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Evaluating Entrepreneurial Mindset Growth through a Robotics Project in a Mechanical Engineering Statics Course

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Evaluating Entrepreneurial Mindset Growth through a Robotics Project in a Mechanical Engineering Statics Course

Statics is a foundational course in the mechanical engineering curriculum, but traditional projects often emphasize only theoretical principles without highlighting their broader applications. To provide a more engaging and relevant learning experience for mechanical engineering students, this work introduces a robotics-based design challenge that integrates quasi-static analysis, programming, and kinematic simulation of a two-degree-of-freedom planar robotic manipulator. In the project, students derive motor joint torque equations using statics principles, implement kinematic models in MATLAB to simulate robot motion, and evaluate design tradeoffs under realistic motor torque and workspace constraints.

The project is structured around the Kern Entrepreneurial Engineering Network (KEEN) framework, which includes curiosity, connections, and creating value as elements of the entrepreneurial mindset. By combining analytical, computational, and design components, the project potentially strengthens a student's understanding of statics while connecting their analysis to real-world robotic system design considerations.

Assessment of entrepreneurial mindset growth is conducted through pre- and post-project surveys, rubric-based evaluation of deliverables, and student reflections. The hypothesis was that embedding KEEN principles and computational tools into a sophomore-level mechanical engineering statics project enhances both technical learning and entrepreneurial mindset development. The results showed that, after completing the project, students demonstrated increased confidence in applying fundamental statics principles. Students also self-reported a high level of understanding and appreciation of the entrepreneurial mindset. The paper also provides project details and lessons learned to enable faculty at other institutions to adapt or create a similar project in their own courses.

I. Introduction

Statics is a foundational course in the mechanical engineering curriculum and a prerequisite for many courses in the engineering mechanics sequence, including dynamics and mechanics of materials. Although the governing principles of statics are broadly applicable, our experience over many years has been that mechanical engineering students do not always perceive the course as directly relevant to the types of systems they expect to design, such as machines, mechanisms, and robotic systems. One contributing factor to this perception could be that many traditional textbook problems emphasize more traditional civil engineering applications, such as trusses and bridges. While these applications are effective for introducing statics concepts, using only these types of examples may unintentionally reinforce the perception that statics is a subject primarily used only by civil engineers.

To potentially improve engagement and understanding, many instructors have incorporated project-based learning (PBL) approaches into their statics courses. Prior work demonstrates that hands-on and design-based projects can help students connect statics principles to real-world systems. In 2008, Hennessey introduced a series of inexpensive hands-on statics projects, including excellent 3D static equilibrium demonstrations [1]. Following in 2011, Marlor presented a balsa wood truss design competition in which students design a truss and analyze the forces in each member, followed by building and loading the truss to experimentally test their system [2]. Also in 2011, Drake presented an excellent low-cost project-course model for statics and strength of materials in which 25 activities were presented [3]. More recently, in 2021, Sadowski and Jankowski introduced a physical truss system with different colored lights to highlight which truss members were in tension and which were in compression [4]. This occurred after students visualized loads using software. In 2025, Thamban et al. documented a workshop-based approach in which students fabricate and explore prototype systems aligned with statics topics such as moment balance, friction, and pulley systems [5]. Thus, prior work in this area demonstrates the effectiveness of PBL for reinforcing statics concepts.

However, many commonly implemented statics projects, such as the ones presented, remain centered on structural and civil engineering-based systems, which may not fully address a mechanical engineering student's desire to see clear connections to more traditional mechanical devices and products. There are, however, articles in the literature describing more mechanical-based statics projects. For example, in 2008 Coller described a hands-on activity in which students analyze the tipping condition of a crane, emphasizing statics principles applied to a real-world machine [6]. In 2021, Treadway et al. assigned many open-ended modeling problems that required students to really think through modeling assumptions prior to mathematically modeling the system. One such example focused on the statics of a hands-free crutch [7]. In 2024, Ardakani and Wiseman presented a learning activity in which students analyze the failure of a radio tower subjected to extreme loading, linking 3D equilibrium to a real-world case study [8]. Also in 2024, Buckley et al. developed the wooden bike frame challenge, in which students use static analysis in the analysis and design of a wooden bike frame that they physically prototype [9]. These projects illustrate how mechanical engineering students can benefit from framing statics within a mechanical engineering context.

In this paper, we seek to provide another example of a mechanical engineering PBL activity that is focused on robotics. Robotics is chosen as it is highly relevant to students in today's quickly evolving robotics landscape that includes autonomous vehicles and humanoid robots. We present a robotics-based design project developed for a sophomore-level mechanical engineering statics course. The project focuses on the quasi-static analysis of a two-degree-of-freedom (DOF) planar robotic manipulator. Students derive joint motor torque equations using statics principles, implement kinematic models in MATLAB to simulate robot motion, and evaluate design tradeoffs under realistic motor torque and workspace constraints.

The project is structured using the Kern Entrepreneurial Engineering Network (KEEN) framework, which emphasizes curiosity, connections, and creating value as key elements of the entrepreneurial mindset [10]. These principles are embedded in the project through requirements that encourage students to explore alternative designs, connect analytical and computational results to realistic constraints, and articulate the value of their design decisions. The hypothesis of this work is that embedding KEEN principles and computational modeling into a robotics-centered statics project enhances both a student's technical understanding of statics and their entrepreneurial mindset development. Entrepreneurial mindset growth is assessed through pre- and post-project surveys, rubric-based evaluation of project deliverables, and student reflections. The paper also provides project details and lessons learned to enable others to adapt or create a similar project for their own courses.

The remainder of this paper is organized as follows. Section II describes the instructional design and implementation of the robotics-based statics project in sufficient detail to support adoption by other instructors. Section III describes the assessment methodology used to evaluate student learning and entrepreneurial mindset growth. Section IV summarizes the results and lessons learned, and Section V concludes the paper and provides ideas for future work.

II. Project Details

This section describes the instructional design and implementation of our new robotics-based design project integrated into a sophomore-level mechanical engineering statics course. The project was implemented as a team-based project (3 to 4 students per team) and structured in three phases covering (i) statics-based motor torque derivation, (ii) MATLAB-based brute force design optimization, and (iii) KEEN-guided reflection on the 3Cs (curiosity, connections, and creating value).

To facilitate the use of this project by others, we summarize the learning objectives, robot configuration and modeling assumptions, problem definition, representative torque expression derivation, the torque optimization process and requirements, and our KEEN integration approach. The project was implemented over approximately six weeks during the second half of the semester. Each phase of the project had formal deliverables for students. Phase I required a formal PDF submission of their free-body diagrams and their corresponding torque derivations. Phase II required a MATLAB brute force optimization code and simulation results, and Phase III required a written KEEN reflection on both the 3Cs and a reflection on the technical results.

a. Learning Objectives

The project was designed to strengthen a student's conceptual understanding of statics principles, while emphasizing the role of computation in design and the focus on a real-world application and value to society. Upon completion of the project, students are expected to be able to:

- Apply static equilibrium principles (free body diagrams, force and moment equilibrium equations) to analyze how a robotic manipulator performs in a realistic industry-inspired task
- Calculate joint torques necessary to maintain the manipulator's configuration while supporting a payload and explore how system parameters (like link lengths and mass properties) influence those torques through a brute-force optimization
- Draw and interpret free body diagrams for multi-link mechanical systems
- Implement torque calculations in MATLAB to evaluate performance over a trajectory
- Communicate engineering analysis and design insights clearly and professionally to support effective technical decision-making
- Understand and implement aspects of the KEEN framework (i.e., the 3Cs)

Thus, the general goal of this project is to allow students an opportunity to apply statics to a real-world robotic system in a way that allows them to combine static analysis and computational design in the context of the KEEN framework and real-world engineering impact.

b. Robot Configuration and Modeling Assumptions

In this project, students analyze a two-degree-of-freedom (DOF), planar serial manipulator consisting of two rigid links actuated by revolute joints, as shown in Fig. 1A. Joint 1 (i.e., the "shoulder" joint) rotates link L_1 relative to ground. Joint 2 (i.e., the "elbow" joint) rotates link L_2

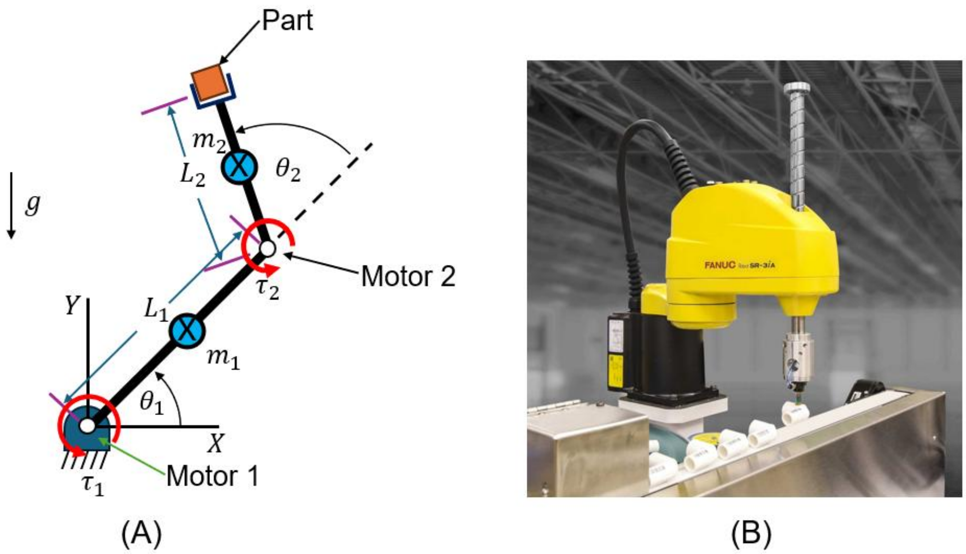


Figure 1: (A) A two-DOF robot manipulator. Motor 1 rotates L_1, and motor 2 rotates L_2 relative to L_1. (B) A real-world SCARA robot performing a pick and place operation.

relative to link L_1. A point mass is applied at the end-effector to represent the gripper and part mass.

This topology was selected because it is sufficiently complex to require multi-link free-body diagrams and nontrivial moment equations, while remaining accessible to sophomore statics students and well-suited for brute-force parameter searches. To reinforce industrial relevance, the manipulator is discussed in class and compared to a SCARA-type robot performing planar pick-and-place operations, as shown in Fig. 1B.

Teams are provided with a system parameters table shown in Table 1, and the analysis is performed under the following assumptions:

- Planar system
- All links are rigid
- No joint friction or motor dynamics
- Gravity acts vertically downward $(-Y)$ direction
- Each link is uniform
- Assume a fixed payload/gripper mass located at the end-effector

c. Problem Definition

In this project, students evaluate and optimize the robot link lengths for a prescribed trajectory. The end-effector is required to follow a fixed circular trajectory (200 discretized points evenly spaced over 0 to 2π) that is shown in Fig. 2. At each trajectory point, the inverse kinematics are calculated to determine the corresponding joint angles, θ_1 and θ_2. Students then compute the required torques, τ_1 and τ_2, at these joint angles using equilibrium expressions they derive in Phase I of the project.

Table 1: System Parameters

Symbol	Description	Numeric Value
ρ	Link density (aluminum)	$2700 \frac{\text{kg}}{\text{m}^3}$
A	Cross-sectional area of each link	0.001 m^2
L_1	Length of link 1 (see Fig. 1)	$L_1 \in [0.3, 0.5]$ m
L_2	Length of link 2 (see Fig. 1)	$L_2 \in [0.2, 0.4]$ m
m_1	Mass of link 1 (at link center)	$\rho A L_1$
m_2	Mass of link 2 (at link center)	$\rho A L_2$
m_p	Payload mass at the end-effector (i.e., gripper and end-effector mass)	1.5 kg (constant)
g	Gravitational constant	$9.81 \frac{\text{m}}{\text{s}^2}$
θ_1	Joint angle at motor 1 (between global X-axis and link 1)	From inverse kinematics
θ_2	Joint angle at motor 2 (referenced relative to link 1)	From inverse kinematics
τ_1	Torque required at joint 1	Derived
τ_2	Torque required at joint 2	Derived

The design variables are the link lengths, which are bounded by the following workspace constraints: $L_1 \in [0.3, 0.5]$ m and $L_2 \in [0.2, 0.4]$ m, as shown in Table 1. A candidate design is considered feasible if it (i) reaches all 200 trajectory points and (ii) satisfies prescribed motor limits of $|\tau_1| \leq 10 \text{ N} \cdot \text{m}$ and $|\tau_2| \leq 5 \text{ N} \cdot \text{m}$ at every point.

For feasible sets of link lengths, a torque-based objective function is used as an energy-efficiency proxy, as shown in Eq. 1

$$\text{cost} = \sum_{i=1}^{200} (|\tau_1(i)| + |\tau_2(i)|). \tag{1}$$

Thus, students must minimize the total torque cost. In our experience with this project, relating the problem to energy-efficiency provides a motivating real-world context for students. The results from the program are the optimized link lengths, L_1 and L_2, that minimize the torque cost while meeting other real-world design constraints. This will result in a unique set of solutions for L_1 and L_2.

Students participating in this project had prior exposure to fundamental statics concepts, including free-body diagrams and equilibrium analysis, but had limited to no formal exposure to topics such as inverse kinematics or numerical optimization. To support student success, these concepts were introduced at a conceptual level through guided instruction and example problems, rather than as fully developed theoretical topics. In particular, inverse kinematics was presented as a geometric relationship between joint angles and end-effector position, and optimization was framed as an iterative search process to satisfy design constraints (e.g., torque limits and workspace requirements). Students were primarily coached through these ideas during

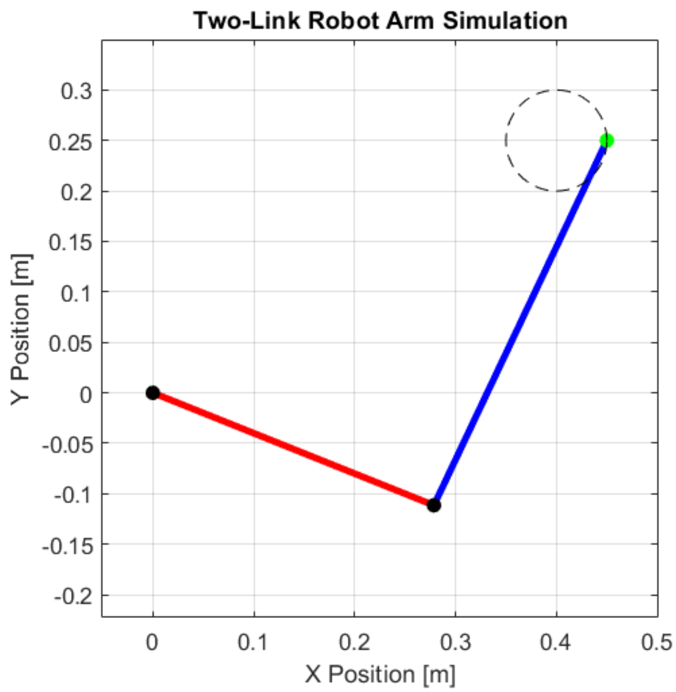


Figure 2: Students must determine the pair of link lengths, L_1 and L_2, that minimize the required motor torque for a given circular path. Motor torque limits and workspace constraints must also be considered.

project work sessions, allowing them to apply concepts without requiring extensive prior background.

d. Phase I: Motor Torque Derivation

Following introduction of the problem and modeling assumptions, the project proceeds in three phases. The first phase of the project is the fundamental statics calculations to calculate the required motor torque. Students are required to provide a typed and professional solution for the torque equations and corresponding free body diagrams. Students derive torque equations in the following form for the motor torque at joint one, τ_1, and the motor torque at joint two, τ_2.

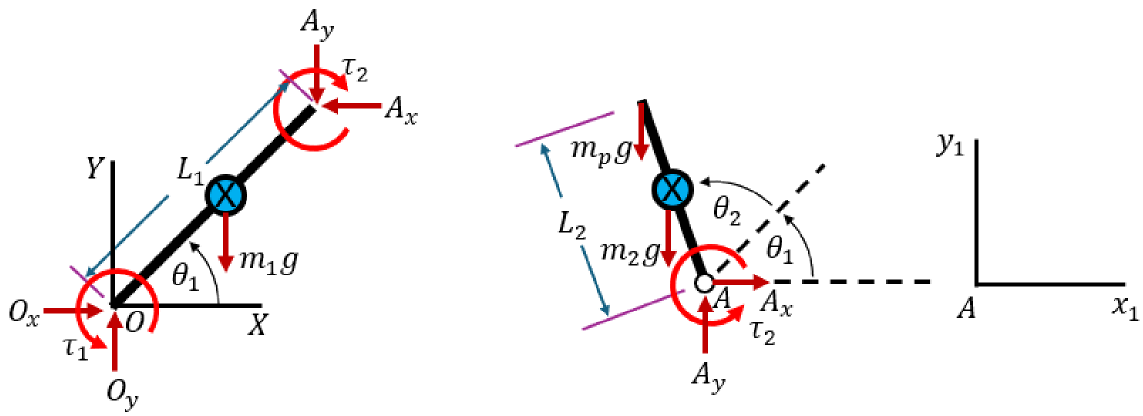
$$\tau_1 = f(\theta_1, \theta_2, L_1, L_2, m_1, m_2, m_p, g)$$
$$\tau_2 = f(\theta_1, \theta_2, L_1, L_2, m_1, m_2, m_p, g).$$

This phase of the project requires students to apply their knowledge about frames and machines to a real-world system. The most efficient solution is found by drawing the free body diagram of each link, as shown in Fig. 3. For link 2, we can sum the moments about point A, given in Eq. 2

$$\circlearrowleft + \sum M_A = \tau_2 - m_2 g \frac{L_2}{2} \cos(\theta_1 + \theta_2) - m_p g L_2 \cos(\theta_1 + \theta_2) = 0 \tag{2}$$

Solving for τ_2, as shown in Eq. 3 gives

$$\boxed{\tau_2 = \left(\frac{m_2}{2} + m_p\right) L_2 g \cos(\theta_1 + \theta_2).} \tag{3}$$



(A) (B)

Figure 3: (A) The free body diagram of link 1. (B) The free body diagram of link 2.

This allows one to calculate τ_1 by summing the moments about O for the free body diagram shown in Fig. 3A, as shown in Eq. 4

$$\circlearrowleft +\sum M_O = \tau_1 - \tau_2 - m_1 g \frac{L_1}{2} \cos\theta_1 - A_y L_1 \cos\theta_1 + A_x L_1 \sin\theta_1 = 0. \quad (4)$$

Thus, the expression for τ_1 is given in Eq. 5 as

$$\tau_1 = \tau_2 + m_1 g \frac{L_1}{2} \cos\theta_1 + A_y L_1 \cos\theta_1 - A_x L_1 \sin\theta_1, \quad (5)$$

where $A_x = 0$ and $A_y = m_p g + m_2 g$ from force equilibrium of link 2. Substituting τ_2 from Eq. 3 and A_x and A_y into Eq. 4 leads to the final torque expression for motor 1, given in Eq. 6 as

$$\boxed{\tau_1 = g\left[\left(\frac{m_2}{2} + m_p\right) L_2 \cos(\theta_1 + \theta_2) + L_1 \cos\theta_1 \left(\frac{m_1}{2} + m_p + m_2\right)\right]}. \quad (6)$$

This completes the derivation of the torque expressions for motor 1 and motor 2.

e. Phase II: Torque Optimization

In Phase II, students implement the torque expressions in MATLAB and evaluate torque requirements along the full trajectory of candidate designs. To focus effort on engineering evaluation (rather than robotics derivation), students are provided with a starter MATLAB script and an inverse kinematics function that computes θ_1 and θ_2 for each trajectory point, given L_1 and L_2.

Teams typically perform a brute-force grid search over the allowable link-length ranges described earlier. For each candidate design, the program: (i) checks reachability for all 200

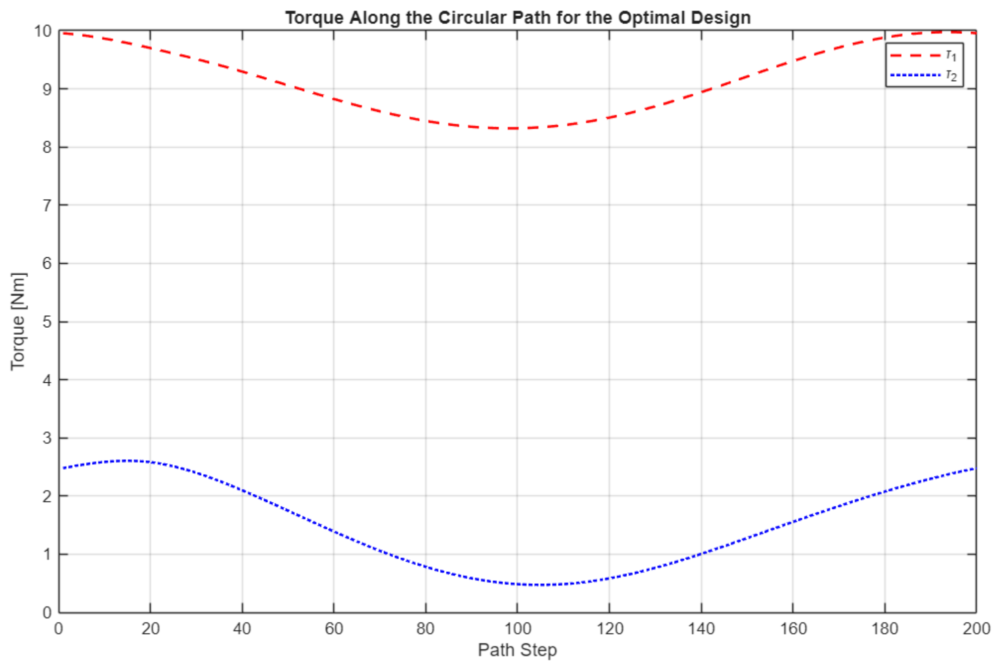


Figure 4: Example optimized torque curves for both motors.

trajectory points, (ii) computes $\tau_1(i)$ and $\tau_2(i)$, (iii) rejects infeasible designs exceeding motor torque limits, and (iv) computes the torque-cost objective for feasible designs. The optimal design is then visualized by plotting τ_1 and τ_2 over the trajectory. An example of this is shown in Fig. 4.

This project phase reinforces computer implementation skills previously introduced in our first-year programming course (functions, loops, vectorization, conditional logic, etc.) while illustrating how computational tools support the design of real-world mechanical systems.

f. Phase III: KEEN Connections and Reflection

In Phase III, teams produce a 2–3 page written reflection structured around KEEN's 3Cs. The reflection prompts are intentionally aligned with the technical work completed in Phases I–II to encourage students to: (i) explore alternative assumptions and design modifications (e.g., different link materials, modified torque limits), (ii) connect statics modeling with kinematic simulation and computational decision-making, and (iii) articulate the societal and economic relevance of torque-efficient design (e.g., energy usage, equipment sizing, safety margins, etc.). Example questions for each of the three categories are provided:

<u>Curiosity</u>

- What would happen if the links were made of a different material, such as carbon fiber (2000 kg/m³) instead of aluminum (2700 kg/m³)?
- If torque limits were increased by 25%, would your optimal design change? Try it and compare.

Connections

- How did you connect ideas from statics, robotics, and programming to solve this design challenge?
- Which joint (shoulder or elbow) generally carried the higher load, and why?

Creating Value

- How could a torque-efficient robotic manipulator design reduce costs, increase safety, or enable new capabilities in real-world applications?
- What field (e.g., surgery, manufacturing, space robotics) might benefit most from your torque-efficient design, and why?

In our experience, the KEEN aspect of the project has been helpful in providing a low-stakes way for students to reflect on their project work.

In summary, students who complete this project apply static equilibrium equations to a real-world planar manipulator, optimize the system parameters to minimize the motor torque, and program the results in an interactive robotic MATLAB-based simulation. Students then reflect on their work through a short reflection paper based on the KEEN framework.

g. Project Assessment

The project was assessed using the rubric shown in Appendix A. The project accounted for 10% of a student's overall course grade. Students worked in groups of 3 or 4. The rubric allows for clear and consistent grading along both technical concepts and understanding of the KEEN entrepreneurial mindset. The rubric is structured to use a mastery-based learning approach such that students are required to demonstrate mastery to be awarded credit. In using this approach, students had the opportunity to have the instructor check their work prior to submission either during in-class time or during office hours. Our experience is that providing a high standard with multiple attempts leads to potentially better learning outcomes. Our recommendation is that the project accounts for 5% to 10% of the course grade to ensure the project is a meaningful portion of the overall course grade.

III. Student Survey Instrument and Administration

To assess the impact of the robotic manipulator design project on student learning and engagement in the course, a pair of anonymous pre- and post-project surveys were administered. The pre-project survey was distributed prior to the introduction of the project to establish baseline measures of students' prior experience, confidence, and perceptions related to statics concepts and engineering problem solving. The post-project survey was administered after completion of all project deliverables to capture students' self-reported learning gains, confidence development, and reflections on the project experience. Participation in both surveys was voluntary, had no impact on course grades, and the responses were collected anonymously using hard-copy questionnaire completed by students in class. The pre-project and post-project survey questions are listed in Appendix B and C. The project was approved under IRB project I-2025-012-MSOE at the Milwaukee School of Engineering. Data were collected from two sections of a sophomore-level statics course. A total of 37 students were enrolled across both sections, and survey participation was voluntary and anonymous.

The pre-project survey primarily focused on students' initial confidence in statics topics such as free-body diagrams, equilibrium analysis, and force decomposition, as well as their prior exposure to hands-on or PBL and computational tools. The post-project survey included parallel Likert-scale items that allowed students to reflect on perceived changes in conceptual understanding, problem-solving confidence, and ability to apply statics principles using computational tools such as MATLAB. Additional post-project items assessed student engagement, perceived relevance of the project to real-world engineering practice, and overall satisfaction with the learning experience. Both surveys also included open-ended questions, which invited students to comment on challenges encountered, aspects of the project that supported learning, and suggestions for future improvements. Quantitative responses were analyzed using descriptive statistics, while qualitative responses were reviewed using thematic analysis to identify recurring trends in student perceptions. The survey quantitative questions are shown on the next page:

Pre-project survey:

1 (Not confident) – 5 (Very confident)
Q1) How confident do you feel about analyzing and modeling real-world mechanical systems using theory from class?
(1 = Strongly Disagree, 5 = Strongly Agree)

Q2) I am curious about how engineering theory applies to real-world systems.

Q3) I actively seek connections between what I learn in class and practical applications.

Q4) I understand how engineering decisions can create value for others (e.g., users, society, industry).

Q5) I see failure or uncertainty as an opportunity to learn and explore.

Post-project survey:

How confident are you now in:
1 (Not confident) – 5 (Very confident)
Q1) Applying statics to model mechanical systems.

Q2) Using MATLAB to simulate engineering models.

Q3) Analyzing design tradeoffs (e.g., torque limits, workspace constraints):

(1 = Strongly Disagree, 5 = Strongly Agree)

Q4) This project increased my interest in exploring new engineering problems.

Q5) I was able to connect statics, programming, and design thinking during this project.

Q6) I can better see how engineering design decisions affect performance, cost, and user value.

Q7) I now see open-ended design problems as opportunities to innovate and create solutions that benefit people or society.

IV. Results and Lessons Learned

a. Survey Results

Analysis of the post-project survey responses indicates that students generally reported positive perceptions of the robotic manipulator design project and its impact on their learning experience in the course. Across multiple Likert-scale items, students reported increased confidence in applying fundamental statics concepts, including free-body diagram construction, equilibrium analysis, and force decomposition, within the context of a realistic engineering system. Students also indicated improved confidence in using computational tools, such as MATLAB, to support statics-related calculations and analysis. These self-reported gains suggest that the project helped students connect theoretical concepts to practical engineering applications.

In addition to perceived learning gains, students reported high levels of engagement and motivation associated with the project-based format. Many students indicated that the robotic manipulator project enhanced their understanding of the relevance of statics to real-world engineering problems and future coursework. Responses to open-ended questions further supported these findings, with students frequently highlighting the value of working with a tangible system, integrating analysis with design decisions, and seeing how statics principles directly informed system behavior. While some students noted challenges related to the open-ended nature of the project and the computational component, these challenges were often framed as productive and ultimately beneficial to their learning.

The quantitative results of both pre-project and post-projects surveys are shown in Figures 5 and 6, respectively. Figures 5 and 6 present the mean student responses and associated variability for the pre-project and post-project quantitative survey items. As shown in Fig. 5, pre-project responses indicate that students entered the course with generally positive attitudes toward engineering curiosity, application of theory, and value creation, with mean responses for these items clustered above the neutral midpoint. However, students reported notably lower confidence in their ability to analyze and model real-world mechanical systems using classroom theory (Q1), suggesting that while students were motivated and conceptually engaged, many lacked confidence in applying statics concepts to authentic engineering systems at the outset of the project.

Post-project results, shown in Fig. 6, reveal higher mean responses across all measured dimensions related to confidence, integration of knowledge, and perception of open-ended design problems. In particular, students reported increased confidence in applying statics to mechanical systems (Q1), using MATLAB to simulate engineering models (Q2), and analyzing design tradeoffs such as torque limits and workspace constraints (Q3). Additionally, higher agreement levels were observed for items related to integrating statics, programming, and design thinking (Q5) and understanding how engineering design decisions affect performance, cost, and user value (Q6). Responses to Q7 further indicate that students increasingly viewed open-ended design challenges as opportunities for innovation and broader impact. While variability in responses remained, the overall upward shift in mean values suggests that participation in the robotic manipulator project was associated with improved self-reported confidence, integration of technical skills, and appreciation of engineering design complexity.

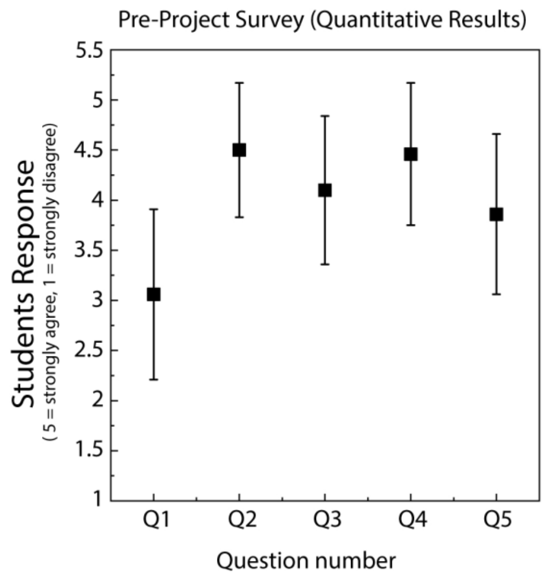


Figure 5: Quantitative results of pre-project survey

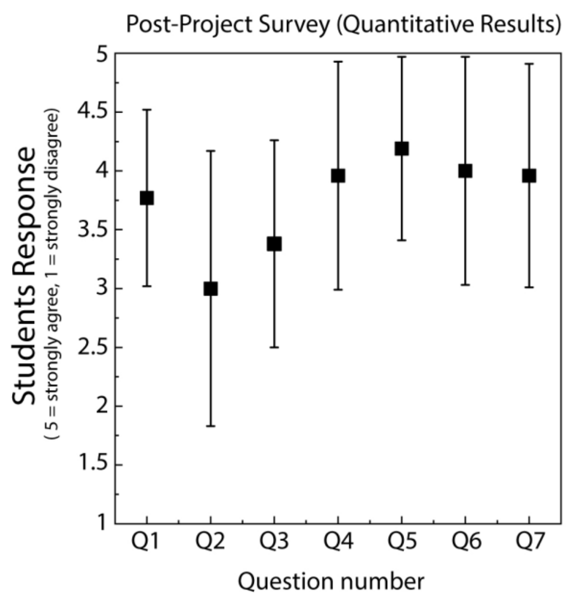


Figure 6: Quantitative results of post-project survey

b. Lessons Learned

Several key lessons emerged from the implementation of the robotic manipulator project and the accompanying student feedback. First, incorporating a physically motivated, application-driven project into a traditionally theory-heavy course such as statics can meaningfully enhance student engagement and perceived relevance without sacrificing core content coverage. Students appeared to benefit most when statics concepts were repeatedly revisited in the context of the evolving project rather than treated as isolated topics.

Second, instructional guidance was identified as a critical factor in student success. Survey responses suggest that providing structured intermediate milestones, example analyses, and guided computational templates helped reduce student frustration while preserving the open-ended nature of the design task. In particular, incremental integration of MATLAB analysis was important in supporting students with varying levels of prior programming experience.

Finally, the results highlight the importance of clear alignment between project objectives, course learning outcomes, and assessment criteria. Students responded more positively when expectations for analysis depth, modeling assumptions, and deliverables were clearly articulated. Based on these lessons, future iterations of the project will incorporate earlier exposure to the system model, additional formative feedback checkpoints, and clearer connections between project activities and core statics learning objectives.

V. Conclusions and Future Work

This paper presented a novel robotics project for a sophomore-level mechanical engineering statics course in the context of the KEEN framework. The project required students to apply quasi-static analysis to a two DOF planar robotic manipulator, derive joint torque expressions, and implement computational optimization using MATLAB. By embedding the project within the KEEN framework, the activity required students to demonstrate curiosity through design exploration, make connections between statics, robotics, and computational tools, and create value by optimizing the robot to reduce motor torque as a proxy for energy usage.

From our perspective, the initial attempt at this project was successful and showed that it has potential to improve student learning and engagement in statics. Student survey responses and reflections indicate that the PBL approach supported improved student engagement and increased confidence in core statics topics, such as writing equilibrium equations and drawing free body diagrams. Some students also reported stronger confidence in using computational approaches to support their engineering decision-making, which reinforced many of their programming lessons from their freshmen year. Additionally, the project encouraged the KEEN entrepreneurial mindset, and students reported a strong understanding of KEEN concepts. Some students experienced challenges associated with the open-ended nature of the project and the MATLAB implementation. We plan to address these issues in the future through additional scaffolding and project checkpoints.

Overall, our initial implementation of this project demonstrated that a robotics-based design challenge can potentially serve as an effective addition to a traditional statics course. Future work will focus on expanding the project to incorporate experimental validation through development of a physical (or potentially simulated) robotic manipulator, enabling students to compare theoretical quasi-static predictions with experimental results. In addition, the project may be extended into a sophomore-level dynamics course, where students could derive the equations of motion and compare the dynamic model results to the quasi-static model results. This future work could further strengthen the connection between fundamental mechanics concepts in statics and dynamics, computational modeling, and real-world engineering design practice in the context of the KEEN framework. Our hope is that other instructors find this work useful and can adopt or adapt the project in their own courses. Another future study could involve allocating weights to different constraints depending on priorities or limitations (e.g., torque limits, constant linkage areas or the prescribed path) to reach a set of feasible solutions.

VI. Acknowledgements

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Appendix A

Section	High	Medium	Low	Points Earned
1. Free Body Diagram	15: Accurate, labeled free body diagrams with all forces, torques, and dimensions. Computer-generated and clearly formatted.	N/A	0: At least one free body diagram is incorrect. Either a force, torque or dimension is incorrect or not shown. Everything may be correct, but the diagram may not be computer generated and clearly formatted.	
2. Torque Derivation	15: Equilibrium equations lead to correct torque equations. Steps in the derivation are shown and correct. Proper coordinate systems used. Final boxed expressions are included.	N/A	0: Derivation is incorrect. At least one error occurs, or coordinate system(s) are missing.	
3. MATLAB Implementation	15: Clean, modular code with professional comments. Uses provided inverse kinematics properly. Evaluates required designs, checks feasibility.	9: Runs with minor issues or inefficiencies. Structure may be unclear.	0: Code incomplete, non-functional, or disorganized.	
4. Torque Evaluation & Design Search	15: Searches design space thoroughly using brute-force or optimization. Applies constraints and selects best feasible design.	9: Properly searches the design space but with a possible minor error in constraint handling, leading to a non-optimal solution.	0: No design evaluation and largely incorrect code.	
5. Torque Plot	10: τ_1 and τ_2 torque curves are shown and correct. Plot is labeled, readable, and correct.	6: Plot present and correct but lacks proper labels.	0: Missing or incorrect plot data.	
6. KEEN: Curiosity	10: Explores meaningful "what if" questions such as material change, geometry variation, or constraint adjustment. Reflects thoughtful design inquiry.	6: Answers some prompts but is lacking depth in responses.	0: Little or no exploratory thinking shown.	
7. KEEN: Connections	10: Strong connections between statics, derivation work, MATLAB implementation, and engineering design decisions.	6: Partial or vague links between components of the project.	0: No clear integration of concepts.	
8. KEEN: Creating Value	10: Thoughtfully discusses real-world application, benefit to a specific field, and implications of torque-efficient design.	6: Mentions real-world application without specific analysis.	0: No clear connection to broader value.	

Appendix B

PRE-PROJECT SURVEY: Measuring Baseline Mindset & Knowledge

Instructions: This survey is anonymous. Please answer honestly. Your responses will help us evaluate the impact of the project on your learning and mindset.

Section 1: Background & Confidence

1. How would you rate your current understanding of *statics* concepts (e.g., free-body diagrams, equilibrium, moments)?
   - ☐ No understanding
   - ☐ Basic understanding
   - ☐ Moderate understanding
   - ☐ Strong understanding
2. Have you previously worked on any projects involving **robotics** or **mechanical systems**?
   - ☐ Yes
   - ☐ No
     If yes, briefly describe: ______________________________
3. Have you used **MATLAB** or other coding tools before?
   - ☐ Yes, I am proficient
   - ☐ Yes, but I'm still learning
   - ☐ No, not at all
4. How confident do you feel about analyzing and modeling real-world mechanical systems using theory from class?
   - 1 (Not confident) – 5 (Very confident): ☐1 ☐2 ☐3 ☐4 ☐5

Section 2: Entrepreneurial Mindset (Aligned with KEEN Framework)

Rate your agreement with the following statements:
(1 = Strongly Disagree, 5 = Strongly Agree)

5. I am curious about how engineering theory applies to real-world systems.
   ☐1 ☐2 ☐3 ☐4 ☐5

6. I actively seek connections between what I learn in class and practical applications.
   ☐1 ☐2 ☐3 ☐4 ☐5
7. I understand how engineering decisions can create value for others (e.g., users, society, industry).
   ☐1 ☐2 ☐3 ☐4 ☐5
8. I see failure or uncertainty as an opportunity to learn and explore.
   ☐1 ☐2 ☐3 ☐4 ☐5

Section 3: Expectations

9. What do you hope to learn or achieve through this project?

10. What concerns or challenges do you anticipate? What aspects of this project (robotics, simulation, teamwork, etc.) are you most excited or nervous about?

Appendix C

POST-PROJECT SURVEY: Measuring Growth in Learning & Mindset

Instructions: This survey is anonymous. Please reflect honestly on your experience in the 2DOF Robotic Arm project.

Section 1: Technical Learning

1. After completing the project, how would you rate your understanding of statics concepts applied to real-world systems?
   - ☐ No improvement
   - ☐ Some improvement
   - ☐ Moderate improvement
   - ☐ Significant improvement
2. How confident are you now in:
   - Applying statics to model mechanical systems:

     ☐1 ☐2 ☐3 ☐4 ☐5
   - Using MATLAB to simulate engineering models:

     ☐1 ☐2 ☐3 ☐4 ☐5
   - Analyzing design tradeoffs (e.g., torque limits, workspace constraints):

     ☐1 ☐2 ☐3 ☐4 ☐5

Section 2: Entrepreneurial Mindset Growth

3. Rate your agreement with the following statements:
   (1 = Strongly Disagree, 5 = Strongly Agree)

- *Curiosity:* This project increased my interest in exploring new engineering problems.
  ☐1 ☐2 ☐3 ☐4 ☐5
- *Connections*: I was able to connect statics, programming, and design thinking during this project.
  ☐1 ☐2 ☐3 ☐4 ☐5

- *Creating Value*: I can better see how engineering design decisions affect performance, cost, and user value.

  ☐1 ☐2 ☐3 ☐4 ☐5

- I now see open-ended design problems as opportunities to innovate and create solutions that benefit people or society.
  ☐1 ☐2 ☐3 ☐4 ☐5

Section 3: Reflection & Feedback

4. What aspect of this project did you find most valuable or interesting?

5. What was the most challenging part of the project?

6. Did this project change how you view engineering or problem-solving? If so, how?

7. Any suggestions to improve this project for future students?