Engaging Girls in Learning Engineering through Building Ubiquitous Intelligent Systems

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***Abstract*— Women make up only 28% of the workforce in STEM fields. It's important to engage more girls in learning STEM; however, girls' interests in STEM careers keep declining. It is well studied that the lack of sense of belonging underlies gender differences in STEM differentiation and achievement. Researchers have found that secondary girls' sense of belonging declines as they age. To enhance secondary female students' interests and self-concept in computing and engineering fields, the UNLV ITEST project sets the focus on engaging Girls in Ubiquitous Intelligence and Computing (GUIC) through a constructivist learning environment. In the GUIC Summer Camp, 40 secondary female students will take three-week training courses in Arduino & Internet of Things and Robotics Design and conduct two-week engineering project development in tiered teams co-mentored by STEM teachers and college student mentors. Based on the active learning method, the training courses are designed with interactive lectures and hands-on labs/activities. The engineering projects in ubiquitous intelligent systems are designed to connect computing & engineering concepts with real-world problems. Project demo results and students' feedbacks have confirmed the effectiveness of the project activities in enhancing female students' interests and self-efficacy in learning engineering and STEM. The unique constructivist learning environment is helpful in improving female students' sense of belonging in STEM.**

Keywords—Engineering, STEM, Active learning, Ubiquitous intelligent system, Robot, Sense of belonging

I. Introduction

The data from the Bureau of Labor of Statistics (BLS), science, technology, engineering, and mathematics (STEM) and information technology (IT) based industries are growing and will continue to grow at the fastest rate in the US. It is projected by BLS that throughout 2020s, the overall STEM employment will grow about 11% [1]. Yet, the number of high school seniors pursuing education and careers in STEM areas is decreasing. Research on STEM career choice categorized three major factors affecting students' choice: 1) students' high school experiences, 2) classroom experiences, and 3) career aspirations [2]. Another study shows that high school students' lack of interests in STEM mainly results from how STEM content is taught by teachers rather than a true disinterest in the subject content. Unfortunately, this situation will not change quickly due to the lack of qualified STEM teachers nationwide.

Women make up only 28% of the workforce in STEM fields, while the gender gaps are particularly high in some of the fastest-growing and highest-paid jobs of the future, like computer science and engineering. It's important to engage more girls in learning STEM. Not surprisingly, girls' interests in STEM careers keep declining. A new survey by Junior Achievement (JA) conducted by the research group Engine in 2019 shows that only 9% of girls between ages of 13 and 17 are interested in careers in STEM in contrast with 27% among teenage boys [3]. It is well studied that the lack of sense of belonging underlies gender differences in STEM differentiation and achievement. The Microsoft survey found that even though girls in Europe and U.S. were interested in STEM subjects around age 11, their interests waned around age 15 [4]. The reasons of the degrading interests in STEM range from peer pressure, to a lack of role models and support from parents as well as teachers, to a general misperception of what STEM careers look like in the real world.

The research also shed lights on ways to better support girls and young women in STEM [5], including: 1) connect STEM subjects to real-world people and problems, tapping into girls' desire to be creative; 2) providing teachers with more engaging and relatable STEM curriculum, such as 3D modeling and hands-on projects; 3) increasing the number of STEM mentors and role models; 4) creating inclusive classrooms and workplaces that value female opinions. Several studies confirmed that girls were actively involved in STEM projects in a hands-on way and they enjoyed the process of creating, innovating, and solving challenges [6]. Girls were persistent in their activities and faced challenges by working together.

The Innovative Technology Experiences for Students and Teachers (ITEST) project at University of Nevada, Las Vegas (UNLV) is focused on engaging Girls in Ubiquitous Intelligence and Computing (GUIC) through a constructivist learning environment [7]. The goals of this project include: 1) to enhance secondary female students' academic self-concept in computing and engineering fields through a constructivist learning environment; 2) to enhance secondary female students' knowledge, skills, and interests in these fields. The major activities include the Spring Mentor Training Workshop and the GUIC Summer Camp. The GUIC Summer Camp consists of three-week training in Arduino & Internet of Things (IoT) and Robotics Design and two-week engineering project development. In each year, 40 secondary female students join the summer camp and work on engineering projects in tiered teams co-mentored by STEM teachers and college student mentors.

Inspired by the aforementioned studies, we have developed the training materials with integrated hands-on labs/activities and the engineering projects in ubiquitous intelligent systems that connect computing & engineering concepts with real-world problems. Students are encouraged to be creative in building these systems. Our mentors are dedicated in creating an engaging environment that encourage students to express themselves and collaborate with their peers. The evaluation results and feedback collected from participating students have confirmed the effectiveness of the developed project activities in enhancing female students' interests in learning computing & engineering.

The rest of the paper is organized as follows. Section II describes the development of the training courses based on active learning method. Section III describes the development of engineering projects. Section IV presents several project demo results. Section V summarizes the students and mentors' feedback. Section VI concludes the paper.

II. HYBRID COURSE DESIGN

The target students for our GUIC Summer Camp are secondary female students who have no programming experience. The training course materials are carefully designed to engage target students and spark their interests in engineering. Considering the unpredictable status of the COVID-19 pandemic, we decided to design the hybrid course materials that can be delivered either in-person or online.

We adopted the active learning method in designing these short-term courses. Active learning is the most successful method in STEM education [8]. Active learning is an approach of instruction that gets students to perform tasks in a class that actively engage them with the materials being taught. The tasks can be discussions, problem-solving activities, case studies, hands-on exercises, etc. Studies from learning sciences, cognitive sciences, and educational psychology confirm the positive effect of active learning [9]. Active learning is considered a new paradigm for providing high quality, collaborative, engaging, and motivating education [10].

TABLE I. TOPICS AND MODULE CONTENT OF ARDUINO & IOT

Module	Topic	Hours	Method	Class Materials & Assignments
1	Introduction to Arduino, Understanding the programming, Basics on components	8	Lecture, Programming, Hands-on	Lecture, Wiring on breadboard and LED/Pushbuttons, Quizzes & Assignments
2	Online simulation using TinkerCad, Arduino IDE, Understanding and Programming Sensors	6	Lecture, Programming, Hands-on	Lecture, Software Installation, experiments with LDR, buzzer, ultrasonic and temperature-humidity sensor, Quizzes & Assignments
3	Interface sensors using ESP32, Introduction to IoT, Communication modules –Bluetooth, WiFi (optional)	8	Lecture, Programming, Hands-on	Programming ESP32 using Arduino IDE, experiments with Bluetooth, experiments with WiFi (optional), Assignments
4	Sensor visualization in Arduino IDE & ThingsSpeak (optional), mobile app interface, Introduction to LoRa communication (optional)	8	Lecture, Programming, Hands-on	Data visualization in cloud using Thingspeak, working with mobile app - Blynk, Assignments
5	IoT-based engineering project demo & selection	2	Lecture, Demo	Sensors used in specific projects

Taking the example of the Arduino & IoT course, the content covered include the Arduino programming basics & Arduino IDE, simulation using TinkerCad, basics of components, programming sensors (including push button, buzzer, LDR, flame sensor, ultrasonic, temperature & humidity), introduction to IoT, ESP32 board, communication interface and cloud platform. The content is organized into five modules, as shown in Table I. Each module contains several lectures, programming exercises, and hands-on circuit construction. Each topic is covered with the reading materials, PPTs, lecture video, and short quiz to test the student's understanding. Each lecture covers a specific topic with several examples each composed of detailed code and/or circuit demo. To hold students' attention, each lecture video lasts no more than 15 minutes. For each code/circuit example, the detailed step-by-step instructions and tips are provided. Each quiz has a short list of questions with simple answers. Each module may come with a homework assignment and/or a mini-project that students can work at home with self-check solutions posted one day after.

Each student is provided with one Arduino training kit consisting of one Arduino Uno board, set of sensors, one ESP32 board, one breadboard, LEDs & resistors, and set of wires. With the kit, the students can build and test the circuits when they go through each module. Notice that the projected hours needed for each topic is an estimate of the average hours taken to go through all materials. The course modules allow some flexibility in covering advanced materials (labeled with optional). In practice, instructors can adjust the time needed based on the students' level. During our 2022 GUIC Summer Camp, the course was delivered in nine days with the total of 32 hours including 3+3 morning and afternoon hours on Monday/Wednesday/Friday, and 3+1 hours for Tuesday/Thursday. The virtual learning community on Discord are setup for all students, mentors, and instructors to communicate with peers and mentors. Several channels were created for specific learning subjects. The feedback from students showed that most of them enjoyed the courses and can digest most of the content well.

III. DESIGN OF ENGINEERING PROJECTS

The engineering projects in ubiquitous intelligent systems (UIS) are carefully designed to address different aspects of ubiquitous intelligence and computing fields targeting smart city and environmental applications including 1) smart citizen services, 2) intelligent transportation system, and 3) intelligent energy planning. In each year, we will design up-to-date computing and engineering projects that: 1) describe a problem of importance to smart city and environmental applications; 2) the problem corresponds to at least one topic listed in the next generation science standard (NGSS) for both middle school and high school levels; 3) utilize the tools that the students have learned during the training and allow the students to develop important technical skills; and 4) permit significant progress over a 2-week period.

A. Engineering projects in UIS

Below lists several sample projects in each category.

- **Smart Citizen Services**

Automatic Attendance Checking System for Smart Classroom (MS-ED, HS-ED: Developing and Using Models, MS-PS, HS-PS: Waves and Electromagnetic Radiation). On regular school days at middle or high schools, teachers need take extra time to call for attendance or have students to sign up on roster sheet. In this project, the students will design an automatic attendance checking system consisting of the RFID card, token, RFID card reader, Arduino Uno with WiFi module (or ESP32 board), and a micro-servo motor (optional).

Automatic Fire/Flame Detector (MS-ED, HS-ED: Developing and Using Models, MS-PS, HS-PS: Waves and Electromagnetic Radiation). In Year 2020, there were 490,500 structure fires reported which caused damages to architectures as well as harm to human beings. The most common causes of structure files are fireworks, electrical distribution, lighting system, candles, and cooking fires. It's important to detect the fire/flame at earlier stage to avoid such accidents and severe damages. In this project, the students will build an automatic fire/flame detector using the ESP32 board, a flame sensor, a buzzer, and a LED light.

- **Intelligent Transportation System**

Smart Parking Lot (MS-ED, HS-ED: Developing and Using Models, MS-PS, HS-PS: Waves and Electromagnetic Radiation). Living in a city environment, people drive and park their cars on daily basis. It is difficult for people to locate the vacant parking spot without detailed information. Some advanced parking garages adopt the technology to monitor the usage of parking lots and indicate the number of vacant spots at the entrance. However, without the detailed guidance, it is not easy for users to find the vacant spot quickly. Is it possible to design a smart parking lot system to help the user find an available parking lot easily? In this project, the students will design a smart parking lot system by integrating the IoT-enabled end node (composed of ultrasonic distance sensor and ESP32 board), a gateway node and the mobile APP.

Line Follower Robot (MS-ED, HS-ED: Developing and Using Models, MS-PS, HS-PS: Waves and Electromagnetic Radiation). Arduino is very suitable to be used as the controller for robotics projects. In this project, the students will build a line follower robot with an Arduino Uno board, infrared (IR) sensors, and a self-built robot car. A wooden robot car can be built with the 3D wood puzzle, two motors, three wheels, a battery, and the Arduino compatible expansion shield. The robot car can be expanded to avoid obstacles using an obstacle sensor or ultrasonic sensor.

- **Intelligent Energy Planning**

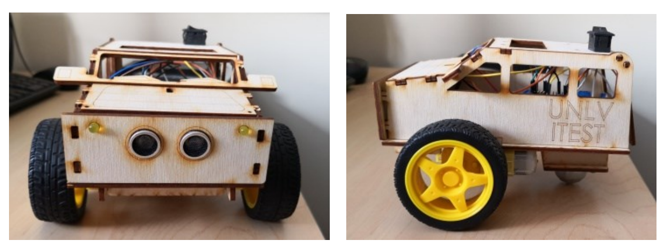
Intelligent Solar Tracker (MS-ED, HS-ED: Developing and Using Models, MS-ESS, HS-ESS: Earth's System). In a smart city, solar panels are widely used to power city facilities like street lamps and pedestrian passing lights, and other decoration lights. To maximize power generation, the solar panel needs to be pointed at the Sun. As the sun direction changes during the daytime, how to track the sun direction so that the solar panel can be rotated to maximize the sun exposure? In this project, the students will design a sun tracker with Arduino. The tracker is made with a solar panel, photo resistors, Arduino Uno board, a small servo, and a wooden frame (supporting either one-axle or two-axle rotation).

Smart Gardening System (MS-ED, HS-ED: Developing and Using Models, MS-ESS, HS-ESS: Earth's System). In Las Vegas, the weather can be extremely hot but sometimes thunderstorms come suddenly. The garden needs a more intelligent watering system to better utilize the scarce water resource. It is not uncommon to see water leaking from the landscape on the street. Is it possible to detect the water leakage automatically? In this project, the students will develop a smart gardening system consisting of the end monitoring system detecting the soil moisture level and water leakage, an irrigation controller, and a mobile APP.

During the mentor training workshop, each mentor team composed of one STEM teacher and one college student will select one project and implement it. The project descriptions will be updated based on their feedback. Each mentor team will also prepare a short video introducing the project to the students.

B. Wooden robot car kit

Arduino-controlled robots can be used in different UIS projects. Cost-effective robot kits that are lightweight, reusable, and consuming less power are desirable. Existing robot kits sold online or posted in online forum are built either with acrylic chassis or card boards (hot glued) which are not reusable. Some require the use of Lego or Mbots components. None of these designs satisfies our requirements. This motivated us to develop the new robot kit collaborated with our industry partner.



(a) (b)

Figure 1 Wooden robot car (a) front view, (b) side view.

The designed wooden robot kit [11] is composed of a 3D wood frame, two motor-driven wheels, one castle wheel, Arduino Uno & shield, sensors, one power bank, and one switch. The 3D car frame is assembled with 14 laser cut wood pieces. The design is lightweight and versatile with the pre-designed mounting holes for different types of sensors. Compared with the car model with 4 motor-driven wheels, the power consumed by this model is much less. A 5000mAa power bank is sufficient to drive this robot car for hours. Without any hot glue, the car frame can be assembled with several small screws in less than two hours. It can be easily taken apart and reused for other projects. Figure 1 shows the front and side view of the assembled robot car.

Using the wooden robot car kit and different sensors, three projects were designed including the line follower robot (with two IR sensors), the obstacle avoiding robot (with one ultrasonic sensor), and the human following robot (with one ultrasonic sensor and two IR sensors). Other UIS projects can also be designed based on the robot car kit.

IV. Engineering project demos

After the three-week training courses, the students will work on engineering projects in two weeks in tiered teams each composed of four students at mixed ages. Each project team will pick two projects that best match their interests after reading the project descriptions posted on the project website [12] and watching the project introduction videos. Each team will be mentored by one STEM teacher mentor and one college student mentor. Each team is required to meet every day either in person or online and demonstrate their projects on the last day of the summer camp. In Discord, each team has a dedicated channel that they can share the project information and host online meetings.

Figure 2 Automatic attendance checking system (2021 demo).

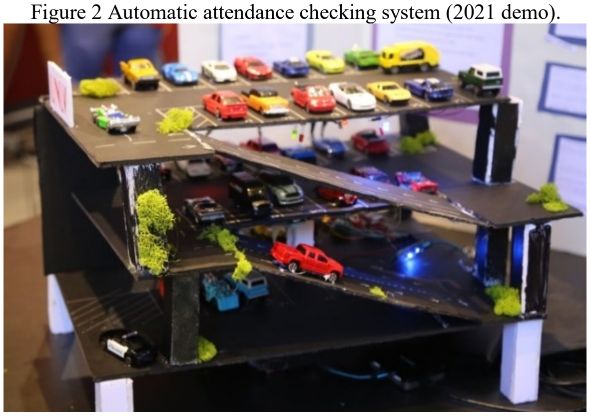
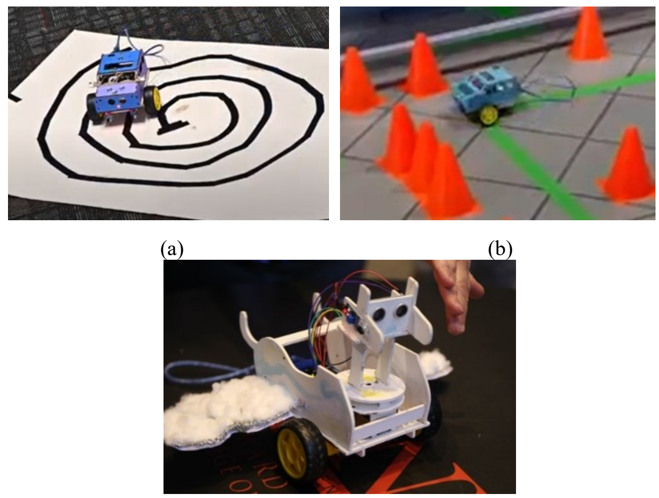


Figure 3 Smart parking lot system (2022 demo).

Combining the strengths of STEM teachers and college students, most mentor teams worked very well in fostering a motivating, creative, and collaborating team environment. Students are encouraged to propose their own ideas in designing the showcase and presenting their work. In 2021, several teams designed their laser cut models. In 2022, all teams decorated their showcase with paintings, crochet pieces, origami, etc. We believe that the project showcase is a good practice of combing STEM with arts.

During the project demo event, each team is required to present their project and show the live demo of a working system. In the presentation, each team is required to show a short video summarizing their project design, testing plan and final demo. Again, we are inspired by students' creativity, dedication, implementation capability, and presentation skills. Figures 2 to 6 show several project demo results.

Figure 2 shows a smart classroom setting with the automatic attendance checking system in a shoebox with Lego figures. Once a student taps her RFID card/token on the card reader mounted on the breadboard, her attendance is recorded to the teacher's cell phone meanwhile the door is opened automatically. Figure 3 demonstrates the three-layer smart parking lot built by the 2022 team. The ultrasonic sensor installed on each parking spot detects if the spot is occupied.



(a) (b)

(c)

Figure 4 (a) Line follower robot car (2021 demo); (b) obstacle avoiding robot car (2022 demo); (c) human following robot car (2022 demo).

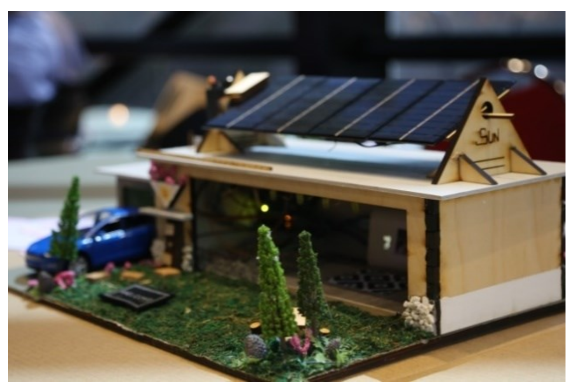


Figure 5 Intelligent solar tracker (2021 demo).

Figure 4 shows three types of robot cars built with the wooden robot car kit configured with different types of sensors. Students demoed several usages of these cars in real-life applications. The intelligent solar tracker system shown in Figure 5 is built with the laser cut house model designed by the 2021 team. Figure 6 shows the smart gardening system decorated with the painting, clay, and crochet designs. All these projects are documented with design files, program codes, implementation tips, and demo videos. They are ready to be shared with the STEM education communities.

Figure 6 Smart gardening system (2022 demo).

In the project demo event, judges with expertise in microcontroller, robot design, and STEM teaching are invited to rank the project teams based on their project design, testing & analysis, problem solving & learning, team work, presentations & live demo, and integration of arts. Four team prizes are given. All mentors and students have been working hard in testing their system and preparing their demos. They are also helping out between teams.

V. Feedback from students and mentors

In both 2021 and 2022 GUIC Summer Camp, we received positive feedback on how the project activities and the constructivist learning environment improve female students' self-efficacy in learning computing and engineering as well as their knowledge, skills and interests in these fields. Below summarizes the quantitative and qualitative evaluation results. The ITEST project video showcase can be found at [13].

A. *Quantitiave results of 2021*

The project activities demonstrated their effectiveness in engaging female students in learning engineering and STEM. The highlights of the post-survey results include: 1) more than 90% agreed or strongly agreed that the camp activities were fun, interesting, and enjoyable; 2) more than 87% agreed or strongly agreed that the camp learning activities increased their STEM knowledge and skills; 3) about 70% students indicated the summer camp increased their interest in taking STEM courses; 4) more than 87% agreed or strongly agreed they can become a successful engineering or computer scientist as long as they give it enough effort. The well-designed engineering projects were related to the real-world problems as seen by most mentors and students. Survey results show that the majority (approximately 75%) of the students believed the camp activities help them understand how to apply knowledge taught in school STEM courses to solve real-world problems.

We theorized that a constructivist learning environment (CLE) [14] for secondary female students, using a unique tiered-team and innovative mentoring structure, would enhance students' sense of belonging (SoBL) and therefore their academic success. The CLE built in the GUIC summer camp allowed for students from different cultural and academic backgrounds to use their own strengths and rely on the strengths of their peers and mentors to learn and complete difficult group tasks. More than 92% agreed or strongly agreed that they enjoyed the collaboration and support among team members during the summer camp. Students were able to communicate effectively, learn & work efficiently in the tiered team guided by mentors. The virtual community mainly based on Discord played an important role in connecting students with mentors, and organizing team-based activities.

B. *Qualitative results of 2022*

During the three-week training period, students' feedback was collected at the end of each week. Students reported that they enjoyed learning the content knowledge and application of the knowledge to the projects. Through this process students took challenges but got inspired to learn more in the future. In addition, all the students enjoyed the instructor's teaching in pacing, checking for understanding, and using multimedia presentation.

They further reported that they have learned how to connect wires and sensors to build circuits. More importantly, students believed that the hands-on experiences also motivated their interests in learning STEM in the future. Other students believed that learning to construct circuits helped them understand how circuits work and how coding can be applied in the real world. One student remarked: "These experiences increased my motivations and interests for STEM since they helped me see STEM as something to that I could actually do and taught it to me in a fun and engaging way"

At the end of the summer camp, students were asked to give feedback on team projects. All students reported they were interested in engineering after the two-week engineering project development. The experiences made them feel "they can do computing and engineering" and they can "use imagination and creativity to solve problems". All the students also reported they feel more motivated to learn STEM in the future. The team projects also motivated their consideration of pursuing STEM when they apply for college.

In terms of female students' confidence in STEM learning, the consensus was seen that their confidence was definitely enhanced. The interesting team projects were found to be related to their confidence. One student wrote: "Because this camp has helped me see that STEM is actually really fun and interesting. My confidence in STEM is fine. I've met new people and made new friends". The experiences emphasized the collaboration with each other which helped them gain confidence as female learners.

A CBL is effective when it includes constructive activities, situated contextual activities, and social activities [14]. The innovative structure of the camp allowed students to build positive relationships, enhancing their SoBL, and helped the participants feel more confident in participating is STEM activities in the future. In the situated contextual activities, the tiered team structure allowed students of different ages and backgrounds to collaborate in completing challenging tasks. This kind of relationship is a key builder of student SoBL [15]. Mentors reported that students supported each other by completing tasks in teams.

When asked for examples of how the students learned to work together to accomplish their goals, mentors replied that they had worked with the students to build relationships and plan for actions to accomplish their goals. One mentor noted that "at first the girls in my team were quiet and kind of not engaged, but they started talking over Discord and actually created a group to chat with each other. Once they were talking and laughing by the end of the first couple days they got right to work and actually did a great job with the project." Another mentor explained that the girls in her group "felt very comfortable together… one of the girls said she couldn't make it to the final two days, the older student offered to give her a ride to the camp." These examples showed that as the girls' belongingness was strengthened in the constructivist environment, their experience with the camp was impacted.

VI. Conclusion

The UNLV ITEST project is focused on engaging secondary female students in ubiquitous intelligence and computing through a constructivist learning environment. In each year, the GUIC Summer Camp involves 40 girls in learning Arduino & IoT and Robotics Design and developing engineering projects in tiered teams co-mentored by STEM teacher and college student mentors. The well-designed interactive training courses and hands-on engineering projects are effective in enhancing female students' interests and self-concept in computing and engineering fields. Students' sense of belonging in STEM is improved through the unique constructivist learning environment. The developed training courses and engineering project materials are available to be shared with the STEM education communities.

Acknowledgment

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