Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #47962

Inspiring Young Minds: Translating Advanced STEM Technology for High School Students for College and Workforce Readiness within the GEMS Programs

Gabriella Marie Luna, University of The Incarnate Word, GEMS Program

Gabriella Luna is an undergraduate student studying Mechanical Engineering with a concentration in Mechatronics at the University of the Incarnate Word. She conducts research in the Autonomous Vehicles and Systems (AVS) Lab and was awarded the UIW MSE Department's Excellence in Engineering Research Award. Gabriella is a core member of the QCardinals autonomous vehicle competition team, which earned the highest undergraduate team ranking in the 2024 international ACC Quanser QCar competition and continues to compete in ongoing challenges. She is also a dedicated STEM advocate, serving as a counselor for the GEMS (Girls in Engineering, Math, and Science) summer program. In addition to her academic and research pursuits, Gabriella is an NCAA Division I swimmer and is fluent in both English and Spanish.

Stephanie Weiss-Lopez, University of the Incarnate Word

Stephanie Weiss-Lopez has overseen GEMS since 2020 as a Project Manager and Coordinator. Ms. Weiss-Lopez is a UIW alum with a degree in Meteorology, currently the AVS Laboratories Project Manager, and an MBA student at UIW. She has over 18 years of management and leadership experience and has been a member of the AVS labs since 2018. Ms. Weiss-Lopez has experience in personnel development, scientific research, and grant writing. During Ms. Weiss-Lopez's leadership GEMS implemented and distributed over 450 free STEAM kits during the COVID-19 pandemic. Ms. Weiss-Lopez's partnership with the PI expanded innovative programs such as megaGEMS Virtual Research camp, miniGEMS virtual after school clubs, miniGEMS virtual Spring Break camp, and the megaGEMS AEOP Apprenticeship.

Dr. Michael Frye, University of the Incarnate Word

Michael Frye, Ph.D. is a Professor of Engineering in the Department of Engineering at the University of the Incarnate Word, in San Antonio, TX. He is an Electrical Engineer who specializes in the field of nonlinear control theory.

Inspiring Young Minds: Translating Advanced STEM Technology for High School Students for College and Workforce Readiness within the GEMS Programs (Other)

Abstract

Girls in Engineering, Mathematics, and Science (GEMS) is a project-based Science, Technology, Engineering, and Mathematics (STEM) program that encourages and empowers the next generation to pursue STEM pathways in education and careers [1], [2]. GEMS after-school and summer programs are designed to educate by providing hands-on experiential learning in robotics, programming, and research [3]-[8]. Consisting of two key programs: miniGEMS, designed for rising fifth to eighth graders, emphasizing robotics through LEGO education [9] and innovative STEM curricula, and megaGEMS, aimed at rising ninth to twelfth graders, focuses on independent scientific research [1], [2].

Each GEMS student explores and investigates hands-on lab experiences in the science of autonomy through ground and air robotics, aiding the students in acquiring important skills essential to obtaining college-level degrees and readiness for workforce development [4]-[6], [8], [10]. GEMS' intentional practices offer engineering and computer science [3], [20] opportunities in areas of San Antonio and Bexar County, addressing the lack of innovative and emerging technology used in industry [8], [11]-[15].

This paper will discuss the megaGEMS Research Camp [1], [2] held during the summer of 2024 and how higher-level research technologies can be taken in by an undergraduate engineering student [3] and then translated to a level at which high school students with no prior knowledge can understand. The ultimate goal was to have high school students understand and be able to use advanced technologies and produce results for a personal project to be presented at a symposium [3]-[6]. To reach the goal, the students had to gain an understanding of Simulink/MATLAB software [16], [17], the Quanser QArm controls [18], how to program the QArm to follow a path, and lastly, how color binary works. After the high school students are given all the background on the software and hardware, the students then create their binary and put it into action. With the guidance of female counselors and staff, the students absorb the latest information, perform their research, practice new skills, and produce legitimate results [3], [5], [6], [10].

This paper will provide details about the STEM program method for implementing upper-level academic research technology into high school research summer camps.

Introduction & Context

GEMS *Background*

Girls in Engineering, Mathematics, and Science (GEMS) was established in the summer of 2015 as a free all-female STEM (Science, Technology, Engineering, and Mathematics) and Programming Summer Camp for twenty-seven middle school students [1], [2], [11]. GEMS has grown, creating two major groups: miniGEMS for middle school or fifth-grade through eighth-grade students and megaGEMS for ninth-grade through twelfth-grade students. GEMS offers after-school programs for miniGEMS middle school students and summer camps for both miniGEMS and megaGEMS.

GEMS' *mission* is to inspire and empower the next generation to be innovative with their future in the STEM fields [1], [2], [13]-[15]. GEMS covers diverse topics of education that the students would not normally be exposed to, such as supporting each other, developing teamwork skills, learning how to better the community with their knowledge, being creative, and developing self-efficacy [3]-[8], [10]. GEMS' *goal* is to increase the number of students interested in STEM careers, especially in engineering and computer programming [1]-[8], [10]. Additionally, the program staffing is distinctive, with the GEMS director and counselors being women with STEM backgrounds. As shown by the Broadening Access to Science Education (BASE) program, which features an all-female staff and a female-focused STEM camp, "the close mentorship of these young women by female role models at both the faculty and undergraduate levels has significantly contributed to its success. Research shows that students often have lower self-efficacy in science and math, highlighting the importance of such mentorship [4]."

GEMS aims to empower the next generation by connecting them with inspiring mentors and industry professionals who serve as powerful advocates and role models in engineering and computer science. Literature reviews compounded the theme that STEM camps improve the interest level of the participants in STEM. Furthermore, STEM camps should be designed to provide hands-on activities and experiments in an empowering learning environment [5], [6].

As of 2024, GEMS has had over 575 students and twenty-eight teachers who have been a part of the after-school clubs and summer camps. A sizable portion remained with the GEMS programs for multiple years, as well as going from miniGEMS in middle school to megaGEMS in high school [1], [2]. GEMS is under the umbrella of Mission and Ministry at the University of the Incarnate Word (UIW) in San Antonio, Texas [12]. GEMS was founded by the Principal Investigator of the Autonomous Vehicle Systems (AVS) Education and Research Laboratories, Dr. Michael Frye, a tenured professor of Electrical Engineering in the School of Mathematics, Science, and Engineering who recognized the need to increase the number of students interest in STEM and more specifically in engineering [3], [8]. GEMS shares the core values of the university of education, innovation, and service through investing in the community [1], [2], [12]. Additionally, UIW is recognized as a Hispanic-serving institution under federal guidelines [11], [12].

The AVS Labs houses ground and air robotics, as well as other equipment for engineering and computer science students to conduct grant-funded research under the supervision of Dr. Frye. The unique equipment provides opportunities for not only undergraduate UIW students but also for the GEMS programs to highlight potential STEM career pathways [4], [6], [8], [10].

The Need for Summer STEM Camps for high school students

In the United States, women represent 47.7% of the labor workforce, as seen in Figure 1, while making up 25% of employees in STEM and 35% of tech jobs at the end of 2023 [19]. According to Women in Tech (a report by The World Bank), women account for approximately 21.3% of those who earned a bachelor's degree in computer and information sciences [20], 22% in Engineering and Engineering Technology [3], 35% with an Economics background, and 39% in Physical Sciences respectively (National Science Foundation) [1], [2], [13]-[15], [19].

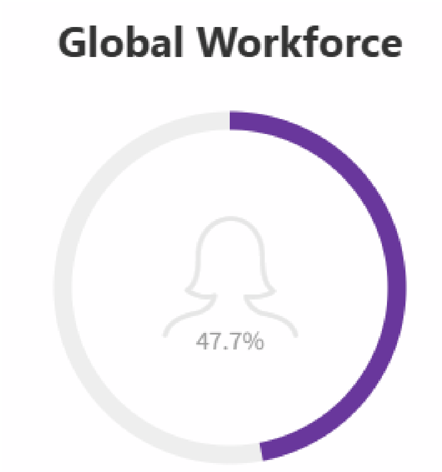

Figure 1. Global Workforce by Gender

In San Antonio, 17.7% live in poverty compared to the state average of 14.2% and the national average of 12.8%. San Antonio is comprised of 64.2% Hispanic, 24.8% White, and 6.4% African American [11], [13]-[15]. Given these statistics, GEMS' *objective* is to increase the number of students choosing STEM-related pathways in high school, STEM-related vocations, or STEM-related majors upon graduation from high school [1]-[8], [10], [20]. Hispanic workers represented only 15% of the total STEM workforce in 2021 [13] and continue to remain low as of 2024 [11]. As mentioned previously, the BASE Summer STEM camps have similar demographics and separation of economic wealth from neighboring counties to the GEMS organization. The evidence discussed states that within the student population, the STEM retention rate is only 30% due to inadequate pre-college science exposure and mentors in STEM disciplines, and enriching the experiences in STEM for students is critical to developing a consistent pipeline [4]. An added literature review states that major factors influencing science course grades in college were demographics such as race and parent education level [4], which represents the lower economic population of San Antonio. This is particularly relevant to the lower-income population in the San Antonio area, where approximately 30% of households speak only Spanish at home, suggesting that many students are English language learners during their K-12 education. Statistically, these households tend to be multi-generational, and parents often have limited educational backgrounds and little to no post-secondary education.

The previously mentioned statistics highlight the urgent need to prepare high school students, and the GEMS programs are dedicated to equipping the next generation with the tools and skills necessary to succeed in college or to enter the workforce [1], [2]. The city of San Antonio has recognized this need as well by launching multiple workforce readiness programs to train while they are earning [11]. This initiative "trains and upskills" employees across thirty-three local employers, which in turn results in higher pay and benefits. Essentially improving quality of life through employee advancement opportunities. The GEMS program, recognizing the need to prepare all high school students, has since expanded to include male students, leading to its rebranding as *Girls & Guys in Engineering, Math, and Science (G^2EMS)*. This change reflects a broader effort to align more closely with both local and national priorities related to pre-college preparation and workforce readiness. However, for consistency, the program will continue to use the previously established acronym throughout this paper.

GEMS has partnerships with schools in San Antonio ISD, Judson ISD, Southwest ISD, and Southside ISD to host miniGEMS After-School STEAM and Robotics clubs throughout the academic school year [1], [2], [9]. Each of these districts is home to Title I schools in both suburban and rural areas. Title I schools are defined as a designation based on the number of low-income students who are at risk for school achievement [4], [7], [8]. To be considered a Title 1 school, a minimum of 40% of the students must qualify for free or reduced lunch.

The GEMS programs create innovative, hands-on curricula that allow students to spark their intellectual curiosity at no cost. GEMS removes obstacles that prevent students from attending, such as providing food/snacks and transportation. By offering countless opportunities, GEMS can develop students' skills beyond the classroom [1], [2], [4]-[6], [10]. Furthermore, the GEMS programs foster a space of empowerment, aligning with Schilling's research, which suggests that "safe social spaces where these women can feel a sense of support and belonging in STEM have positive impacts on their perceptions of overall belonging" [4]. Every program offered by GEMS creates a supportive learning and empowering environment that ignites students' intellectual curiosity and inspires a love for learning.

Recruiting and Funding

The GEMS programs recruit from rural and suburban areas of San Antonio in Bexar and surrounding counties [8]. For the megaGEMS summer research camps, each student receives a stipend for the research for the four weeks [1], [2]. This incentive is crucial as students can achieve the same financial goal by working a fast-food job or instead conducting college-level research, developing a strong CV (Curriculum Vitae), gaining research experience, and obtaining college and workforce readiness [8]. It is important for students to create a CV that emphasizes their education, research experience, and volunteer or school activities as they prepare for their post-secondary education, rather than a resume that highlights work experience and professional skills. Additionally, the students can grow their social network through industry panels and guest speakers throughout their summer, where they have the opportunity to share their CVs directly with engineers in the industry.

megaGEMS Unite serves as a pipeline for students graduating from the miniGEMS middle school programs who wish to continue exploring their intellectual curiosity through hands-on STEM research [4]-[6], [8]. In addition, the students are encouraged to join year after year to strengthen their skills and investigate new topics to increase their bandwidth and later job potential.

All GEMS programs are grant-funded, providing afterschool clubs, summer camps, and various events all at no cost to the students [1], [2]. GEMS has been funded through multiple Army Education Outreach Programs such as the High School Apprenticeship Program [21] and the Unite program [22] administered by the Technology Student Association (TSA)[23]. The Army Education Outreach Program (AEOP) offers a collaborative and cohesive portfolio of STEM programs that engage, inspire, and attract the next generation of STEM talent administered through the AEOP consortium. Each provides funding resources to create and host programs to empower the next generation of the workforce with the tools and skills that are highly sought out [3], [4], [7], [8], [21].

The AEOP Unite [22] program is managed by TSA [23], a nationwide summer program for talented high school students that enhances personal development, leadership, and career opportunities in STEM, whereby members apply and integrate these concepts through activities, competitions, and related programs [8]. TSA's vision is to accelerate student achievement and support teachers by offering engaging opportunities to develop STEM skills.

The Unite program provides financial resources to fund the megaGEMS 4-week Summer Research Program for talented high school students and encourages students to pursue college majors and careers in engineering and other STEM-related fields [21], [23]. The students can experience career opportunities, develop soft skills, and broaden their STEM skills while earning an education stipend and building a competitive Curriculum Vitae [4]-[6], [10]. All students highlight their final research in poster and presentation format at the End of the Summer Showcase and submit a research abstract to the AEOP to be published in the AEOP Research Journal [21], [23].

Summer Camps Continued Learning

Every summer, the GEMS camp is held for all high school students who are interested in pursuing a STEM-related field with a concentration in engineering and computer science [1], [2]. This camp is conducted in collaboration with AEOP, Unite, and many other important sponsors [13]-[15], [21]-[23]. When the students come in for the camp, they learn particularly important skills such as building their CVs, drafting college-level scientific papers, foundational coding skills [20], and presenting the research at the End of Summer Symposium [7].

The students are presented with research projects that are administered in a draft-like way. The projects are created by the counselors and UIW faculty to present to the students in a slideshow describing the purpose and expectations for each project. From there, the students each pick their top three choices and submit them to the counselors for evaluation. The GEMS counselors then take all the choices and organize them based on the rankings provided by the students. The ultimate decision comes from how well the counselors predict which students will work together best and which projects lean into each student's strengths and goals [5], [6], [10]. The students are then paired off with their partners for the next few weeks and begin doing research and conducting experiments.

This paper will focus on one specific project conducted in the summer of 2024 with two high school students advised by an undergraduate engineering student/counselor and the GEMS

Director. The research project focused on the color detection capabilities of the Quanser QArm, as seen below in Figure 2 [18]. The project tasked the students with programming the QArm to detect and highlight a Prickly Pear Cactus based on the specific color of the cacti. Two students were assigned to this project with guidance from the subject matter expert in the lab, the undergraduate engineering student who had been conducting research with the equipment.

Figure 2. Quanser QArm (multiple angles)

The students were tasked with discovering whether or not color detection can be implemented within the QArm and to provide proof of concept. Despite knowing the overall goal of the project, the students had to gain knowledge of software and upper-level math or college-level math to be able to understand the QArm's capabilities. This process will be further explored in the following sections.

Students Research

Technology Building Blocks

The megaGEMS Unite Summer Program provides students with the opportunity to enhance their knowledge and skills by learning the Python coding language, MATLAB, Simulink, and Quanser research equipment [16]-[18]. One opportunity is exposing the students to Python to allow the students to learn the foundations of a coding language, which is key in workforce readiness among engineering and computer science fields. Python is currently one of the most widely used programming languages in the computing world, known for its versatility and user-friendly nature [24], [25]. Since gaining popularity in 2010, Python has become a cornerstone of any aspiring engineer's or programmer's toolbox. Recognizing its importance in the engineering field, the GEMS program integrated Python basics into the curriculum as an essential component of the student's learning journey [5], [10], [20]. Additionally, Python is open source, making it a free resource that allows students to gain knowledge and experience without a financial burden.

During the GEMS 4-week summer program, students participated in a daily one-hour session titled "Coding Academy," where they were introduced to Python [2], [24], [25]. The lessons began with foundational concepts, such as syntax and variables, and gradually progressed to more advanced topics like loops and conditionals [20]. By the end of the program, students were equipped with basic Python skills that served as a foundation for more complex programming challenges. Additionally, previous research was conducted regarding the successes of the GEMS Coding Academy.

Secondly, Python syntax is similar to MATLAB [16], [24], [25], making it easier for students to transition between the two platforms. A solid understanding of Python syntax and functionality helped students navigate MATLAB's unique programming environment, especially for tasks involving data analysis and engineering applications. Again, further enhances the high school students with skills sought after in engineering and computer science. MATLAB [16] and Simulink [17] are programming languages favored by engineers and scientists for their proficiency in handling mathematical computations, simulations, and engineering applications [3]. It operates using matrices and arrays, making it an ideal tool for data analysis, wireless communications, image processing, and control systems.

Simulink, an extension of MATLAB [16], [17], provides a graphical interface for modeling, simulating, and analyzing systems. Unlike MATLAB's text-based coding approach, Simulink uses block diagrams with signals and connections, allowing users to visualize their designs. During the megaGEMS camp, Simulink was essential for programming the Quanser QArm, making it imperative for the students to gain a working knowledge of both MATLAB and Simulink [16], [17].

Lastly, for the QArm to detect the specific color, the students had to learn about binary color detection, which is the process where image pixels are reduced to two values—black or white. The white represents the foreground (the color of interest), while the black signifies the background. In this project, binary color detection was implemented through thresholding, a technique that isolates specific color segments to identify objects.

The success of binary detection depends on accurately defining the RGB (red, green, and blue) values of the target color. Students learned to measure and calibrate these values, often requiring multiple iterations to perfect their segmentation. Mastering this process was critical for achieving precise object detection and successful outcomes in their experiments.

Quanser QArm

The Quanser QArm, developed by a Canadian company specializing in engineering education tools, served as the focal hardware for the megaGEMS Summer Research program [18]. Released in 2020, the QArm is equipped with features such as an RGBD (Red, Green, Blue, Depth) camera, grippers, and LED lights, making it ideal for both research and educational purposes [18]. Notably, the QArm is compatible with both Python and Simulink, providing flexibility in its applications and opportunities to utilize the skills with each.

Upon receiving the QArm, the undergraduate engineering student (the author) was tasked with reviewing its manual, which consisted of thirteen detailed modules designed for individuals with advanced knowledge of robotics and engineering. Over the course of two weeks, this information was meticulously translated and condensed into an accessible format for high school students with limited STEM backgrounds.

In addition, the author conducted extensive pre-camp testing to ensure the QArm was functional and ready for use. This process included running experiments, troubleshooting issues, and designing simplified lessons to guide the students in understanding the arm's capabilities by the undergraduate engineering student.

Implementing obtained skills on the QArm

The project goal was to determine whether the Quanser QArm [18] could accurately detect a specific cactus plant based on its unique binary color. By leveraging binary color detection, the arm would ideally identify and isolate the cactus in various environments. This capability could serve as a foundation for larger-scale projects involving autonomous identification and interaction with natural objects.

The QArm curriculum began with foundational labs focusing on basic motor controls and gradually progressed to more advanced modules, including object detection and visual servoing [18], [26]. Before the students were allowed to use the more advanced features of the arm, such as the visual servoing capabilities, they first had to understand the basic motor skills of the QArm. What makes the QArm more advanced than other robotic arms is its ability to mimic human arm movements, giving it a broad range of motion and degrees of freedom. Its individuality of motor skills comes from its unique design with a multi-joint motion that allows for precise articulation, controlled grasping, and coordination [18]. Simulink code for the motor skills of the QArm features a separate control panel for each of its three limbs: the bicep, forearm, and gripper [17]. Additionally, there are controls for the base, with all movements measured in precise angles. This setup provides the QArm with human-like dexterity and enables highly controlled movements, which are essential for its effective performance in industrial applications.

Visual servoing is a technique in robotics where a robot or in this case the QArm, uses real-time feedback from a vision sensor/camera to control its movement, essentially allowing it to "see" and adjust its actions based on what it observes in the visual scene, combining aspects of image processing, computer vision, and control theory to achieve precise manipulation or navigation tasks [26]. To prepare the students for these tasks, they conducted initial research on the QArm’s features, Simulink, and binary color detection [16]-[18]. Supplementing this research were handwritten notes provided by the undergraduate mentor, which broke down complex concepts into manageable sections.

Daily lessons on the QArm allowed students to build their confidence and familiarity with its controls. One particularly engaging exercise involved the arms “learn” and “perform” modes, where students programmed the arm to replicate specific movements. This activity provided valuable insights into the arm’s mechanics, laying the groundwork for more complex tasks. What can be seen in Figure 3 are the 3-D diagrams that MATLAB created from the "learn" mode and then executed in the "perform" mode [16]-[18]. Figure 3A shows how the QArm tracks the movements as the students are guiding the arm through the desired motion and returns a graph displaying exactly where the arm moved within the environment. In this case, the QArm was guided around its workplace environment, and this was done so that the QArm had a record of the space in which it could function. Along with the 3-D graph, the MATLAB code will also produce a 2-D graph (Figure 3B), showing how the x,y, and z coordinates change over time as the QArm is being guided. These graphs are important because they show that the QArm can retain, understand, and return information fed to it. For example, to test the QArm, the students decided to teach a path of a basic shape to see how it would perform. Figure 3C shows the 3-D path of the heart that was taught to the QArm by one of the students.

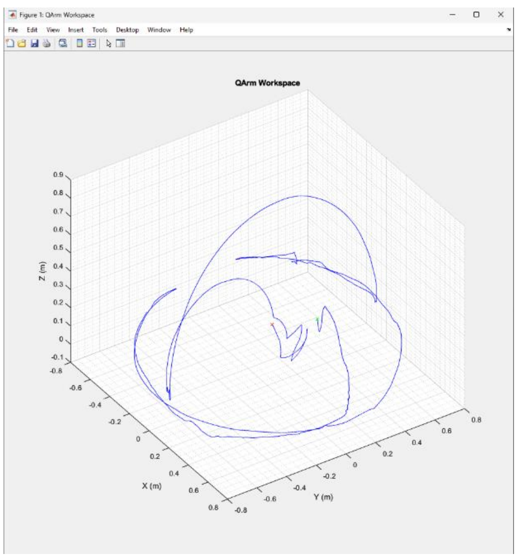

Figure 3A. QArm "Learn" Environment Path

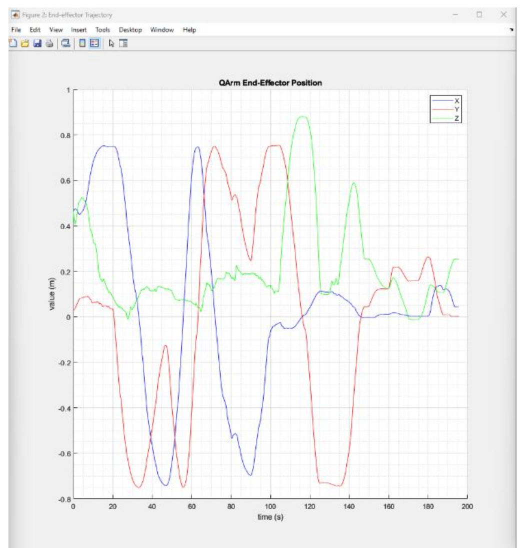

Figure 3B. QArm "Learn" 2-D Graph

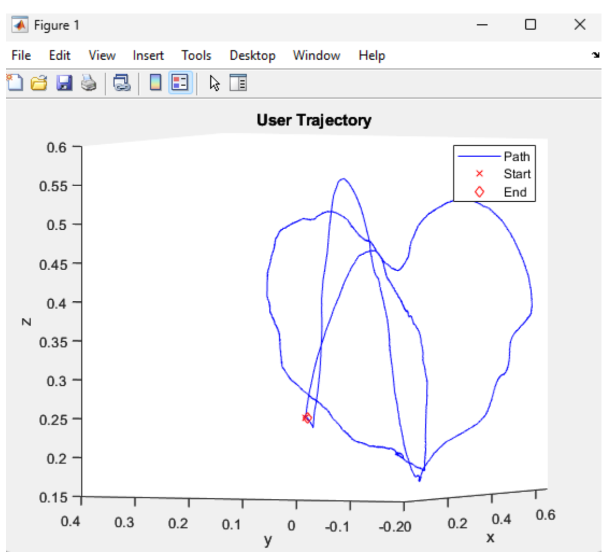

Figure 3C. QArm "Perform" Student Path

The program culminated in modules on image acquisition and processing, object detection, and visual servoing [26], which were critical to the student's final project. While the image acquisition and processing module helped the students understand how the camera takes pictures and sorts colors, it did not go fully in-depth on how the camera can be used to detect objects using color. However, the visual servoing module, in particular, provided a framework for the students' Simulink code, allowing them to customize and implement the solutions developed by the students.

For the students to understand exactly how the arms camera can intake images and colors, they were responsible for running the labs for all the modules about the use of the camera and how to conduct any form of object detection.

Before the students were allowed to begin experiments with the cacti, they had to run experiments with other inanimate objects. Specifically, they were given multicolored blocks and were asked to distinguish a specific color. Though the task was simple enough, the complexity came in that the blocks were close in shades of color, and they were asked to have the QArm identify an extremely specific shade. For example, Figure 4A below shows the initial color identification conducted for the students to grasp the concept of how the QArm processed color and how to use the basic color detection code given in Simulink. The figure also shows how the QArm RGB camera turns an RGB image into a greyscale image and will then highlight the specified color. In Figure 4B, further color analysis done by the QArm can be seen. As a distinct color is selected to be identified, the camera will highlight the corresponding-colored block. In the furthest left image in 4B, the color selected for the camera to identify was pink, therefore, the top block became white as it is the pink block, and the bottom two blocks became black. In the middle image, the color selected to be identified was neither pink, blue, or green, so none of the colors were highlighted. In the furthest right image, the color selected was a shade between pink and blue, but not exactly match. This is why the middle and top blocks are highlighted in a shade close to white, while the other block is shaded darker.

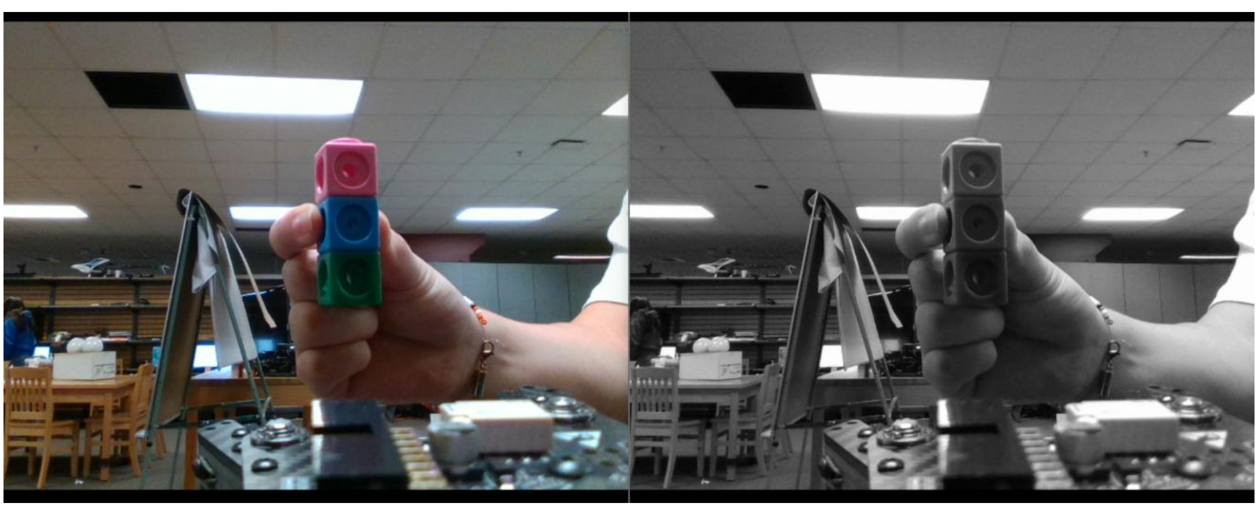

Figure 4A. Color Identification Process

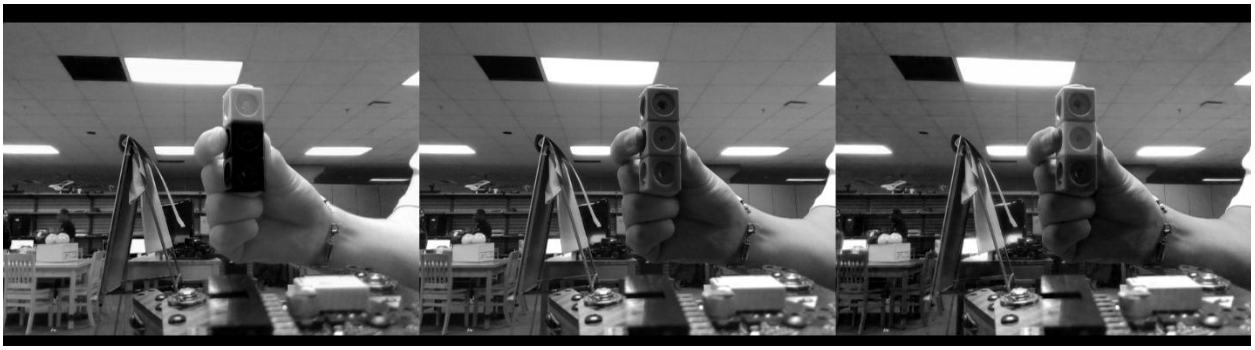

Figure 4B. Color Identification With Specified Colors

As the GEMS counselor and subject matter expert, guidance was provided throughout the QArm process for the students, but much of the learning and eventual application of skills came from the students' efforts. The knowledge and abilities gained through trial and error were crucial for achieving the desired results and accomplishing the goals set.

Student Challenges

When embarking on this project, there were a few challenges to address, some of which proved to be more difficult than initially anticipated. In addition to the primary challenge of the limited time of the 4-week camp, the students struggled with their limited understanding of the complex topics needed to fully grasp the QArm's functionality. The QArm was developed with the intent of being used by undergraduate and graduate engineering researchers with the assumption of a background in Calculus (single and multivariable), differential equations (DE), and linear algebra, which are prevalent for engineering fields but beyond the scope of a high school student. Coupled with the limited time to produce results, the unfamiliarity with upper-level math became an even bigger obstacle to overcome. Inadvertently, during the first three weeks, daily lessons were carved out to catch the students up or teach them key elements in Calculus, DE, and linear algebra concepts to allow the students to understand the mathematics of their project. By doing this, students were able to fully grasp how to apply math to a real-world problem.

Amongst the mathematical hurdles, each student had difficulties understanding the advanced language that was used to describe the parts of the arm, as well as the language used in the Simulink code. Despite having daily Python lessons, the students also used some of their time outside of camp to dive into the syntax of MATLAB and the structuring of Simulink [1], [16], [18], [24], [25]. This again shows the character and maturity of the high school students wanting to conduct a high-caliber project and dedicated to learning [5]-[7], [10].

Another challenge faced was that of the specificity of the color of the Prickly Pear Cactus. Once the correct algorithm was created to activate the camera and begin detecting color, the students still had to ensure that the camera detected the correct color. For this project, the Prickly Pear Cactus had an extremely specific shade of green associated with it; the hue of this shade was later discovered to be 147.6°. As Simulink identifies its colors based on a color wheel, the exact hue of green needed was found at an angle of 147.6° from the top and moving clockwise.

Finding the hue degree to match the shade of the cactus was essential for the camera to be able to differentiate the Prickly Pear from another plant. This required some extremely specific attention to detail and a lot of fidgeting with the specifics, which also became time-consuming for the students.

The last hurdle, and the simplest one, is that on top of having to spend a large amount of time with the QArm, they also had to put together their scientific posters and presentations for the End-of-Summer Symposium. This meant that the students' ability to manage their time was critical as they not only had to complete the research project but also had to create their scientific poster and practice presenting their findings.

Student Obstacles

An obstacle arose with the two students assigned to the project being in different grades, meaning they also had an additional math knowledge gap. As stated previously, daily lessons in Calculus, DE, and linear algebra concepts were reviewed to allow the students to have all the information needed to conduct their research. Knowing this meant that the notes created for the students had to consider the fact that one student had ninth-grade math knowledge and the other had 11th-grade math knowledge. The undergraduate engineering research student completed notes with varying math levels and provided pictures and diagrams, which were color-coded for better readability. The students spent time on their own conducting research as well as time with the translated notes to learn as much as possible about the skills they were lacking. Their research, coupled with daily sessions with the QArm, quickly compensated for the lack of unfamiliarity they entered into the project. In addition, the students worked diligently together to ensure they remained on track to complete their project.

Once the basics of the QArm were fully understood, the only remaining obstacle was being able to properly identify just the right shade of green present in the cacti and training the camera to detect that shade. Because the camera is an RGB (red, green, blue) camera, it is not as easy to just input green to the max and hope it reads it correctly. With the help of RGB color pickers and some trial and error, the students were able to find just the right combination of red, green, and blue that would allow for the cactus to be recognized. There was some later tweaking that had to be done to ensure that the camera would only recognize that specific green and not confuse it with other green plants or different cacti species. Thankfully, this came towards the end, and the students were able to dedicate a good amount of time to testing different plants and greens in different surroundings to make sure the camera was performing at top capacity (Figure 5).

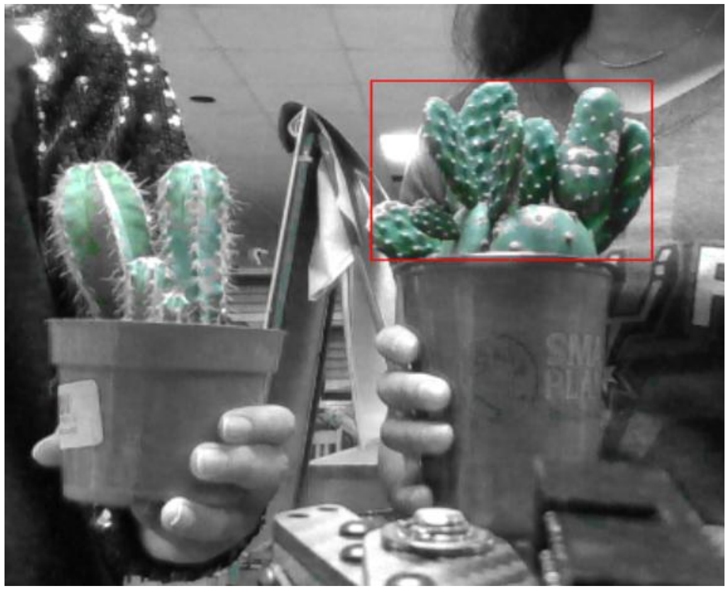

Figure 5. Proof of Concept – Red box indicates the QArm identifying the specific color of the Prickly Pear Cactus (Hue 147.6º)

Research Outcomes

Despite the challenges and obstacles, the students were successful in programming the QArm camera to detect the Prickly Pear Cactus. They were able to program the camera to signify the cactus by placing a red box around the cactus and even having the red box track the cactus in its surroundings, as shown in Figure 5. The interesting part of the projects and the results is that the longest part of the project was getting the students up to speed with the QArm [18], learning how it works, making sure they know how it functions, and getting the basic algorithm working. However, the students gained knowledge and skills that will benefit their future educational paths. Once that was complete, programming the camera to detect the green was the fastest part. Thankfully, adjusting the camera specificities was as simple as changing a few numbers and then troubleshooting multiple times. When it came time for them to create the final algorithm, as the counselor, I sat back and gave them full control of the QArm, computer, and program [4]-[6]. Figure 6 (below) shows the Simulink environment containing the fully functioning color detection algorithm.

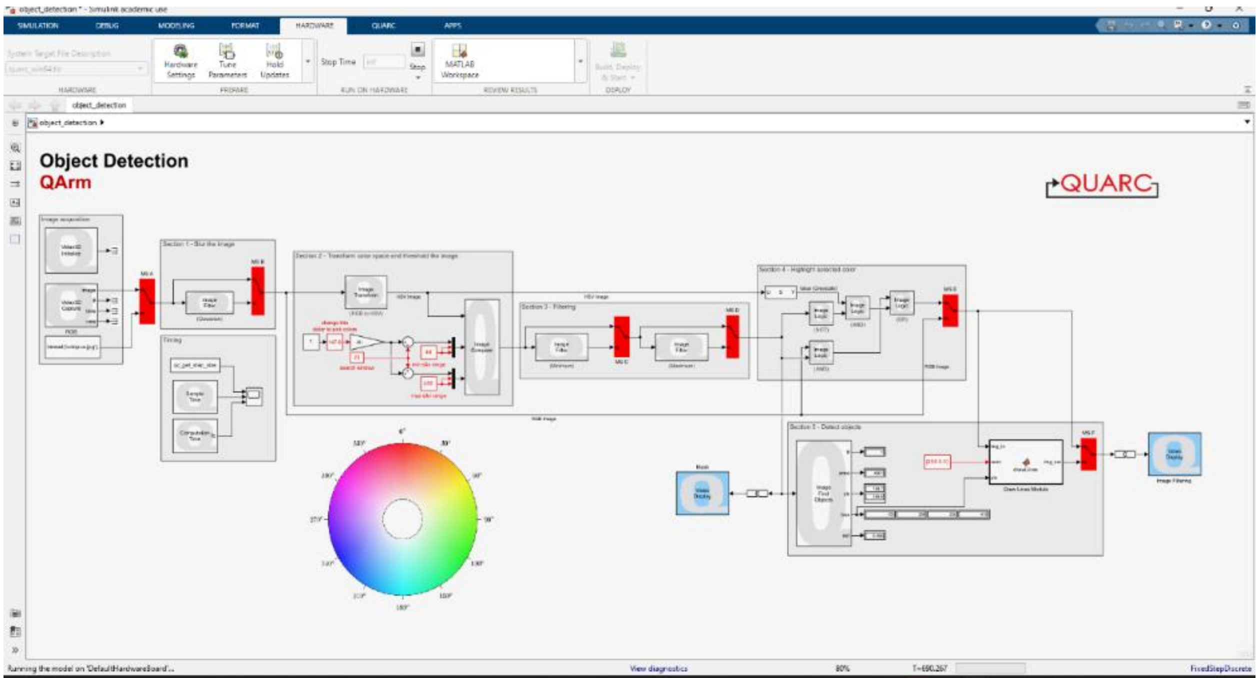

Figure 6. QArm Object Detection Proof of Concept Algorithm

The final algorithm was designed, and the students could capture and save it from the camera. This turned out to be ideal because it allowed the students to collect proof of their success. Fortunately, the lab had many different individual Prickly Pear plants, which allowed the students to experiment with multiple plants and make sure that their algorithm was as accurate as possible. With the QArm storage capabilities, the students were able to display their findings in many different ways. The object detection could have been displayed in grayscale, where the color that the camera was told to detect would appear as white and all the other surroundings would appear darker shades of grey and/or black, or it could be displayed in full RGB scale for more precise and realistic images. The results of both detections can be seen below in Figure 7 in addition to showing the camera's accuracy in that it detects the Prickly Pear cactus over the green blocks. Figure 7 shows the exact object identified indicated by the red box.

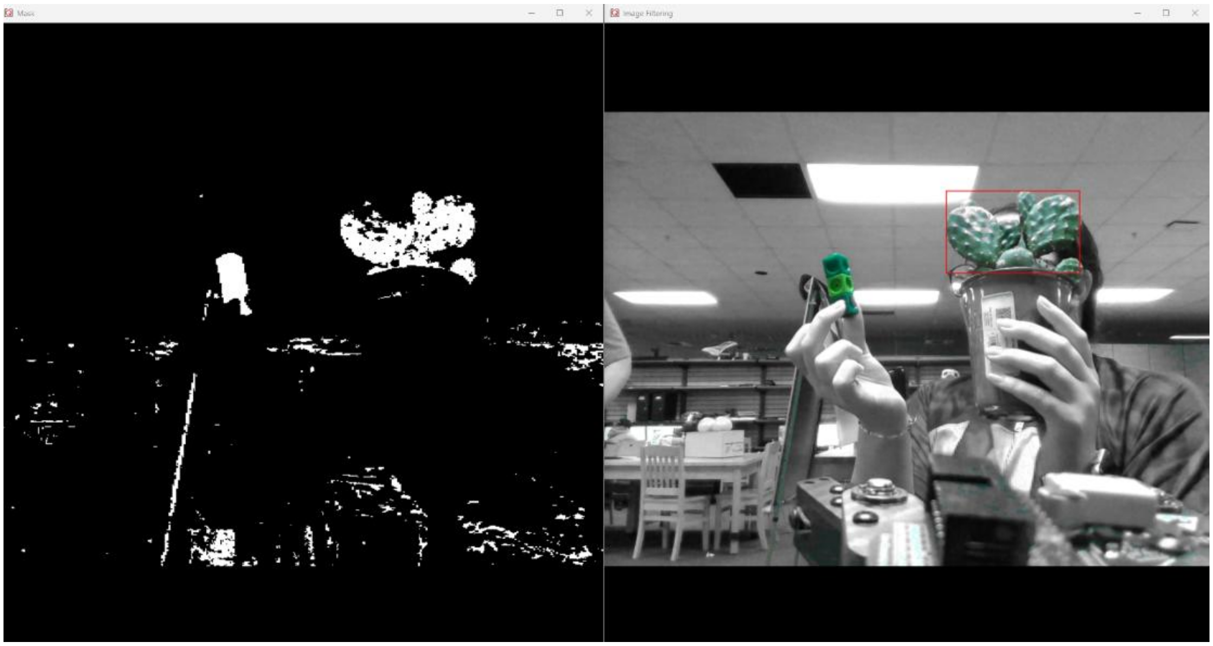

Figure 7. QArm Object Detection through Color Identification

The QArm was loaned on a trial basis for a limited time. Being able to prove that the QArm abilities are good for research purposes and proving that the camera can properly detect objects and use RBG is even better. Moreover, the research conducted by the megaGEMS students was a crucial element in a larger research project currently in the AVS Labs at UIW.

Object detection has become a large component of many industries, including agriculture, environmental sciences, and even manufacturing. Object detection is the process of locating and identifying a specific object or item in an environment or image. A perfect example that connects directly with the student's project is that of precision agriculture. Being able to detect objects, especially with color, would be revolutionary in aspects such as harvesting and pest control. In a manufacturing sense, the capabilities of object detection would help in quality control, assembly, and part identification. The results from the project show that the QArm has incredible potential beyond just the scope in which it was tested. The possibilities of what the QArm could be capable of are almost limitless if two high school students with limited knowledge and time were able to develop a color-based object detection algorithm, one that worked extremely well [18].

As the QArm is a new addition to the engineering world, the successful results of the students' projects serve as proof-of-concept for the QArm's capabilities and that the QArm can perform in real scenarios and has validated the QArm's application to research and education. Demonstrating that the QArm can be used as an educational tool only reinforces its appeal to be used in industrial scenes and systems [18].

In teaching the students skills such as programming, robotics, and the scientific process, the students gained an upper hand in their future. Those skills are what the engineering industry is always looking for, and instilling those skills as young as possible comes with many benefits

[3]-[8], [10]. Overall, the goal of the program is to encourage the next generation of female and male students to pursue STEM in post-secondary school and career while increasing their self-efficacy and confidence. Again, this further aligns with literature reviews of similar programs.

Program Feedback

Surveys

Besides the physical results produced, a survey was also conducted to gauge the students' thoughts and reactions to the project as well as to see any growth that was made throughout their time with GEMS [4]- [7]. The purpose of the survey was to receive feedback on the project, but more specifically on the QArm. It was important to understand how the QArm was perceived by the students based on their previous knowledge and compare it to the growth they experienced over the course of the program [7].

Overall, the results showed that there was a definite increase in the students' knowledge across the board. They both stated that in working with Quanser technology, their STEM knowledge, overall technology skills, and soft skills increased [4]-[6], [10]. As a bonus, they also indicated that because of the project, their interest in STEM and STEM-related fields increased, and they even indicated that they would consider pursuing a STEM career in the future. Problem-based learning has been found to improve motivation towards learning and self-directed learning, allowing participants to create meaning for themselves in what they do, as stated by Schilling's research in *The STEM Gender Gap: An Evaluation of the Efficacy of Women in Engineering Camps* [3].

What did you learn the most about working with Quanser products?	• What I learned most about working with Quanser products is the fact that their products all share internal/external similarities. For example, a lot of their products include the same RGB camera and are coded under Simulink and other software. • I learned about how Simulink works.
What challenges did you have with your project?	• The challenges we faced during our project were understanding some of the concepts of the arm and going through trials with the software of the arm. Because we were in unknown terrain, at first, we had trouble understanding concepts but eventually understood. We also encountered some problems with the software because sometimes it would not cooperate and load. • Understanding the intricacies behind the hardware of the QArm was difficult.

What was your favorite part of the project with the Quanser QArm?	• My favorite part of the project with the Quanser QArm was definitely physically moving the arm so it could learn when going through labs. Other than that, I also enjoyed the RGB camera and its ability to detect color when shown on the Video Display. • My favorite part of the project was learning how to code the arm to move.

Figure 8. Student Survey Questions and Student Responses

Lessons learned

Many things were learned over the course of the summer. One of the main lessons learned by the students was time management. For the first time, the students had to produce specific results in a limited amount of time, but with proper instruction and planning, the project was successful. Being able to complete this project gave the students the knowledge that with proper planning and time management, anything can be done in any amount of time [4], [5], [10].

Another lesson learned by the counselors is that students learn in various ways; in this case, they learn better through hands-on work. Throughout the project, it became apparent that the students were able to grasp the concepts and the QArm better when they were given time to use the QArm and experiment with it. The students were able to experience problems similar to engineers in the industry, allowing them to solve problems and brainstorm to create their own meaningful experiences, as stated by Schilling [3]. Additionally, hands-on work with the equipment motivated and empowered the students, giving them the confidence to make decisions and embrace failure as a learning opportunity.

In the survey that was conducted at the end of the summer seen in Figure 8, the students stated, "My favorite part of the project with the Quanser QArm was physically moving the arm so it could learn when going through labs. Other than that, I also enjoyed the RGB camera and its ability to detect color when shown on the Video Display." This was important because it kept the students interested and passionate about finishing their project [5], [6], [10]. This can be directly tied back to the fact that the general interest in STEM-related fields by girls increases in middle school but decreases in high school [4]-[7]. In proving that hands-on work increases interest, that principle can be applied in the future to improve interest level in STEM when they enter high school and keep it high throughout high school [4]-[7], [10]. Phelan's paper explores how evidence shows that active, hands-on learning and laboratory experiences enhance persistence in STEM majors, and how early interest in science during K-12 correlates with a student's intention to pursue a science major in college" [4].

Conclusion and Future Work

This summer proved to be successful in proving that it is possible to take high-level undergraduate and graduate technology and translate it into digestible information for high school students. It was evident by the GEMS counselor and director that the method that was implemented was formatted correctly and allowed for maximum results and knowledge absorption. The lessons learned during the program were important to consider in future projects, GEMS summer camps, and within their future workforce [1], [2]. Phelan says it best: “Programs that engage high school students in unique STEM experiences will likely continue to play a profound role in recruiting and retaining bright young minds in STEM fields” [4]. Although the GEMS organization is small, its impact on the students who attend is significant.

The project that was completed by the students was also a small part of a larger project that the AVS Labs undergraduate and graduate researchers were currently working on. Despite the Quanser QArm being loaned temporarily, the binary detection that the students developed can still be used and implemented in the other hardware that the lab was using for the larger project, including the Quanser QBots and Quanser QDrones [18].

The students' success is now proof that the students who participate in these summer programs are capable of conducting high-level research [3], [5], [6], [8], [10]. In being able to translate undergraduate and graduate-level work and having the students conduct a project and successfully produce results, the GEMS program can grow and have future generations of students participate in similar projects. Organizations and programs that provide hands-on exposure in STEM are incredibly important to retaining the STEM pipeline among the next generation to attend college and enter the workforce.

Additionally, the rebranding of *G^2EMS* aligns with both national and industry demands, addressing the critical shortage of skilled and educated students who are prepared to pursue higher education and enter the workforce within the engineering and computer science fields. This strategic expansion aims to better equip the next generation with the necessary skills and knowledge to meet the advancing needs of the economy, ensuring they are well-prepared for success in college and their future careers.

Acknowledgments

The megaGEMS high school summer programs are funded by various grants from the Army Education Outreach Program (AEOP): AEOP High School Apprenticeship Programs (HSAP) (Grant W911NF2010260), and the AEOP Unite high school administered by the Technology Student Association (TSA) and member of the AEOP Consortium formed by the AEOP cooperative agreement award (W911SR-15-2-0001).

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