Engaged Student Learning through IoT-based Capstone Projects: Particular Look at Student Engagement in Historically Underrepresented Groups

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***Abstract*—The COVID-19 pandemic resulted in changes in learning methods and attitudes in the STEM fields. The pandemic forced institutions of higher education to explore remote teaching/learning systems and tools some of which remain in use today. Such remote teaching/learning systems and tools present challenges for most STEM fields that involve hands-on experiences through laboratory or workshop environments that require access to devices, instruments and/or equipment. The engaged student learning through IoT project was introduced as a means to enable students to perform hands-on learning activities in their own time and space with minimal need for and dependence on university laboratory resources. In this paper, we describe engaged student learning through problem- and project-based learning (PBL) in IoT-based projects in senior capstone design courses at two Hispanic-Serving Institutions. Particular attention is paid to engagement and learning of historically under-represented student groups in capstone teams. Students in multidisciplinary teams borrowed IoT devices for the duration of their course work to discover and learn on their own with instructor guidance and developed course materials. The evaluation of the student performance and feedback indicate that students have benefited from access to IoT devices outside the laboratory environments by developing creative solutions to the undertaken capstone projects as well as problem-solving skills that are expected in the workforce. In this statistically small student sample size, there were no notable differences observed in the success of historically underrepresented students vs. all other students in the IoT-based projects in terms of engaged student learning. The IoT devices enabled the teams to undertake multidisciplinary and interdisciplinary projects that involved mechanical engineering, electrical engineering, mechanical engineering technology, and computer science students, each contributing to different objectives of the project to achieve the overall goal.**

Keywords—Internet of Things, IoT, Project-Based Learning, problem-based learning, engaged student learning, peer learning, team learning, interdisciplinary projects, capstone projects.

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I. Introduction

The COVID-19 pandemic caused many permanent changes in student learning methods as well as attitudes in the STEM fields. The pandemic forced institutions of higher education to explore remote teaching/learning systems and tools that have forever changed higher education. Standard remote teaching/learning systems and tools come with inherent challenges for most fields that involve hands-on experiences. Not all learning can be achieved through software simulations or by watching videos; students must “tinker” with real hardware, understand the limitations of devices, equipment, and components beyond their theoretical behavior through first-hand experiences, and be able to troubleshoot to solve technical problems in real devices.

In this paper, we describe and assess engaged student learning through IoT-based projects in senior capstone design courses at two Hispanic-Serving Institutions (HSIs), namely, Texas A&M University-Corpus Christi (TAMUCC) and Texas A&M University-Kingsville (TAMUK). IoT-based projects enable engaged student learning through hands-on problem- and project-based learning (PBL) in the students’ own time and space, and with minimal dependence on campus laboratory resources. 60% or more of the students in each team were from underrepresented student groups, including Hispanic and African American students. The projects are assessed as a whole and with particular attention to students from Historically Underrepresented Groups (HUG) at these two HSIs.

A. Research Questions

This project aims to address the research questions:

1. Will workplace flexibility increase students’ self-learning and PBL skills?
2. Can peer collaborative learning successfully continue remotely in hands-on projects?
3. Will the IoT-based PBL in distance learning assist or hinder historically underrepresented students in the targeted STEM disciplines?

B. Pedagogial Theoretical Background

1) Problem/Project Based Learning (PBL) and Cooperative/Collaborative Learning

Project based learning allows students the opportunity to inductively learn through being presented with a challenge to resolve and exploring the needed information, typically in teams, to address those challenges [1]-[7]. These challenges give students the exposure to practicing authentic problem solving by engaging with real-world problems. Such problems are usually ill-defined and therefore encourage students to work through ambiguity, engage curiously and work creatively to reach a resolution. This inductive pedagogical model has been proven effective in engaging students in their learning. However, putting students in teams on a project does not automatically mean that all students would work together and be actively engaged.

Cooperative learning ensures that students not only work together but also have equitable opportunities to achieve successful learning outcomes [8]. Brent, Prince, and Felder explain that cooperative learning entails "positive interdependence, individual accountability, positive real time student interactions, appropriate use of collaborative skills and regular self-assessment of team functioning" [9]. These elements support effective collaboration both in person and online settings.

Engaged student learning requires that the students work on their own tasks but also work in teams to accomplish the goals of team projects.

In this project students engage in PBL, collaborative learning and cooperative learning through their senior capstone design project course sequences.

C. IoT Applications

IoT applications are abundant in literature [10]-[15]. Jean *et al.* use an app PhoneIoT to turn a cellphone into an IoT device [10]. This facilitates use by students since most students already have a cellphone. Fidai reviews IoT devices in the classroom, forecasting its future use [11]. Other groups have incorporated IoT into course curricula in computer science [12], in a microcontrollers course [13], and embedded systems laboratory [14]. Podolskiy *et al*. investigates using IoT through collaborative work in open-source projects. We report our previous work on creating engaged student learning environments using IoT in [16], [17], as well as more recent work on IoT-related learning materials to assist students in engaged student learning through IoT [18].

In the remainder of this manuscript, we describe the IoT based projects, and analyze engaged student learning through the assessment of student peer team surveys, student performance, and Advisory Board and industry representatives' reviews.

II. Methods

A. IoT Kits and other IoT Devices

IoT kits were composed of two different sets of devices including Raspberry Pi and Keysight U3810A. The IoT kits from Keysight were checked out to students so they could work on their project in their own time and chosen location on or off campus. Keysight IoT kits came with a number of on-board digital and analog sensors. Students were also allowed to request and purchase other sensors as needed that were more specific to their projects. The IoT kits were checked out at the beginning of each project to those team members who were responsible for any IoT-related tasks and deliverables in the project. Some teams received more than one IoT kit. Students working on IoT borrowed the IoT kits for the duration of their capstone projects sequence courses over nine months to discover and learn on their own with instructor guidance and instructor-developed course materials to assist the students. The kits were returned at the end of the courses after the projects were completed.

B. IoT-based Capstone Projects

The project team has been engaged in project-based learning (PBL) in multiple courses. Senior Engineering Capstone Projects are particularly suited to problem- as well as project-based learning (PBL) by design, since the students must first identify a technical problem (engineering or science), and determine solution methodologies, researching and identifying concepts they do not know or revising those they need for the project, thus seeing the project from the idea phase to a final working prototype (project-based learning). Capstone projects are also good representation of problem-based learning, since at TAMUCC, the seniors are required to identify engineering concepts and formulate the problem using appropriate equations, then identify required parameters and their values to adapt the problem to their project.

In Spring 2023, out of eight multidisciplinary senior engineering projects and teams at TAMUCC, three adopted IoT-based concepts in Electrical Engineering, Mechanical Engineering and Mechanical Engineering Technology programs. Similarly, at TAMUK, three projects incorporated IoT into their projects in Electrical Engineering and Computer Science. This document focuses on these projects which started in fall 2022 (September) and ended in spring 2023 (May). Details of the capstone projects and project team membership are presented in Section III. *A*.

The team members were expected to work collaboratively and cooperatively, both of which result in engaged student learning. Each student was expected to demonstrate "ownership" to a technical portion of the project, based on their discipline, and work cooperatively, since the results of one team member's tasks could impact the work of another. The team members were also expected to work collaboratively since testing and integration had to be completed as a team to achieve the final working prototype.

C. Assessment

Assessment involved a) student surveys b) student performance assessed by instructor, and c) advisory board feedback.

1) Student Surveys

Student surveys captured students' self-assessment of their learning, including their IoT knowledge through the IoT-based capstone projects. These surveys are under review and not presented here.

Additional student surveys investigated team dynamics with relevant collaboration/cooperation attributes that also indirectly demonstrate engaged student learning. Student peer team assessment was conducted for all teams and team members regardless of project. Attributes that are relevant to collaboration, cooperation as well as engaged student learning include:

1. Coordinating efforts with other group members
2. Working well with others
3. Successfully carrying out plans and reaching goals
4. Committing to the goals of the group
5. % Contribution/Effort (out of 100% for each)

Each attribute was assessed at five levels as Excellent (5), Good (4), Acceptable (3), Marginal (2), and Unacceptable (1).

2) Student Performance

Student performance in IoT teams was assessed by the course instructors as part of the course outcomes assessment for the course. For the IoT project teams, these assessment methods analyzed whether students successfully met the proposed IoT-related development and integration goals in their capstone projects. Assessment rubric was based on Excellent, Good, Acceptable, Marginal and Unacceptable. Students were assessed based on the expectations of their discipline. For the purposes of this project, students from HUG were separately assessed and their success compared to the overall student membership of the teams.

3) Advisory Board Feedback

Advisory Board (AB) members as well as other industry representatives were asked to assess capstone projects with IoT during the senior capstone project presentations at the end of Spring 2023. AB and industry representatives' assessment was strictly team based and did not distinguish among the team members either in terms of demographics or otherwise.

The IoT projects were assessed based on four criteria:

1. Knowledge of IoT
2. Quality of the Capstone Project
3. Timeliness of the Project
4. Relevance of the Project to Industry

Each criterion above was assessed whether it exceeded expectations (4 points), met expectations (3 points), marginally met expectations (2 points), or was limited or did not meet expectations (1 point). The assessment form also allowed the reviewers to leave comments if there were any.

III. Student Projects

In this section selected capstone projects that incorporated IoT are described, together with team constituency from student teams who have completed their degree. Selected projects represent those from graduating seniors of spring 2023. Each project constituted a nine-month effort by each student team.

A. Selected Capstone Projects

Six capstone projects and their teams analyzed in this paper are listed below:

TAMUCC Projects and Teams

1. IoT-enabled Unmanned Traffic Management (UTM) System [19], (6 members: 3 Electrical Engineering, 2 Mechanical Engineering, 1 Mechanical Engineering Technology; Students from historically underrepresented groups (HUG): 4; all-male team)
2. Silver Security: IoT-based Home Security System for Elderly Care [20], (5 members: 2 Electrical Engineering, 3 Mechanical Engineering; 3 from HUG; 2 female, 3 male)
3. Sand Scorpion: Metal Debris Detecting Robot with IoT [21], (5 members: 4 Electrical Engineering, 1 Mechanical Engineering; 3 from HUG; all-male team)

TAMUK Projects and Teams

1. Real-Time Monitoring of Groundwater Levels in Wintergarden Region [22], (4 members: 4 Electrical Engineering, 3 from HUG, all-male)
2. Database Website for Pressure Readings [23], (3 members: 3 Computer Science, 2 from HUG, 1 female, 2 male)
3. Digital Pressure Recorder [24], (3 members: 3 Electrical Engineering, 3 from HUG, 1 female, 2 male)

A high-level representation of IoT connectivity for IoT-enabled UTM System project is represented in Figure 1, with sensor data display through cloud service interface. In this project, students developed a protocol to communicate between unmanned ground vehicles (swarmies) and unmanned aerial vehicles (drones) for traffic control, obstacle avoidance and object transport. IoT was incorporated to view sensor data through the cloud and cloud user interface.

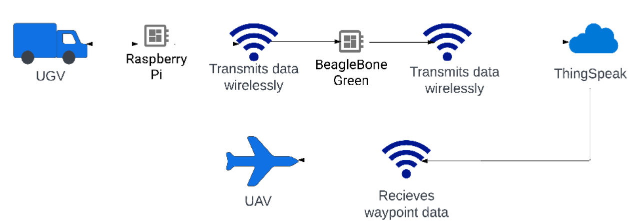

Fig 1. High-level representation of IoT connectivity of the IoT-enabled Unmanned Traffic Management System, demonstrating communication among sensors on unmanned ground vehicle (UGV) and unmanned aerial vehicle (UAV) through cloud service [19].

The Silver Security project is represented in Figure 2 that includes the sensor and controller connectivity, communication through the cloud and a user interface. This project was fully developed including a functional cell phone app for visualization of sensor data and alert system depending on sensor data fusion results.

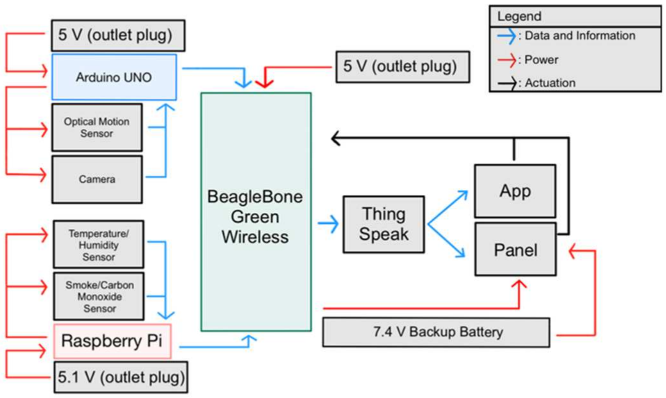

Fig. 2. Block Diagram of a Home Security System Integrated with IoT [20].

Figure 3 depicts the IoT connectivity for the Sand Scorpion project. This diagram does not demonstrate the sensors that were integrated into the robot that communicated with the IoT devices. The goal of this project was to develop a robot that would detect subsurface metal debris at the beach, and in its next phase, mark the location of such debris to be collected. IoT was devised as a communication tool to transmit sensor data and location of debris in the sand.

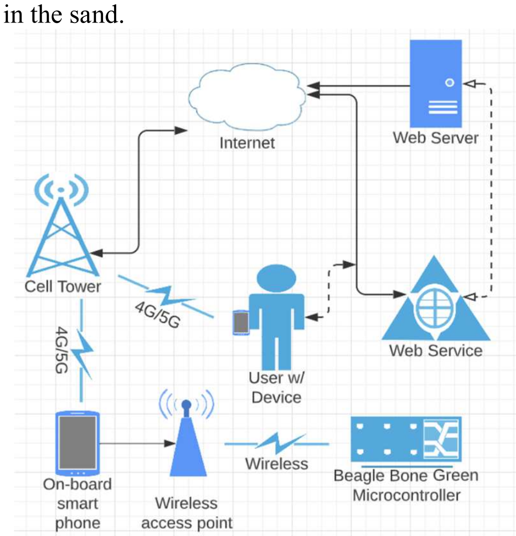

Fig. 3. IoT Network Diagram for Sand Scorpion Project [21].

IV. Results and Evaluation

A. Student Surveys: Student Peer Team Assessment for Student Engagement

Student peer team assessment was conducted by team members for their own team's members at TAMUCC as discussed in Methods section. Figure 4 shows the results of peer assessment of the five most relevant attributes related to collaboration, cooperation, and engaged student learning.

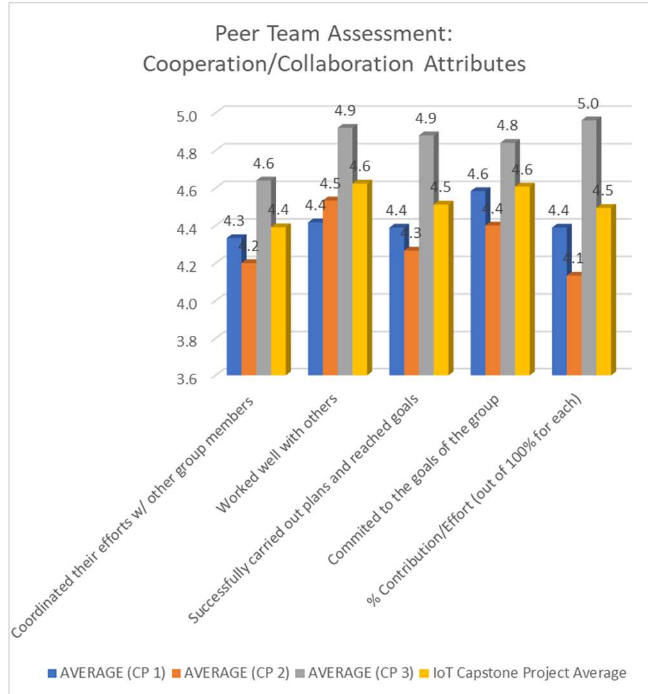

Fig. 4. Peer Team Assessment: Attributes Relevant to Cooperation and Collaboration and Engaged Student Learning.

Based on the rubric used, the average score for the team members by the team members ranged from 4.1 to 5.0, which corresponds to Good to Excellent rating. One team and its members consistently rated their team constituents above 4.5, suggesting a highly functional and engaged team. One out of three teams had average scores from 4.1 to 4.5 for team members suggesting one or two members of the team who might not have been fully engaged. Even then, overall results suggest that team members collaborated and cooperated at a level of Good to Excellent.

B. Student Performance

Sample capstone project IoT-related deliverables are shown in Figures 5-7 (TAMUCC) and Figures 8-9 (TAMUK). Figure 5 displays gyroscope data through ThingSpeak cloud service that was accessible to users real-time.

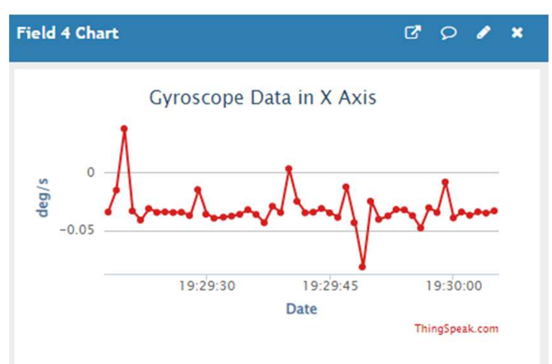

Fig. 5 Gyroscope data displayed real-time through ThingSpeak cloud service. Only data for X axis is shown [19].

Figure 6 captures one of the IoT-based deliverables for Silver Security project where the students developed an app that used real-time sensor data to determine if call for help is to be sent.

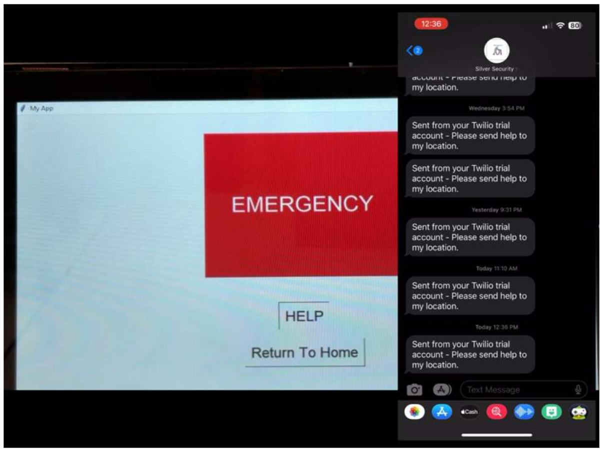

Fig. 6. IoT Interface to Request for Real-time Help Based on Sensor Data [20].

Figure 7 shows the implementation of IoT communication.

Fig. 7. Mobile Application Home Page User Interface (UI) for IoT Data [21].

Figure 8 represents the project with Wireless Sensor Networks (WSN) for Real-Time Monitoring of Groundwater Levels.

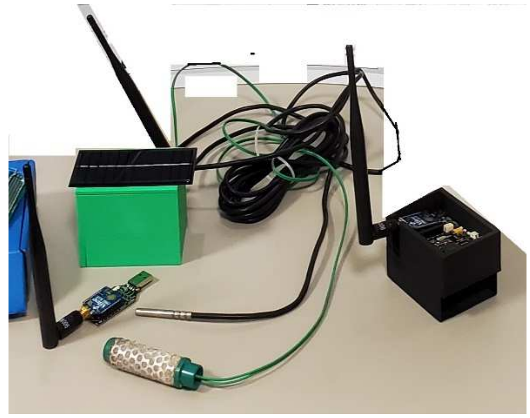

Fig. 8. Real-Time Monitoring of Groundwater Levels [22].

Finally, Figure 9 depicts the final deliverable for the Digital Pressure Recorder Project.

Fig. 9. Final Prototype for Digital Pressure Recorder [24].

Two of the three TAMUCC IoT teams successfully executed their project to completion, meeting all project goals and objectives. One of the teams completed their project at the subsystem level, including the development of IoT communication and user interface, and implementation of sensors to the IoT kit's BeagleBone Green Wireless microcontroller; however, the IoT was not fully integrated to the prototype even though its functionality was demonstrated separately as a stand-alone solution with user interface. Sensors utilized in all projects include temperature, humidity, smoke, carbon monoxide, ultrasound, and vision sensors, gyroscope, as well as a Colpitts oscillator designed as a sensor.

The TAMUK teams successfully implemented their IoT-based senior design projects. Each of their projects utilized different sensors. For example, one project utilized soil moisture and soil temperature probes while the other had pressure sensors. The teams were able to connect the processor board used, such as a PLC or an ATmega1281, in their respective projects to websites they created to visualize sensor data collected in the project.

Individual student-based performance evaluation is summarized in Table I.

TABLE I. SUMMARY OF PERFROAMCE EVALUATION RESULTS (HUG: HISTORICALLY UNDERREPRESENTED GROUPS)

	TAMUCC		TAMUK	
	All Students	Students from HUG	All Students	Students from HUG
Performance Evaluation Results	Excellent 62.5% (10 / 16)	Excellent 60% (6 / 10)	Excellent 100% (10/10)	Excellent 100% (8/8)
	37.5%: Good (6 / 16)	40% Good (4 / 10)		
Capstone Project Manager/ Leader	3	1	3	3

Table I shows the student performance evaluations at the course instructor level. The results show that all students performed at a level of Excellent (62.5% of all students, 60% of students from HUG) or Good (37.5% of all students, 40% of students from HUG. Due to the small sample size (n_1 = 16, TAMUCC, n_2 = 10, TAMUK), the results are comparable between students from HUG and all students.

Table I also shows student demographics leading each project. Out of 3 IoT projects from TAMUCC, one team was led by a student from HUG, and two were led by other students. In the TAMUCC projects, all capstone team project leaders were from HUG. These results show that historically underserved students are engaged in leadership roles within the project.

C. *Advisory Board's Assessment of IoT-Based Capstone Project Presentation*

The capstone projects were assessed by participating Advisory Board members and other industry representatives who reviewed the projects for IoT content at TAMUCC. The reviewers based their assessment on the final presentation of the seniors during final senior capstone project presentations at the end of the semester (spring 2023).

As shown in Figure 10, two out of three reviewers (AB members and industry representatives) gave the three IoT projects a score of 4 out of 4. One evaluator indicated that the teams did not capture or discuss cybersecurity related issues in IoT and how to mitigate them sufficiently in their presentation, and hence the score of 2.5 out of 4 was assigned. Another reviewer with the same average low score stated that one of the team presentations lacked a discussion on IoT integration into the system. This feedback is doubly valuable for this project because, besides assessing projects, AB and industry representatives' assessment also helps the project leadership team by ensuring additional emphasis is put on these concepts when conducting engaged student learning through IoT to strengthen students' knowledge and skills, and when determining the necessary topics to be covered in supplemental course materials.

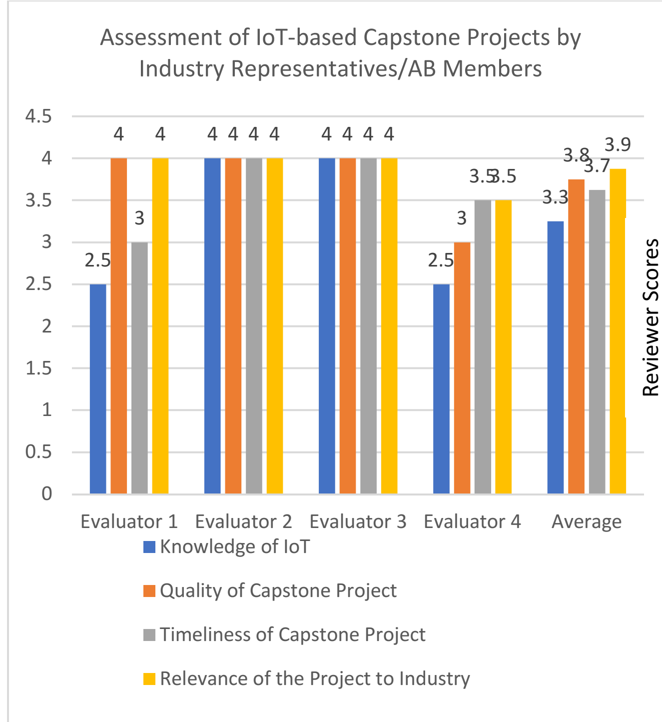

Fig. 10. Assessment of IoT-based Capstone Projects by Advisory Board Members and other Industry Representatives (TAMUCC teams).

V. CONCLUSION

Engaged student learning has been assessed in IoT-based undergraduate senior capstone projects at two HSIs, with particular consideration to underserved minority students in the project teams. The teams consisted of 60% or higher number of students from HUG, including Hispanic and African American. Student engagement was assessed through peer student assessment of team members on criteria that indirectly reflected on team collaboration, cooperation and student engagement. Course instructors also evaluated student performance in the coursework with emphasis on engaged student learning with IoT. Additional assessment tools were based on project Advisory Board as well as industry representatives review of final capstone projects oral presentations.

The evaluation of the student performance and feedback indicate that students have benefited from access to IoT devices outside the laboratory environments by developing creative solutions to the undertaken capstone projects as well as problem-solving skills that are expected in the workforce. The IoT devices enabled the teams to engage in multidisciplinary and interdisciplinary projects that involved mechanical engineering, electrical engineering, mechanical engineering technology, and computer science students, each contributing to different objectives of the project to achieve the overall goal.

Both teams and students performed at a level of Good to Excellent in assessed categories. No notable differences were observed in student engagement and success in students from HUG and overall students represented in the teams, noting that the sample size was 16 students total at TAMUCC and 10 students at TAMUK. Although it would not be possible to make strong conclusions from the findings of this project, some trends are apparent:

Based on the success of the IoT-based capstone projects and students working in them, it can be inferred that workplace flexibility did increase students' self learning and PBL skills, which was one of our research questions. All teams and team members performed at a level of Good or Excellent in the tested criteria.

Similarly, we find that peer collaborative learning can successfully continue remotely in hands-on projects, answering the second research question. This is also apparent in the success of the final projects that require both cooperation and collaboration, therefore engaged student learning, for subsystem integration and testing to create a functional capstone project prototype.

Finally, we found no evidence, in this limited sample size, that suggested IoT-based PBL in distance learning hindered historically underrepresented students in targeted STEM disciplines (Computer Science, Electrical Engineering, Mechanical Engineering, Mechanical Engineering Technology). On the contrary, the evidence suggests that IoT-based PBL in distance learning assists historically underrepresented students similarly compared to other students, addressing the third research question.

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