asked for suggestions to help improve the project. Several focused on more instructions, more deadlines, making it an individual project, and implementing more accountability. These reflect the survey results described in sections 4.2 and 4.3. Others responded that nothing was needed to improve on the project.

Students were also asked if they envision using the makerspace lab again and 90% responded yes. The majority planned on using it for personal projects while some for both personal and class related projects. Those who responded no indicated that they had their own 3D printer. The main tool and skill students learned from using the makerspace for this project was 3D modeling and printing.

Section 5 - Discussion / Conclusion

Our case study showed that despite the limited exposure to a makerspace prior to this project, students found it to be a useful learning tool and believe that this project provided them with a good experience and increased their confidence and understanding of cybersecurity and biometrics concepts. Students came into the project with some skepticism about teamwork, but the majority were positive about it post-project.

We conclude that our research and use of the 5E Instructional Model and makerspace project-based experiential learning approach has shown benefits, and it is effective at bridging the gap and increasing students' understanding of theoretical cybersecurity concepts and practical implementation. It is our intention to continue this study through several iterations of this course to build a dynamic database and allow for cross-course analysis.

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