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Integrating a Design Project into a Mechanics of Materials Course to Enhance Student Engagement and Learning

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Abstract

Mechanics of Materials is a core course in the mechanical engineering curriculum that introduces fundamental concepts such as stress and strain, stress–strain behavior, material properties, and the analysis of structural components including bars, shafts, and beams under various loading conditions. The course emphasizes the connection between theoretical principles and real-world mechanical design applications. Our mechanics of materials course is a four-credit course consisting of three hours of lecture and two hours of laboratory instruction per week. Lectures focus on theoretical development and problem-solving, while laboratory sessions integrate hands-on experiments—such as tensile, compression, shear, and torsion testing—with virtual finite element analysis (FEA) simulations of axially loaded members, twisted shafts, and bending beams. Historically, the course did not include a design project, which limited opportunities for students to apply theoretical knowledge to realistic engineering problems. To address this limitation, a team-based design project was introduced to enhance student engagement and experiential learning. In this project, students designed a suspender arm for a gondola lift system by conducting a brief literature review and designing the component to withstand combined loading conditions through theoretical calculations. Finite element analysis was used to evaluate stress distributions and factors of safety. The project culminated in a comprehensive technical report. This paper presents the development and implementation of the project and summarizes student feedback indicating improved conceptual understanding, increased motivation, and stronger integration of theory with engineering practice.

1. Introduction

Mechanics of Materials is a required core course in the mechanical engineering curriculum and is typically offered at the sophomore level. The course builds upon prerequisite knowledge from engineering statics and mathematics and serves as a foundation for upper-level courses such as machine design, structural analysis, and finite element methods. Core topics include stress and strain, axial loading, torsion, beam bending, combined loading, and stress transformations. The primary objective of the course is to enable students to analyze and predict the mechanical behavior of structural and machine components subjected to various loading conditions.

Design projects are increasingly recognized as effective pedagogical tools in mechanical engineering education [1, 2, 3]. They aim to connect theoretical concepts with practical applications, promote active learning, and enhance student motivation. Within mechanics-focused courses, design projects have been shown to improve conceptual understanding by enabling students to visualize abstract concepts—such as stress distribution, deformation, and failure mechanisms—through hands-on and open-ended problem solving [4, 5].

Numerous successful implementations of design projects have been reported specifically in Mechanics of Materials courses. These projects range from small-scale component design assignments to comprehensive, semester-long projects involving analytical calculations, computer-aided design (CAD), and experimental validation. Prior studies indicate that integrating design projects into mechanics courses improves student engagement and supports the synthesis of theoretical knowledge with engineering practice [6, 7, 8]. Furthermore, some studies suggest that design projects enhance students' confidence in applying mechanics principles and strengthen their ability to integrate analysis with modern engineering tools such as finite element analysis (FEA) [4, 9, 10].

Despite the documented benefits reported in the literature, the current offering of this course at our institution did not include a class design project. Instruction relied traditionally on lectures, homework assignments, and laboratory experiments. While effective in delivering fundamental theory, this approach provided limited opportunities for students to integrate multiple course topics within a comprehensive design context.

The purpose of this paper is to present the creation and implementation of a class design project in our Mechanics of Materials course and to analyze student survey data and qualitative feedback. The project was developed to reinforce core Mechanics of Materials concepts while promoting active learning and engineering design skills.

2. A newly developed class design project

Concise summary of our mechanics of materials course

The Mechanics of Materials course at our institution is a four-credit sophomore-level course consisting of three hours of lecture and two hours of laboratory per week. It is offered after students have completed prerequisite courses such as Engineering Graphics, Engineering Statics, and Introduction to Engineering Design.

The primary textbook for our course is *Mechanics of Materials* by R. C. Hibbeler. Homework assignments are administered through the Pearson Mastering Engineering platform, which requires students to register for access. Through this platform, students are also provided with an electronic version of the textbook.

The lecture topics covered in this course are comparable to those offered at peer institutions and are summarized in Table 1. Lectures are structured to progress systematically from theory to application. Instruction begins with clear definitions of fundamental concepts such as stress, strain, and material behavior, followed by the derivation of governing equations based on stated assumptions, idealizations, and boundary conditions. These formulations are then applied to the analysis of common structural components, including bars, shafts, and beams under various loading conditions. Worked examples are presented during lectures to demonstrate step-by-step problem-solving procedures and to illustrate the practical use of theoretical models. Students are encouraged to ask questions during lectures and are occasionally invited to solve example problems on the blackboard during lecturing when volunteers are available. Homework assignments are used to reinforce learning by providing opportunities for students to independently apply theoretical concepts to representative engineering problems.

Table 1 The weekly plan of lectures and labs

Wk#	Lecture topics	Lab topics
1	Chapter 1: Stress	Lab 1: Safety, Lab equipment and reviews of Statics
2	Chapter 1: Stress	Lab 2: Compression test
3	Chapter 2: Strain Chapter 3: Mechanical properties of materials	Lab 3: Double Shearing test
4	Chapter 3: Mechanical properties of materials Chapter 4: Axial load	Lab4: Tensile tests without extensometers
5	Chapter 4: Axial load Exam 1 for ch1, ch2 and ch3	Lab 5: Standard tensile test
6	Chapter 4: Axial load	Lab 6: The virtual experiments about axial normal stress on bars
7	Chapter 5: Torsion	Lab 7: Instron torsion test on circular solid shafts
8	Chapter 5: Torsion	Lab 8: Instron torsion test on hexagon shafts
9	Chapter 6: Bending	Lab 9: Virtual lab-torsions
10	Chapter 6: Bending Exam 2 for ch4 and ch5	Lab 10-11: Design beam deflection experiment (Design part)
11	Chapter 7 Transverse shear	Lab 10-11: Design beam deflection experiment (Conduct the designed lab)
12	Chapter 8: Combined loading	Lab 12: Virtual lab on bending and shear stress
13	Chapter 9: Stress transformation	TBD
14	Exam 3 for ch6, ch7, ch8 and ch9 Reviews and Q&A	Q&A
15	Final exam period	

The laboratory consists of both physical experiments and virtual finite element analysis (FEA) simulation labs. They are listed in Table 1. Laboratory topics are intentionally aligned with lecture content, ensuring that relevant theoretical concepts are introduced prior to experimental or simulation-based exploration. The primary objective of the laboratories is to reinforce lecture material and deepen students' conceptual understanding.

Physical laboratories utilize five Instron universal testing machines for compression, shear, and tensile testing, as well as four Instron torsion testing machines. Virtual laboratories are conducted using SolidWorks Simulation to perform FEA-based investigations [11].

Brief descriptions of the laboratory activities are provided below:

- Lab 1: Safety, Laboratory Equipment, and Review of Statics
  Introduction to Instron universal and torsion testing machines, laboratory safety protocols, machine components and functions, and basic operation of the Instron Bluehill software.
- Lab 2: Compression Test
  Compression loads are applied to short cylindrical specimens of various materials to observe deformation and failure modes after normal stress concepts are introduced.

- Lab 3: Double Shearing Test
  Double shear tests are conducted on round rods of different materials to determine ultimate shear strength.
- Lab 4: Tensile Tests without Extensometers
  Tensile testing of rods and flat specimens is performed to obtain stress–strain curves and observe fracture behavior.
- Lab 5: Standard Tensile Test
  Dog-bone specimens of different materials are tested using extensometers to obtain accurate stress–strain data, particularly in the elastic region.
- Lab 6: Virtual Lab on Axial Normal Stress
  SolidWorks Simulation FEA simulations are used to verify the uniformity of normal stress across cross-sections under axial loading.
- Lab 7: Torsion Test on Circular Shafts
  Circular shafts are tested in torsion to failure, and experimental data are used to construct shear stress–strain curves.
- Lab 8: Torsion Test on Hexagonal Shafts
  Torsion tests on hexagonal bars are conducted to examine deviations from classical torsion assumptions.
- Lab 9: Virtual Lab on Torsion
  SolidWorks Simulation FEA simulations verify the linear variation of shear stress along the radius of a circular shaft.
- Labs 10–11: Design-Based Beam Deflection Experiment
  Students design experimental objectives and procedures, then conduct beam deflection tests and analyze the resulting data.
- Lab 12: Virtual Lab on Bending and Shear Stress
  SolidWorks Simulation FEA simulations are used to verify linear bending stress distributions and compare shear stress results with theoretical predictions.

A new design project for our mechanics of materials course

The Mechanics of Materials course at our institution is well established, with comprehensive lecture topics and corresponding hands-on laboratory activities. The primary objective of the course is to prepare students for mechanical design by developing a strong foundation in stress analysis and material behavior. However, despite this emphasis, the course previously did not include a design project. Student feedback consistently indicated a desire for opportunities to apply theoretical concepts to realistic design problems. In response to this feedback, a team-based design project was developed and integrated into the course.

Three key considerations guided the selection of the design project. First, the project was required to avoid overly complex structures, as students had not yet completed a machine element design course and therefore lacked the background needed for advanced component analysis. Second, the project needed to involve a typical and representative structural component commonly encountered in mechanical engineering practice, allowing students to focus on fundamental Mechanics of Materials concepts rather than excessive geometric or analytical complexity. Finally, the project was designed to include combined stress conditions and to require the development of a three-dimensional model along with finite element analysis (FEA) simulations. These criteria ensured that the project reinforced core course concepts while providing students with practical experience in modeling and computational analysis.

The design project developed for this course focused on the design of a suspender arm for a gondola lift system. The four primary objectives of the group project were to:

- Work collaboratively in teams of up to four students to complete the full engineering design cycle.
- Analyze combined axial and bending stresses in a square cross-section suspender arm using theoretical methods.
- Develop a three-dimensional model of the suspender arm and perform FEA simulations to evaluate stress distribution, deformation, and factor of safety; and
- Prepare and submit a comprehensive technical report documenting theoretical calculations, FEA results, and the overall design process.

A gondola lift is a cable-propelled transportation system commonly used in ski resorts, amusement parks, and urban environments. Each gondola cabin is suspended from a steel cable and supported by a suspender arm that connects the cabin to the cable grip mechanism, as illustrated in Figure 1. This component is subjected to combined axial and bending loads and must be carefully designed to ensure structural integrity and safety under worst-case loading conditions.

Figure 1 An example of gondola lift system (https://www.poma.net/en/product-range/detachable-gondola-lift-mountain/)

A simplified schematic of the gondola lift system used in this project is presented in Figure 2. The total weight of the gondola and passengers was assumed to be 1500 lb., acting at the center of gravity located at point G. The suspender arm, labeled ABCDE, had a square cross-section and was made of a material with a yield strength of $S_y = 90$ksi and an ultimate tensile strength of $S_{ut} = 105$ksi. The required factor of safety for the suspender arm was specified as 5. The inner bending radii at points B, C, and D were 2.5 inches. Each design team was required to size the suspender arm and perform FEA simulations to verify that the resulting factor of safety is greater than or equal to 5. If the factor of safety was less than 5, teams were required to modify their design and repeat the simulation until a satisfactory design was achieved.

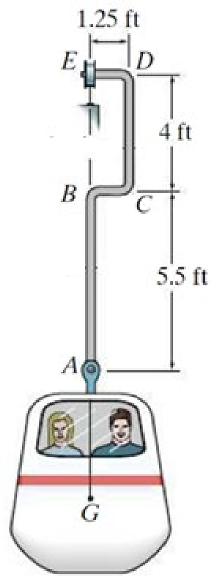


Figure 2 The simplified schematic of a gondola lift system [12]

3. Implementation of the class design project

The class design project was released in Week 10, after bending stress theory had been explained and discussed in lectures. The following preparation and support were provided to help students successfully complete the design project:

• Prior to taking this Mechanics of Materials course, students had completed Engineering Graphics, where they learned how to use SolidWorks to create 3D models and mechanical drawings, as well as how to modify SolidWorks models.

• By Week 4, students had learned how to calculate the normal stress in a bar. By Week 10, they were able to calculate bending normal stress in beams. In Week 12, they were introduced to combined stress and learned how to calculate stress due to axial loading and bending.

• In Week 2, allowable stress design (ASD) and the concept of the factor of safety were discussed. Students practiced dimensional design problems for axial bars and shafts through lectures and homework assignments.

• In Lab 6 (Week 6) and Lab 9 (Week 9), students completed two virtual labs using SolidWorks Simulation (an FEA package). The FEA package was treated as an instrument in which when sufficient inputs were provided, the different simulation results as outputs would be available. They were guided to provide inputs such as assigning material properties, applying simple constraints (such as fixed supports), and specifying basic loads (such as forces and torques). They were also guided to use standard meshing and visualization tools to display some outputs such as stress and the factor of safety results. In Lab 12 (Week 12), students conducted a virtual FEA lab on a beam subjected to bending moments and shear forces.

Therefore, students had sufficient theoretical knowledge and technical skills to complete the design project. Through this project, they applied theoretical concepts to a practical engineering design problem.

During Weeks 10 and 11, design teams were tasked with conducting a brief literature review on the history of gondola lift systems, the different types of gondola lifts, and their real-world applications. This activity significantly increased student interest in the project by helping them better understand the relevance and practical significance of the system being designed. Teams were also required to hold internal meetings to review the project requirements and develop a structured plan for project execution.

In Weeks 12 and 13, following lectures on stresses due to combined loading, students were guided through theoretical stress calculations considering axial loading only, bending moment only, and combined axial and bending loads. For theoretical analysis, students were advised to neglect stress concentration effects at the 90-degree bend locations. Using the theories presented in lectures, teams performed preliminary design calculations to determine the initial cross-sectional dimensions of the suspender arm.

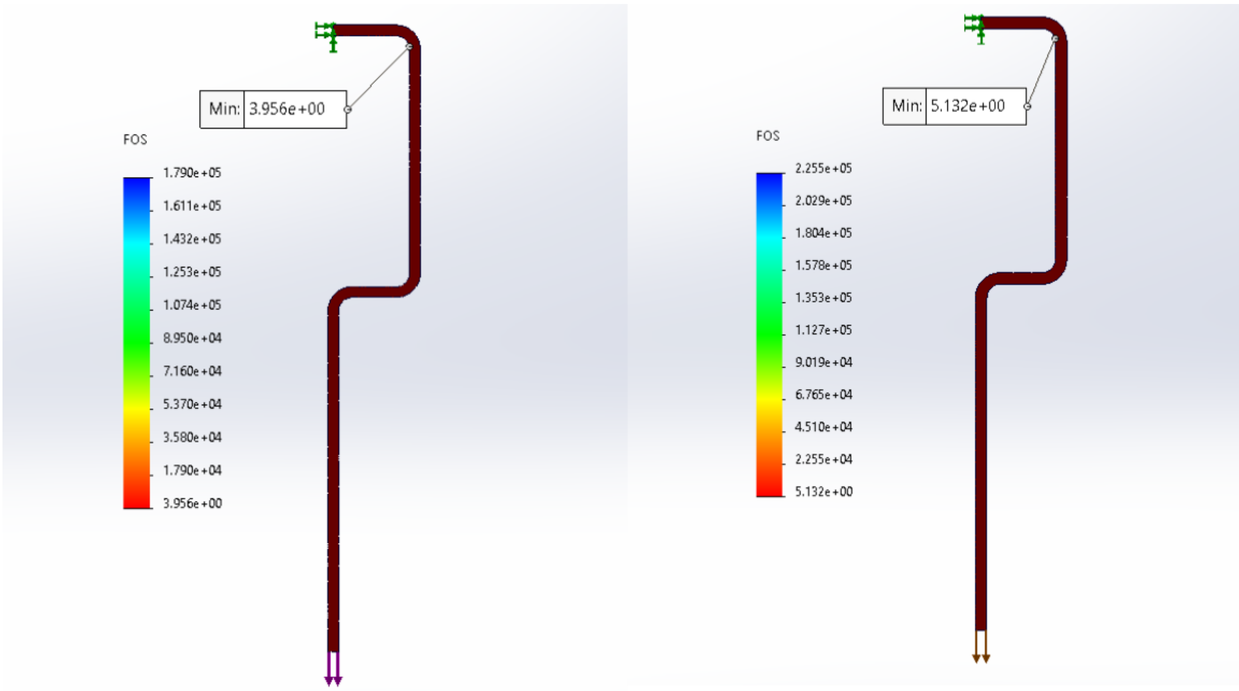
Beginning in Week 12, one lecture period per week was partially devoted to monitoring project progress, during which a 10-minute question-and-answer session was conducted. Additional support was provided through scheduled after-lecture meetings with design teams to address technical questions and design challenges.

In Weeks 13 and 14, after the initial dimension was obtained through theoretical analysis, teams developed three-dimensional models of the suspender arm and conducted finite element analysis (FEA) simulations to evaluate stress distributions and factors of safety. Because students had previously completed multiple virtual FEA laboratories (Labs 6, 9, and 12), they had sufficient experience using SolidWorks Simulation as a tool for conducting virtual FEA analyses.

Lab sessions in Weeks 13 and 14 were primarily used to conduct FEA simulations and refine the suspender arm design. Figure 3 a) shows the factor-of-safety distribution for the initial theoretically calculated dimension of 1.972”. It was a simulation result from one student design team. The resulting factor of safety was 3.956, which was lower than the required value of 5. This discrepancy occurred because stress concentration in the bending region was not considered in the theoretical calculation.

When the FEA-simulated factor of safety was below the required value, teams were instructed to modify their designs and repeat the analysis until the factor of safety slightly exceeded 5. Some teams estimated the revised dimension using the relationship between bending stress and the cross-sectional dimension of the suspender arm. However, most teams relied on a trial-and-error approach, increasing the dimension incrementally. Figure 3 b) presents the factor-of-safety distribution for a revised design with a dimension of 2.150”. The corresponding factor of safety was 5.132, which slightly exceeded the required value of 5. This dimension was used as their final design.

The project concluded with the preparation and submission of a comprehensive technical report.



a) Factor of safety distribution of initial design with dimension 0f 1.972”

b) Factor of safety distribution of initial design with dimension 0f 2.150”

Figure 3 Factor of safety distributions of the initial and the final designs from a design team

Based on interactions with the design teams and direct classroom observations, several key findings were identified:

1) Most teams demonstrated high levels of enthusiasm and engagement with the design project. Students reported that applying lecture-based theories to the design of a real structural component strengthened their understanding of course concepts.
2) Even students had completed engineering graphics course, some students experienced difficulty modifying their three-dimensional models when dimensional changes were required, indicating limited experience in creating parametric models that support efficient design iteration.
3) A subset of students struggled with the design refinement process and were uncertain how to systematically modify the geometry to achieve the minimum required factor of safety of 5.

The above phenomena are normal because they are only sophomore students. The issues will be eventually resolved in later more advanced technical courses.

4. Class survey and data analysis

At the end of the semester, a class survey was conducted to collect student feedback on the newly implemented design project. The survey consisted of five questions. The first four questions used a five-point Likert scale (Strongly Agree, Agree, Neutral, Disagree, and Strongly

Disagree), while the fifth question was open-ended and invited additional comments or suggestions. The survey questions are listed below:

1) The design project helped me better connect theoretical concepts with real-world engineering applications and increase my interest in studying this course.
2) The project facilitated me to have better understanding of Mechanics of Materials topics covered in the course.
3) We implemented theory to determine geometric dimensions, created 3D models and applied FEA simulation to verify the design results in this design project
4) Conducting a design project should be a required component of a Mechanics of Materials course.
5) Any comments or suggestions for the class design project.

Two sections of Mechanics of Materials, with a total enrollment of 38 students, participated in the survey. A total of 27 responses were received, corresponding to a response rate of 71.1%.

A bar chart summarizing the responses for Survey question 1 is shown in Figure 4. For Survey Question 1, 96.3% of respondents agreed or strongly agreed that the design project helped them connect theoretical concepts with real-world engineering applications and increased their interest in the course. One student (3.7%) disagreed with the statement.

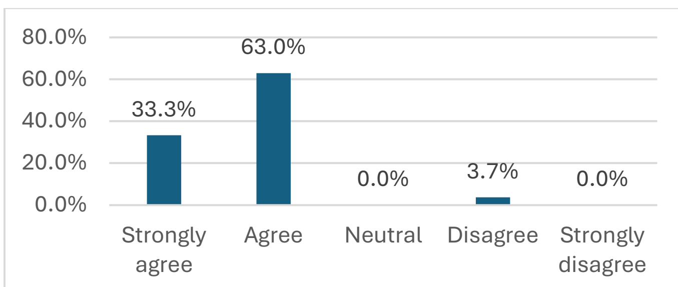


Figure 4. Distribution of responses to Survey Question 1.

A bar chart summarizing the responses for Survey question 2 is shown in Figure 5. For Survey Question 2, 85.2% of students agreed or strongly agreed that the design project improved their understanding of Mechanics of Materials topics. However, four students (14.8%) selected the "Neutral" option, suggesting that while the overall impact was positive, there was room for improvement.

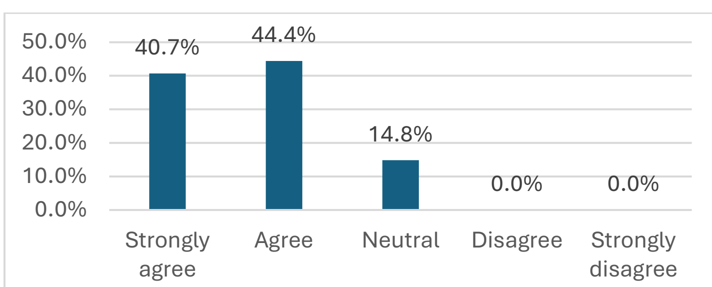


Figure 5. Distribution of responses to Survey Question 2.

A bar chart summarizing the responses for Survey question 3 is shown in Figure 6. For Survey Question 3, 92.6% of students agreed or strongly agreed that the project enabled them to apply theoretical analysis, create three-dimensional models, and use FEA simulations to validate their designs. Two students (7.4%) selected "Neutral".

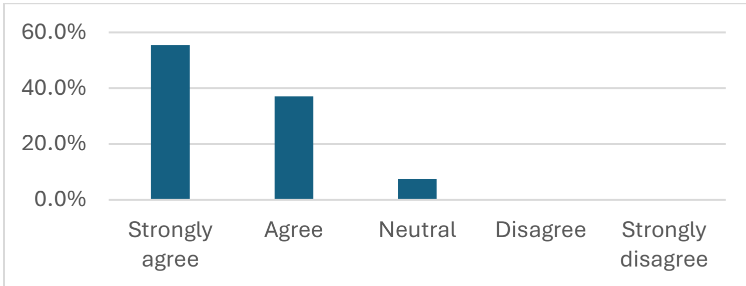


Figure 6. Distribution of responses to Survey Question 3.

A bar chart summarizing the responses for Survey question 4 is shown in Figure 7. For Survey Question 4, 96.3% of respondents agreed or strongly agreed that a design project should be a required component of a Mechanics of Materials course, with one student (3.7%) selecting "Neutral".

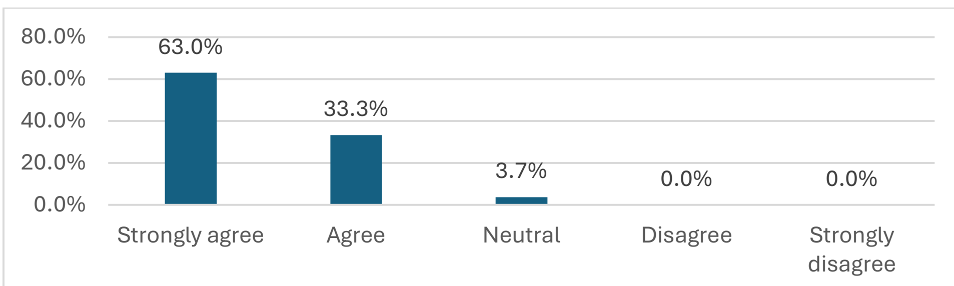


Figure 7 Distribution of responses to Survey Question 4.

In addition to the quantitative results, numerous comments were received through the open-ended question. Many comments were highly positive, including:

- "Getting to see this knowledge be applicable in the engineering design process really inspires me to continue my mechanical engineering degree."
- "I really enjoyed this project and found it a good application of the theoretical formulas we learned."
- "No suggestions—I enjoyed this project and felt it helped me tie the course into a real-world scenario while practicing tools and skills such as FEA."
- "The design project was great; it would be really cool to have a real-life simulation integrated into the class as well."

Students also provided constructive suggestions for improvement, such as:

- "More instruction on how to set up the simulation, especially boundary conditions, would be helpful. I wasn't sure where to fix the arm, and my choice may have affected the results."

- “Leave more design decisions open-ended. Instead of specifying all dimensions, provide a load and connection locations.”
- “I would suggest allowing students to choose their own project teams.”

Overall, the survey results indicate that student feedback on the class design project was highly positive. The strong levels of agreement across all survey questions suggest that the inclusion of a design project in the Mechanics of Materials course was a successful instructional enhancement.

5. Discussions and conclusions

The introduction of a class design project into the sophomore-level Mechanics of Materials course proved to be an effective instructional strategy for enhancing student engagement and reinforcing core mechanics concepts. Survey results, student comments, and instructor observations collectively indicate that the project successfully bridged the gap between theoretical analysis and real-world engineering applications, which is a central goal of mechanics education and is consistent with prior studies on project-based learning in solid mechanics courses.

Survey data showed strong student support for the design project. More than 96% of respondents agreed or strongly agreed that the project helped them connect theoretical concepts with real-world engineering systems and increased their interest in the course. Similarly, over 92% of students reported that they applied theory to determine geometric dimensions, created 3D models, and used FEA simulations to verify their designs. These results confirm that the gondola suspender arm project effectively integrated analytical calculations, CAD modeling, and computational analysis, allowing students to experience a simplified but authentic mechanical design process.

Although 85.2% of students agreed that the project improved their understanding of Mechanics of Materials topics, a small portion of students selected a neutral response. This suggests that while the project was beneficial for most students, its impact varied depending on individual background and skill level, particularly in parametric modeling and FEA setup. Instructor observations further revealed that some students struggled with modifying 3D models efficiently and identifying effective design changes to achieve the required factor of safety. These challenges highlight the need for additional instructional support, such as brief tutorials on parametric CAD modeling, design iteration strategies, and clearer guidance on applying boundary conditions in FEA simulations.

The overwhelmingly positive response to Survey Question #4, in which 96.3% of students agreed that a design project should be a required component of a Mechanics of Materials course, underscores the perceived value of incorporating design experiences at the sophomore level. Student comments emphasized increased motivation, relevance, and confidence in applying mechanical principles, while constructive suggestions provided actionable feedback for improving future implementations. Recommendations included offering clearer simulation constraints, allowing greater design freedom, and providing flexibility in team formation.

Several limitations of this study should be noted. The survey sample size was limited to two course sections at one semester, and the assessment relied primarily on self-reported student perceptions.

In conclusion, the incorporation of a design project into a Mechanics of Materials course was successful in promoting active learning, strengthening the connection between theory and practice, and enhancing student engagement. The results support the integration of design projects as a valuable pedagogical component in foundational mechanics courses and provide guidance for refining and scaling such implementations in mechanical engineering curricula.

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