Advancing Student Success by Implementing Research-Based Challenges in Capstone Design

Dr. Eleazar Marquez, The University of Texas Rio Grande Valley

Eleazar Marquez is an Assistant Professor of Practice in the Department of Mechanical Engineering at The University of Texas Rio Grande Valley

Dr. Hiram Moya, The University of Texas Rio Grande Valley

Dr. Hiram Moya earned his Bachelor of Science degree in Industrial Engineering from Texas A&M University at College Station, Texas in 1996. After working in Accenture for 5 years, he founded and became the managing Partner of HMGroup LLP. In 2004, he ear

Dr. Jesus Gonzalez, The University of Texas Rio Grande Valley

Dr. Jesus Gonzalez is currently an assistant professor in practice in the Department of Manufacturing and Industrial Engineering of the College of Engineering and Computer Science. He holds a PhD from The University of Sheffield in United Kingdom in Mate

Advancing Student Success by Implementing Research-based Challenges in Capstone Design

In this study, a team of faculty members from The University of Texas Rio Grande Valley (UTRGV), participating in a research collaboration with two National Laboratories, created and implemented a set of capstone projects that aligned with the research demands and expectations of the funding entity. The objective of the collaboration effort between the three entities is to: 1) explore innovative manufacturing techniques that support the national security and scientific missions of the laboratories, and 2) prepare UTRGV students to secure internships and employment in high research areas. The capstone projects were implemented on the senior design curriculum and served as a foundation and precursor for students to develop technical skills, knowledge, and confidence to be successful post-graduation on day-one of their internships or full-time employment. A total of four projects were created and implemented. To this end, students from multiple departments have been hired to participate in the project. A working prototype is expected from each team, and the results of the exploratory research endeavors will be delivered to the grant sponsors.

I. BACKGROUND AND MOTIVATION

The collaborative effort between The University of Texas Rio Grande (UTRGV) and a National Laboratory initiated in the Fall of 2023. The National Laboratory delineated two objectives: 1) find innovative manufacturing techniques that support the national security and scientific mission, and 2) prepare UTRGV engineering students to secure internships and employment in high research areas. Congruently, the internal goal of the faculty collaborating in the project was to 1) support student success by promoting the participation of underrepresented minorities in research venues, and 2) increase the number of underrepresented students hired in the engineering workforce. Research indicates that underrepresented students trail other groups in pursuing graduate school, being employed in STEM fields and higher education [1]. Further, minority groups such as African American (3.8%), Latino (4.1%), and Native American (0.4%) compromise a relatively low percentage of underrepresented communities pursuing graduate school in STEM disciplines [4]; the Black community comprises 9% of STEM workers, while 7% of the STEM population is represented by the Hispanic community [3].

Phase 1

To this end, student recruitment process at UTRGV began in the Spring 2024 semester by adopting the Identify, Build, Integrate, Evaluate, and Extend (IBIEE) model developed by Marquez and Garcia, which is centered on nurturing a disposition from the project faculty members to proactively identify and recruit engineering students into the research collaboration effort [5]. The recruitment process includes five major components: 1) identify students in the classroom setting, 2) build relationships, 3) inquire about short and long-term academic interest, 4) evaluate academic interest, and 5) extend invitation to participate [5].

Numerous students were interested in the research position, but given the budget restrictions, only students with an acceptable grade-point average (GPA) were offered a position [2]. A total of three graduate students were hired across different departments: two from Manufacturing Engineering and the other from Statistics. In terms of the undergraduate students, a total of nine were hired; three from Mechanical Engineering, four from Manufacturing Engineering, and two from Engineering Technology [2]. Thus, a total of twelve underrepresented students across different engineering disciplines were hired to participate in the project's initial phase. From this first cohort, three completed internships with the National Laboratory during the summer of 2024 and received full-time employment post-graduation. Four other students received internship offers for the summer of 2025.

II. CAPSTONE PROJECTS

Phase 2

Given the success of the initial phase, the National Laboratory asked UTRGV participating faculty to develop various capstone design projects that aligned with their research demands and expectations. The selected capstone projects were implemented on the senior design curriculum in the Fall of 2025, and served as a foundation, and precursor, for students participating in the research effort to develop technical skills, knowledge, and confidence to be successful post-graduate. To this end, a total of four capstone projects were created and implemented:

PROJECT 1: Design and Implementation of a 5-DOF Articulated Robot for Pick-and-Place Operations

Project Description

The first proposed project was the Articulated Robot, which integrated a five-degree-of-freedom (DOF) robotic arm that autonomously performed a sequence of tasks either inside or outside of a glovebox. The suggested system integrated mechanical design, motion control, sensor systems, and embedded programming.

System Features

The Articulated Robot contained the following features:

- Articulated arm with rotary joints
- Microcontroller-based control system (e.g., Arduino, STM32)
- Interchangeable end effector (gripper or suction cup)
- Programmable repetitive task

PROJECT 2: Ergonomically Designed Workbench for Glovebox Operator Task

Project Description

The second proposed project integrated mechanical design, computer vision, and statistical modeling to create a responsive, ergonomically adaptive workbench system for glovebox operations. The capstone team had to:

- Analyze glovebox tasks to identify ergonomic challenges.
- Collect and model anthropometric data to predict strain.
- Design a lift mechanism that adjusts based on worker dimensions.
- Implement a vision system to capture and interpret body measurements.
- Build and test a prototype that demonstrates real-time ergonomic adjustment.

The project involved:

- Ergonomic Analysis: Study of strain induced by glovebox tasks using anthropometric data.
- Data Modeling: Use of statistical tools to correlate body measurements with ergonomic stress.
- Vision System: Camera-based system to capture worker dimensions and translate them into actionable data.
- Mechanical System: Design and fabrication of a lift mechanism that adjusts the workbench height and position.
- Automation: Integration of sensors and actuators to enable real-time adjustment based on worker input.

PROJECT 3: Design and Manufacturing of a Gantry-Type Robot to Assist Operators in Confined Spaces

Project Description
The third proposed project focused on the design and implementation of a modular, three-axis gantry robotic system for high-precision material handling. The system was developed using a structured engineering design process, including concept development, simulation, fabrication, integration, and validation.

The project incorporated:

- Mechanical design and CAD modeling of the gantry structure.
- Kinematic modeling and motion control implementation.
- Integration of motors, sensors, and end effectors.
- Development of a control interface for user interaction.
- Prototyping and testing of the complete system.

The system was fabricated using CNC machining and assembled with high-tolerance components. Control was implemented through embedded systems or PLCs, with a user-friendly interface for monitoring and operation.

PROJECT 4: Design and Development of a Remote Non-Contact Surface Roughness Measurement System for Curved Surfaces Inside a Glovebox Handling Radioactive Materials

Project Description
The fourth proposed project aimed to develop a remote, non-contact system for measuring surface roughness on curved components within glovebox environments used in nuclear and radiological laboratories. Traditional contact-based profilometry is unsuitable due to contamination risks and limited accessibility. Therefore, the proposed system integrated optical sensing, automated positioning, and remote operation to ensure safety, precision, and reliability in radioactive settings.

III. PROJECT METRICS

In this study, a total of 15 undergraduate students from the Manufacturing Engineering Department at UTRGV were hired to complete the capstone projects; 12 males and 3 females. Fourteen students identified as Hispanic while 1 student identified as White. The following self-developed metrics were proposed for each project:

Metrics for Evaluation of Project 1
The following metrics were utilized to evaluate the Articulated Robot project:

- Task Accuracy: Precision in cup placement and delivery
- Repeatability: Consistency of motion across multiple cycles
- System Responsiveness: Time taken to complete the task
- User Interface Usability: Ease of use and clarity of feedback
- Mechanical Reliability: Durability and robustness of the robotic arm

Metrics for Evaluation of Project 2
The following metrics were utilized to evaluate the Workbench project:

- Ergonomic Improvement: Reduction in predicted strain based on posture analysis
- Adjustment Accuracy: Precision of lift positioning based on optical input
- System Responsiveness: Speed and reliability of real-time adjustments
- Mechanical Performance: Load capacity, stability, and durability of the lift
- Cost Efficiency: Balance between performance and material cost
- User Satisfaction: Feedback from test users on comfort and usability

Metrics for Evaluation of Project 3
The following metrics were utilized to evaluate the Gantry-Type Robot project:

- Dimensional Accuracy: Precision of movement along X, Y, Z axes
- Repeatability: Consistency of motion and positioning
- Load Capacity: Maximum payload the system can handle reliably
- System Reliability: Performance under continuous operation
- User Interface Usability: Ease of control and monitoring
- Integration Quality: Seamless operation of mechanical, electrical, and software components

Metrics for Evaluation of Project 4
The following metrics were utilized to evaluate the Non-Contact Surface project:

- Accuracy of roughness measurements compared to commercial tools
- System functionality within glovebox constraints
- Reliability and repeatability of measurements
- Effectiveness of remote operation and user interface
- Completeness of documentation and clarity of final presentation

IV. RESULTS & DISSCUSSION

Project 1 – Articulated Robot

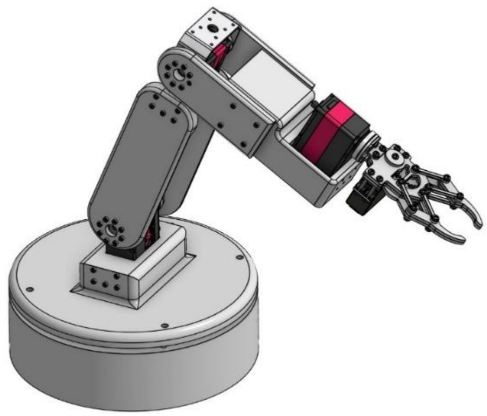

Figure 1. SolidWorks Model of Articulated Robot

Work Accomplished

In terms of the System Requirements and Architecture, students used functional requirements to design system architecture, building the robot by mechanical, electrical, and programming phases.

- Material and component selection – selected and justified all necessary components and configured how they would interface to create a prototype.
- Mechanical Design and justification – utilized relative engineering practices to design all structural components.
- Electronics, Control and GUI Implementation – configured electronics and GUI for operation and developed wiring diagram and system configuration for manufacturing repeatability.

Lessons Learned

Key technical and project management lessons include:

- Safety margins for design – through applying a worst-case scenario and safety factor while selecting components and programming robot.
- Power Delivery vs. Signal Control – power distribution is just as important as PWM signal quality.
- Rapid prototyping and root cause analysis for troubleshooting system – when creating a robot from scratch, it is important to iterate the design and learn how to identify what needs to be optimized.

Project 2 - Workbench

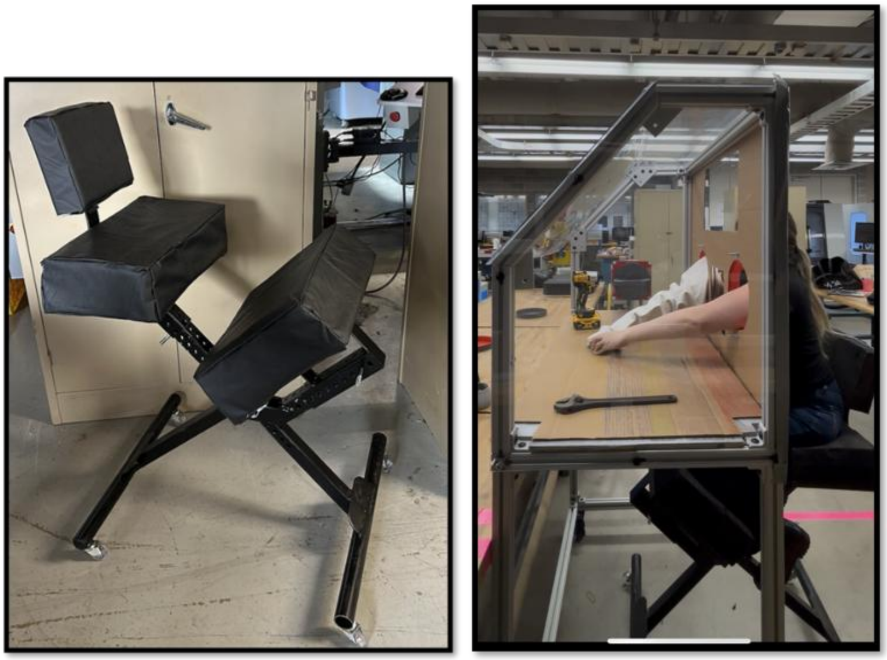

Figure 2. Workbench Design

Work Accomplished

Three design versions were created, and two working prototypes developed, incorporating elements such as telescopic rails, adjustable knee and lumbar supports, and multi-axis seat height and angle adjustments. Preliminary validation included reach measurements and task difficulty ratings during fine and gross motor activities. These findings, while based on a limited sample, indicate that the chair concept is feasible, responsive to documented ergonomic issues, and provide guidance for targeted improvements in Senior Design II.

Lessons Learned

Preliminary results indicated that participants reported lower difficulty scores and improved comfort when using the chair compared to baseline conditions. However, results also indicated that Version 2A was unable to fit the height needs of participants in the 5th percentile female, as evidenced by a team member. Shoulder to elbow angle range evaluations of video footage of gross and fine motor skills testing showed overextension outside of Occupational Safety and Health Administration's "Ideal Angle Range" for Version 2A and for Version 2B angle was in ideal range.

Based on testing findings, the team concluded that the extended height adjustment on Version 2B was more ideal and aligned with project goals than Version 2A. More extensive testing would also provide better overall data to showcase errors and successes in design. Shoulder discomfort was the highest rated for both prototype versions and is a point of concern for the team that will require design evaluation and adjustment for Senior Design II.

Project 4 - Non-Contact Surface

Accomplishments

Extensive research was completed in selecting a sensor capable of taking measurements within a tolerance, where 1 micron was accepted by the subject matter expert as opposed to 0.8 micron from blueprint. The sensor was also within budget restrictions, any sensor supplier within measurement range and resolution was within 5 figures.

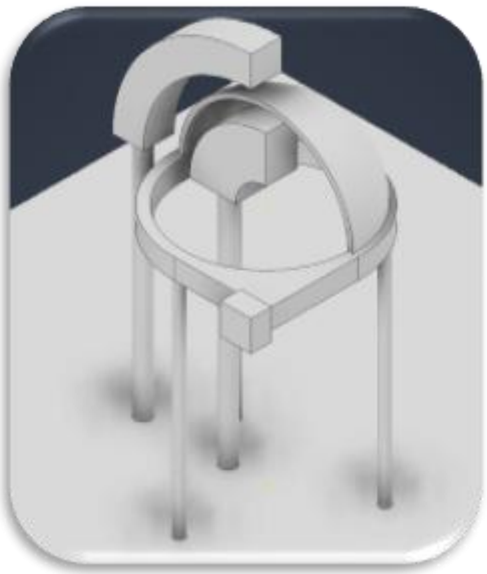

Figure 3. Non-Contact Surface Model

Technical Lessons

- Extensive research was done on optical instruments that can be used to measure the surface profile of the evaluation artefact. The characteristics of laser triangulation and confocal sensors were investigated. Laser triangulation sensors offer an affordable solution with acceptable measurement range, however, highly reflective surface can affect their performance. Confocal sensors have better resolution and are less sensitive to reflective surfaces, but the cost is higher compared to laser triangulation. The team, led by the project advisor, negotiated prices and partial donation from the vendor to the project. This allowed the team to incorporate this technology.

The team has placed particular emphasis on the preliminary design and planning stages, generating comprehensive and rigorously detailed engineering drawings to systematically mitigate risks associated with the assembly and integration of the various subsystems comprising this novel apparatus.

V. CONCLUSION

The teams were assigned with projects based on National Laboratory objectives. These efforts are directly advancing our overarching objective of cultivating technical, analytical, and professional competencies necessary for students' long-term success. Through engagement in projects aligned with National Laboratory priorities, students are not only gaining exposure to cutting-edge manufacturing practices and research methodologies, but also acquiring the specialized skills increasingly sought across high-impact scientific and security-related industries. This deliberate alignment ensures that participants are being systematically prepared for competitive internships, research appointments, and future careers in national laboratories, advanced manufacturing sectors, and other strategically important areas of the U.S. workforce.

Throughout the program, students have been consistently challenged with complex, real-world engineering and scientific problems. Most importantly, they have demonstrated resilience and adaptability—leveraging teamwork, peer-to-peer learning, and collaborative problem-solving to overcome technical and operational obstacles. These experiences reinforce not only their technical foundation but also essential professional competencies such as communication, project management, and interdisciplinary cooperation.

The anticipated outcome is that each team will complete its assigned project at a level that not only meets but exceeds expectations. In doing so, the students will provide compelling evidence that individuals from historically underrepresented regions and backgrounds can excel in research-intensive environments when afforded equitable access to opportunity, appropriate tools, and sustained mentorship. Ultimately, this initiative is contributing to the development of a diverse, highly skilled talent pipeline capable of supporting the nation's scientific innovation ecosystem.

REFERENCES

[1] S Hurtado, K Eagan, T Figueroa, B Hughes. Reversing Underrepresentation: The Impact of Undergraduate Research Programs on Enrollment in STEM Graduate Programs. Los Angeles: Higher Education Research Institute, 2014.

[2] Marquez, E., & Moya, H., & Srivastava, A. K. (2025, June), *Supporting Student Success in Engineering by Promoting the Participation of Underrepresented Minorities in Research Venues* Paper presented at 2025 ASEE Annual Conference & Exposition, Montreal, Quebec, Canada. 10.18260/1-2-57167.

[3] Funk, C., Parker, K. Pew Research Center, January 2018. "Women and Men in STEM Often at Odds Over Workplace Equity"

[4] National Science Foundation, & National Center for Science and Engineering Statistics. (2013). Women, Minorities, and Persons with Disabilities in Science and Engineering: 2013. Arlington, VA.

[5] Marquez, E., Garcia Jr., S. Nurturing Brilliance in Engineering: Creating Research Venues for Undergraduate Underrepresented Minorities in Engineering as an Initiative from Faculty Members that Foster Academic Inclusion, Development, and Post-graduation Instruction. *2019 ASEE Annual Conference & Exposition*. June 16-19, Tampa, Fl. Paper ID: 24641