The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #41090

Link Element Design for a Landing-Gear Mechanism in a Statics and Mechanics of Materials Course

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Abstract

In this work, we describe a project involving a link element design for a landing gear mechanism as part of our Statics and Mechanics of Materials I course. During this project, students are asked to design a safe and lightweight linkage that will allow the landing gear to safely and slowly retract from a vertical position to a nearly horizontal one without breaking or stretching more than 10% of its original length. This project is introduced at the halfway point of the 10-week term, at which point students are familiar with the 2D equilibrium of rigid bodies and the concepts of stress, strain, and the factor of safety. General geometry and dimensions of the testing apparatus are provided to the students along with experimental properties of Nylon 6/6, from which the linkages are laser cut. Student groups are expected to produce a CAD file of their design along with a detailed memo documenting their analysis and design process. In this paper, we will present technical details about the project along with the different approaches each instructor takes in presenting, conducting, and assessing the project in their class. We will also discuss the challenges faced by the instructors and students and present detailed student and instructor feedback on the effectiveness of this design project in enhancing student learning.

Introduction

Problem-based learning (PBL) has gained significant traction in recent decades as an alternative to the traditional learning paradigm of the student being lectured on a concept, memorizing it, and subsequently working through assigned problems to understand how to use it. In PBL, groups of students work collaboratively under the guidance of an instructor to resolve complex, realistic problems[1]. While PBL has its roots in the training of medical students, the framework that it provides fits well with the open-ended and design-oriented nature of many engineering fields. In fact, problem-based learning has been incorporated in teaching courses as varied as construction techniques[2], engineering thermodynamics[3], and multi-core programming[4], just to name a few.

By their very nature, *fundamental* engineering courses do not easily lend themselves to an integrated design or open-ended element that meaningfully enhances student learning. This is especially true in the case of Statics, where the primary learning objectives of drawing correct free-body diagrams and applying them to equilibrium equations to solve for unknowns are usually assessed through well-posed problems with unique solutions. An in-depth review of papers in ASEE's PEER repository reveals that the most common open-ended project utilized by instructors in their Statics courses involves designing, analyzing, constructing, and testing scaled model truss bridges using elements made from spaghetti[5], wooden popsicle sticks[6], straws[7], aluminum[8], PASCO sets[9], PLA (3-D printed)[10], high-density fiber board[11], balsa wood[12,13,14], and even toothbrushes and plastic knives[15]. Variations such as emphasis on a redesign component to the project exist[6,8,14] between the aforementioned cases, but they generally follow a similar template. Other instructors have implemented open-ended projects that are more unique, some of which include the static analysis of the iWalk 2.0 hands-free crutch[16], estimating canine hip forces through static equilibrium in a biomechanics course[17], and the design and analysis of a small-scale turbine with an eye towards infusing an entrepreneurial component to a Statics and Dynamics course[18].

In this paper, we present a project involving the design of a link element for a landing gear mechanism that provides a real-world application to what students learn in an otherwise traditionally taught Statics and Mechanics of Materials I course. In the upcoming sections, we will discuss the technical details of the design project, along with the different approaches that we each take to present, conduct, and assess the project. We will conclude this work by presenting detailed student and instructor feedback on the effectiveness of the project in meeting the learning objectives for the course.

Some Context on the Institution, Curriculum, and Course

The authors of this work all teach in the Department of Mechanical Engineering (ME) of Rose-Hulman Institute of Technology, a small private institution located in the Midwest. Roughly one-third of the students at our institution are ME majors. Statics and Mechanics of Materials are taught together as part of a two-course sequence in the ME curriculum. Statics and Mechanics of Materials I focuses more on traditional topics in Statics such as 2D and 3D equilibrium of particles and rigid bodies, analysis of structures, and friction while incorporating basic elements of Mechanics of Materials such as normal and shear stress and strain, statically indeterminate systems, and factor of safety. Statics and Mechanics of Materials II primarily focuses on more advanced topics in Mechanics of Materials such as shear force and bending moment diagrams, Mohr's circle, and combined loading. The first course of the sequence is offered during every quarter of the academic year, with the primary offering being the Winter quarter for ME freshmen. The Fall quarter offering of the course is usually populated by students in their first quarter at the institute who have been admitted with Calculus II at a minimum. Most of the students who take the course during the Spring quarter are either repeating the course or have fallen behind in the Calculus sequence.

Project Learning Objectives

After completing this project, students must be able to:

- *Design* a link that meets all constraints using static equilibrium analysis, mechanics of materials, and engineering judgment.
- *Use* tools such as SolidWorks, Excel, and MATLAB to aid in the design process.

- *Communicate* effectively through a memo, utilizing standard writing conventions, to make relevant claims, supported by valid reasoning and specific evidence.
- *Demonstrate* the ability to work in a team to meet goals and accomplish tasks.

Technical Details

Objective The objective of this project is for students to design a lightweight and safe link for a prototype of a landing gear mechanism, whose schematic is shown in Figure 1, that will allow the landing gear to safely retract to a specified angle.

Requirements for a successful design The link must meet all of the following constraints for it to be considered it a successful design:

- It must assemble to the landing gear mechanism via two 0.25-in-diameter shoulder screws as shown in Figure 1.
- It must initially hold the wheel-and-strut assembly in position to within $\pm 5^{\circ}$ with respect to the vertical axis.
- It must allow the wheel to be slowly lifted up and held in position at approximately 10° below the horizontal axis.
- The link cannot break or experience permanent deformation more than 10% of its original length.

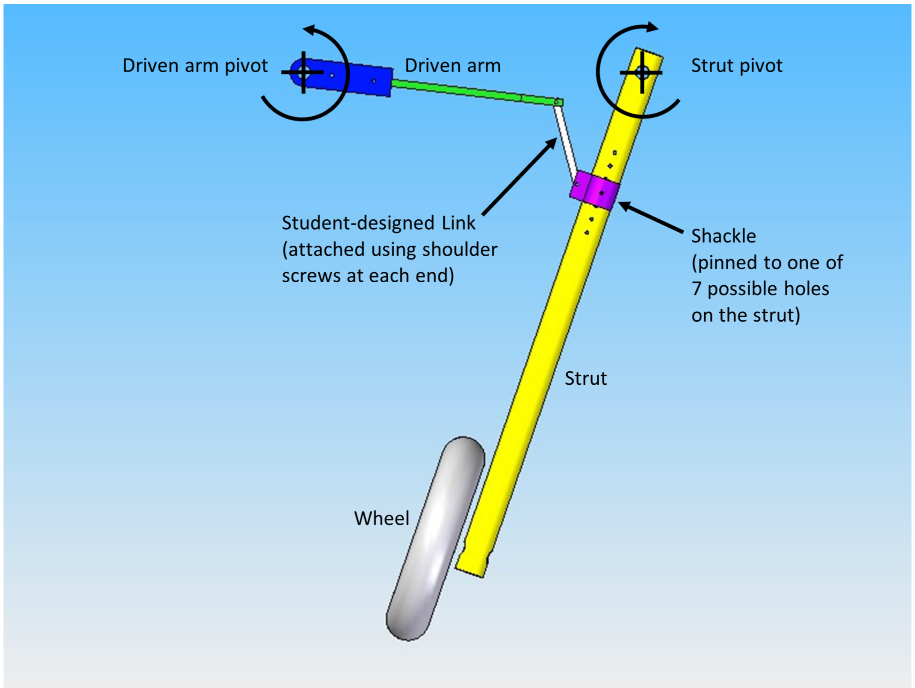


Figure 1 Schematic of the landing gear mechanism prototype. The link to be designed is shown in white.

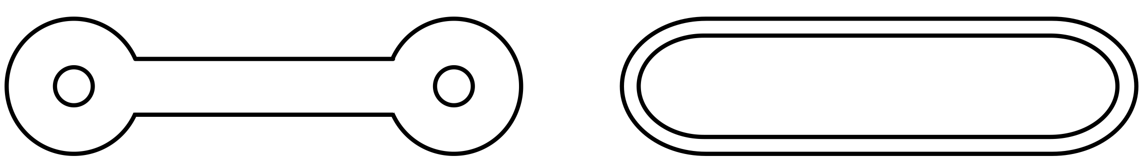
Links that pass the above requirements are subsequently differentiated based on mass, with the lightest links receiving the higher grades.

PROJECT DELIVERABLES The project is introduced to the students during a lecture period at the end of the fifth week of a ten-week quarter. Students work in groups and are required to submit the following deliverables as a team:

1. A CAD file in .dxf format defining the outline of the link and the thickness to which it should be laser cut. This deliverable is due about *3 weeks* after project assignment.
2. A printed, typed memo that summarizes the team's design, analysis, and performance, with attachments providing documentation of the analysis and design process. A memo template and grading rubric is provided to students. This deliverable is due *5 weeks* after project assignment.

DESIGN CONSIDERATIONS When designing their links, students must consider the following interrelated open-ended factors:

- **2D link profile**: Students are not mandated to use any particular type of 2D link profile. However, experience shows that even when no guidance is provided by the instructor on the profile, virtually every group of students employs either the dog bone or rubber band designs, as shown in Figures 2(a)-(b), respectively.
- **Link profile thickness**: Every link is laser cut from a Nylon 6/6 sheet by a technician, so the link material is not a design parameter. However, when submitting their CAD file deliverable, students must select their link thickness from three available options: 0.062", 0.094", or 0.124". A thinner link would be lighter, but would also experience a larger maximum stress for the same width. The tolerances associated with the laser cutting process may also be a factor in determining which link thickness to choose.
- **Factor of safety**: Students must select and report the factor of safety they employed in calculations in their final memo submission. This value must account for uncertainties in the material properties of Nylon 6/6 and using static equilibrium to calculate stresses for what is ultimately a dynamic (albeit very slow) scenario, among other factors. Since lighter links that are able to successfully meet all project requirements receive a better grade, the trade-off between risk and reward is a significant factor in the final design. Factor of safety was discussed during one day of lecture, which hopefully guides students' design choices. Each instructor lectures about unknown and uncontrollable factors that impact the function of an engineered element. Some



(a) (b)

Figure 2 Two most common link profiles: (a) the dog bone and (b) the rubber band designs.

instructors hint at deeper knowledge that students do not have yet, like stress concentrations. The project grading structure gives more points for links that survive the testing with large factor of safety than for links that fail the testing.

- **Hole location on the strut**: There are seven holes on the strut where the shackle that holds one end of the link may be positioned. The proper hole location is partially dictated by the length selected for the link such that it is able to hold the wheel-and-strut assembly in an initial position that is within $\pm 5°$ with respect to the vertical axis.

ADDITIONAL INFORMATION PROVIDED TO STUDENTS In addition to the aforementioned information, students are provided with dimensioned engineering drawings of the landing gear mechanism, the weight of the wheel-and-strut assembly and the associated center of mass location, along with tensile test data for different samples of Nylon 6/6. A list of frequently asked questions and answers relating to topics such as the tolerance of the laser cutter, size of the laser beam, minimum link size, and how to create a .dxf file from an existing SolidWorks model is also provided to students. Students are also allowed access to the landing gear setup, shown in Figure 3, during business hours until the CAD file deliverable due date for the purpose of making any additional measurements that they need.

METHOD OF ANALYSIS The crux of the analysis boils down to treating the link as a two-force member and determining the tensile force it experiences with respect to its orientation relative to the horizon by applying static moment equilibrium about the strut pivot. The relationship between the angle of the driven arm, the link, and the strut is rather difficult to determine, especially for most freshmen. There are two equivalent approaches that can be utilized to determine the relationship between these angles:

- **Vector approach**: Employing a combination of the laws of sine and cosine along with the vector sum relationship between the link vectors involved allows for the angle relationships to be determined.

Figure 3 Retraction of the landing gear setup with a student-designed link.

- **Linkage analysis approach**: The landing gear mechanism is, in essence, a fourbar linkage, where the driven arm is the crank, the link is the coupler, the strut is the rocker, and the mounting frame is the ground. Some simple linkage analysis allows for the link and strut angles to be determined as a function of the driven arm input.

Each faculty member takes a different approach with respect to presenting these methods of analysis to students. This will be discussed further in the next section.

Instructor Approaches to Presenting, Conducting, and Assessing the Project

BACKGROUND As of the 2023-2024 academic year, 11 different instructors have taught Statics and Mechanics of Materials I with the link element design project, 3 of whom are co-authors on this paper. This project has been part of the course well before any of the co-authors started teaching it; credit for its development goes to our colleagues. For the sake of simplicity, the co-authors of this paper will be assigned and referred to by a letter from here on out. Information regarding the number of sections and students who were engaged in the link element design project by each instructor and whose experiences have been documented in this section is tabulated in Table 1.

Table 1 Number of sections of Statics and Mechanics of Materials I and students taught by each co-author who included the link element design project as part of the course.

Instructor	Total number of sections (students)		
	Fall	Winter	Spring
A	0 (0)	2 (44)	0 (0)
B	3 (80)	0 (0)	0 (0)
C	0 (0)	4 (96)	0 (0)

PROJECT ROLLOUT TO STUDENTS The manner in which the project is introduced to students is fairly similar between the instructors with some slight differences.

Instructor A: The project is introduced to the students during the period that immediately follows the lecture on two-force members. By this point in the term, students are familiar with rigid-body equilibrium, normal stress and strain, and factor of safety. During this lecture, the items discussed in the **Technical Details** are presented to students in the same order that they are in this paper. This instructor does not provide any guidance to students with regards to the 2D link profile. However, the instructor gives students access to an Excel worksheet with column headers that relate to the important terms students need to consider, if they choose the vector approach. A document laying out how to analyze the fourbar linkage analysis approach using the projection method[19,20] is also provided to the students; they are, however, told that the approach will not be discussed in class and the students would have to learn it on their own. For the remainder of the lecture, students self-select themselves into groups of three and begin initial discussions on how to approach the problem and delegate tasks.

Instructor B: This instructor introduces the project in a similar way to Instructor A. The major difference is that Instructor B does not introduce fourbar linkage analysis but does include a document with some guidance on the vector approach, mainly calculating relevant geometry for the assembly that they can extend to different angles of the strut. Instructor B also assigns groups of 3-4 rather than letting students self-select, then provides additional prompting for the first day of project work. Students begin by brainstorming a list of Statics concepts that they think will be helpful during their projects. Instructor B also requests that each group be ready to show a free-body diagram by the end of the class period.

Instructor C: Motivated by a desire to minimize embarrassment for students struggling with the relevant Statics skills, Instructor C has modified the project to require individual designs at the beginning of the project but a single class average design for analysis and testing. The initial design stage requires individual students to choose a few dimensions for a dogbone link profile and provided thickness: length, body width, and outside diameter. The individual work required to arrive at these dimensions focuses on the analysis of forces, material yield strength, and the geometry during the linkage operation. The second stage is a reverse-engineering analysis of the averaged dimensions from the entire class (which is usually a reasonable design). Since there is only one class average design, all students are essentially working the same problem for their final deliverable.

The kinematic analysis of the linkage is a big task for first-year students and can introduce a variety of errors, separate from the actual Statics skills that the project is intended to exercise. Students are often overwhelmed by the geometry, even when gently guided to kinematic tools like vectors or graphical models. This two-stage approach allows students to learn from their mistakes early in the project. A wildly undersized or oversized individual design is never publicly known, allowing students to save face. By comparing their own design with the class average, students can work to understand their mistakes during the term instead of during the last week of the term after testing day. Also, an analysis of the class average design requires Statics skills but a competition-winning design requires a full consideration of the kinematics, best-case hole location, worst-case retraction angle and force, and accuracy of the laser cutter, amongst other concerns. The winning designs often have disturbingly small factors of safety, which might send a troubling message to students about engineering ethics. Simply put, the class average approach followed by Instructor C attempts to keep fundamental Statics skills at the center of the work. It also avoids the public embarrassment of a failed link on testing day that might trigger feelings of not belonging in Engineering.

MONITORING STUDENT PROGRESS The instructors maintain a similar approach to monitoring student progress.

Instructors A/B: Each group has until the middle of the eighth week to submit their first deliverable: the CAD file defining the outline of their link. Prior to this deadline, a lecture day during the seventh week is dedicated as a project work day in class for each group to make advances on their design and for the groups to interact with one another. For the most part, the instructor provides the students with virtually no help during the design process. Another lecture day at the end of the ninth week is designated as a project work day for students to work on their memo deliverable, which is due on the last day of classes.

Instructor C: Instructor C monitors student progress during three in-class project days, each with a particular objective: Find the link force, Choose the link dimensions, and Finalize the project deliverables. The first project work day occurs after students have learned rigid body equilibrium, frames and machines, and two-force members. The second project work day occurs after students have learned basics of axial normal stress, material properties like yield strength, and factor of safety. The final project work day occurs after testing so that students can finalize their analysis on work and memo.

Since Instructor C's approach does not use student teams, monitoring progress is mostly giving individual encouragement. Clarifying geometric approaches and FBDs is common early in the project. Later on, many students need help transforming the material testing data we provide into a yield strength. During the last work day, students are ready to receive help on good documentation and communication in the memo. This guidance is sometimes provided in one-on-one conversations with students who ask for help. Accounting for the demonstration day, 4 in-class periods, or 10% of the total instruction time for the course, are dedicated over the second half of the term for the students to continue to make progress on this project under instructor guidance.

PROJECT ASSESSMENT Not all the instructors assess the project in the same way.

Instructor A: This instructor treats the project as a friendly competition between student groups. "Competition Day" is held at the beginning of the ninth week of the term. Prior to "Competition Day", the instructor receives two laser cut samples of each design and weighs and measures the length of each one before distributing them back to the groups. Each group is assigned a 10-minute time slot where they are asked to bring their laser cut link and connect it to the hole location on the strut that they had considered. The instructor checks to ensure that the wheel-and-strut assembly is in an initial position that is within $\pm 5°$ with respect to the vertical axis. A member of the group then activates a switch that is connected to a motor that retracts the wheel-and-strut assembly until it is nearly horizontal. The wheel-and-strut assembly is then extended back into its original position. A group member then removes the link and hands it to the instructor to measure its new length. In one iteration of the project, students performed a tensile test using an Instron machine to determine the ultimate yield stress in the link.

The project grade, which is 15% of each student's final grade, will be based on two components of equal weight: Performance during "Competition Day" (50 points) and the memo and analysis (50 points) that each group must submit by the end of the term. The performance portion of the grade is based on whether or not the team's link passes the test and how the successful design compares to other designs in the section based on the criterion that a lighter link is more desirable:

If the link fails because...

- it does not assemble to the device: 25/50.
- it fractures at any time during the test: 30/50.

- it exceeds the permanent deformation limit after testing: 30/50.
- it holds the strut in a mostly vertical position before testing but not within $\pm 5°$ of the vertical axis, but performs successfully otherwise: 34/50.

If the link passes the test, the mass of the group's link compared to all surviving links is considered:

- Bottom third lightest in the section: 38/50.
- Middle third lightest in the section: 42/50.
- Top third lightest in the section: 46/50.
- Lightest in the section: 50/50.

The memo template and grading rubric are shown in Appendix A.

Instructor B: Instructor B holds a "Competition Day" that is similar to Instructor A's. Rather than assigning a 10-minute time slot, though, all of the students arrive at the same time and watch the competition. During one iteration of the project, this instructor organized the testing to begin with the heaviest link and progress to the lightest link so that the team which designed with the highest level of risk is the "finale" of the competition. In the most recent iteration, the order of the testing was voluntary. This instructor's rubric is also a little different, where the link's performance accounts for 30% of the grade, and the quality of their memo and analysis accounts for 70%. Instructor B's adjusted scale for the performance portion is shown below:

If the link fails because...

- it does not assemble to the device: 15/30.
- it fractures at any time during the test: 17/30.
- it exceeds the permanent deformation limit after testing: 17/30.
- it holds the strut in a mostly vertical position before testing but not within $\pm 5°$ of the vertical axis, but performs successfully otherwise: 20/30.

If the link passes the test, the mass of the group's link compared to all surviving links is considered:

- Bottom third lightest in the section: 21/30.
- Middle third lightest in the section: 24/30.
- Top third lightest in the section: 27/30.
- Lightest in the section: 30/30.

Instructor B uses a memo template identical to Instructor A, where the rubric is scaled up to account for 70% of the grade.

Instructor C: The project score structure is simplified because there is no calculation to be done about the best or worst link design. Similar to Instructor B, the point distribution between the performance and documentation elements is redistributed in this approach. The performance score comes from the class average design results: fracture = 0%, plastic deformation = 15%, failure to assemble correctly = 20%, success = 30%. The written memo and analysis of the class average design earns the remaining 70% of the project score, following a similar rubric as the other approaches but with rescaled point values.

Evaluation of the Effectiveness of the Project

INSTRUCTOR OBSERVATIONS Instructor C has significantly more experience teaching the course and utilizing the project as a part of it compared to Instructors A and B. Because Instructor B's observations are tied to the student feedback, their impressions are presented in the **Student Feedback** section.

Instructor A: Since nearly all students take the Statics and Mechanics of Materials I course in their freshmen year, this project is the first time they are exposed to design as part of a group in their academic career. As such, there are elements of the project, particularly during the analysis and writing of the memo, that require more hand-holding on the part of the instructor. Teaming conflicts occasionally occur, but surprisingly, group dynamic issues have been far less prominent for this project than in the other courses that this instructor has taught. To gain some perspective on team dynamics, this instructor has a prompt at the end of the final exam asking the student how they would divide up a $\$1,000$ bonus for the work done on the design project amongst the members of the group. In this instructor's experience, very few students indicate a significant deviation from an equal distribution of the bonus. With regards to the project itself, most students really enjoy "Competition Day". There is genuine excitement as the landing gear retracts, particularly when a group took more risk and went for a lighter link design. Students cheer for one another (at least, outwardly!) and those whose links break during the retraction receive compassion from their fellow students. The competition aspect of the project is certainly one that this instructor will keep for future terms. As mentioned earlier, students were able to determine the true ultimate yield strength of their sample via a tensile test. The instructor found this to be a valuable experience for the students, although the time commitment required made it difficult to repeat again. All in all, this instructor cannot imagine teaching this course without this project component. It neatly integrates many of the topics taught during the term, there is a genuine design element involved, and the goodness of the design is then evaluated through a test.

Instructor C: One of the secondary benefits of Instructor C's approach is that grading the student work is easier, since the class average design has only one correct analysis. Initial sorting of the student submissions can be done based on predicted link force and estimated factor of safety, both primary results in the memo. Not needing to recalculate the kinematics for each link length and hole location is a significant time saver.

Testing day is not as dramatic in this approach. To add back some of the missing excitement, without embarrassment to students, Instructor C usually tests a FOS = 1.0

design after the class average link has been tested. It usually looks quite undersized compared to the class average link. If this edge-case design does not fail during the described test, students usually enjoy seeing it fail with an increased load or slight dynamic loading.

It's difficult to say if the objective of removing student embarrassment is achieved without a qualitative study. Or if the feeling of not belonging in engineering ever really was a threat to students whose links varied dramatically from the common designs. Such qualitative work might be taken up in the future.

STUDENT FEEDBACK The course instructors have received feedback about the project from their students through course evaluation comments and surveys.

Instructor A: This instructor received only four comments about the project in their course evaluations, all of which have been presented below verbatim:

- *The project also helped me to practice these skills and apply them to a real-life situation, which I felt was very helpful.*
- *The project is a great example of engineering in the real world. There are a few problems with it, but I think it is one of the course's greatest strengths, allowing students to put their knowledge to work and design something.*
- *The project showed some real life application.*
- *Maybe a little bit more guidance is needed on the project. I feel like by talking with different teams, there were a lot of different approaches all yielding different values. It would be nice to know a bit maybe after the link test how to use the theory to find the values.*

From these comments, it is clear that the students appreciate the real-world application of the theory that they learn in class through this design project, although more can be done on the part of the instructor to highlight the fact that a genuine design project does not have a unique solution.

Instructor B: Here are several comments pertaining to the project from this instructor's course evaluations:

- *I love the final project we had so we could apply the topics we learned into practicality.*
- *Students worked in groups to complete a design project in the latter half of the quarter. It was nice to be able to apply course material in a tangible manner.*
- *The project was a good way to use the knowledge gained in class in a slightly more realistic way.*
- *I wish the project for the class was more engaging. We had almost four weeks to complete not that hard of a project. I became not as engaged with the project towards the end. In the future, I hope the project is different and more interesting for students.*

> *However, I did enjoy their [sic] was a project in the course because it allowed us to apply the skills we learned.*

Instructor B's students generally seemed to appreciate the realistic context of the project but with one student expressing that it was not very engaging. While this student's opinion could be uncommon, it may be worthwhile to collect feedback from students specifically asking if the project was engaging and/or added value to the course.

During the Fall 2023 iteration of the course, Instructor B distributed a survey to gather feedback from students about their experiences with the project. The survey contained the following seven items, where Items 1-3 request Likert-scale ratings from 1 (Strongly Disagree) to 5 (Strongly Agree), and Items 4-7 are free response.

1. Completing this project required the use of engineering reasoning.
2. I used concepts I learned in Statics to complete this project.
3. I did a better job designing this link than I would have done without the knowledge I gained in Statics.
4. List at least three concepts you learned in Statics this quarter that were important for your project.
5. Did you draw on knowledge from other classes to complete the project? If so, explain below.
6. If applicable, compare this project to other design projects or engineering competitions you've done in the past. (*e.g.*, How was it similar, and how was it different? Was it more/less challenging?)
7. Did the competition element of the project add value? Explain below.

A summary of the responses to Items 1 through 3 are provided in Table 2. Note that no students selected the responses "Strongly Disagree" or "Disagree" for any of the questions, so these options are eliminated from the table. Based on the responses in Table 2, the project seems to contribute a valuable challenge since almost all students agreed that they needed to use engineering reasoning and statics concepts skills to complete the project successfully.

Table 3 contains a summary of students' responses to the Item 4 prompt, "List at least three concepts you learned in Statics this quarter that were important for your project." They are ranked from most to least common responses, where the number of students who listed that particular item are shown in the second column. Responses that only appeared once are not included.

The four most common responses make sense in the context of the approach many students in Instructor B's class used to complete the project. Free-body diagrams (FBDs) and static equilibrium (sum of moments) are probably high on the list because many students began their project by drawing a FBD of the combined strut and wheel, then using an equilibrium equation which summed moments about the strut pivot (labeled in Figure 1) to calculate the force in the link for various angles of the strut. They then used stress calculations, material

Table 2 Summary of responses to Likert-scale prompts $N = 35$

Prompts	Neutral	Agree	Strongly Agree
Item 1: Completing this project required the use of engineering reasoning.	1	12	22
Item 2: I used concepts I learned in Statics to complete this project.	0	14	21
Item 3: I did a better job in designing this link than I would have done without the knowledge I gained in Statics.	0	10	25

Table 3 Summary of responses to Item 4

Concept	Number of students
Stress/Strain	19
Static Equilibrium (Sum of Moments)/Moments	17
Factor of Safety	15
Free-Body Diagrams	11
Yield Strength/Material Properties	7
Deformation	7
Static Equilibrium (Sum of Forces)	5
Static Equilibrium	5
Two-Force Members	4
Axial Stress/Loading	4
Vector Math	2
Shear Forces/Stress	2

properties, and a factor of safety of their choosing to help them determine an appropriate cross-sectional area for their link.

In response to the question, “Did you draw on knowledge from other classes to complete this project?”, 31 out of 33 respondents indicated that they did. The most common skill that students reported using from another class was computer-aided modeling in SolidWorks, a skill that most students were learning concurrently with Statics. Some students also highlighted the use of programming skills in MATLAB. The MATLAB-focused course normally occurs a little later in the curriculum, and so fewer than half of the students had the requisite knowledge to use MATLAB for their projects. Still, it is encouraging that those with MATLAB experience recognized it as a useful tool for repeating geometry and force calculations for different angles of the strut. Other commonly cited courses included physics and various levels of mathematics classes, primarily those involving trigonometry and vector math as well as courses for which they had used Maple to perform calculations.

When asked to compare this project with other design or engineering projects they'd done in the past, 21 respondents indicated having done other design or engineering projects in the past. Nine of those students thought that the statics project was more challenging than previous projects, and three said that the statics project was less challenging than previous projects. The remaining respondents did not explicitly mention the level of challenge but compared the features of the statics project and past projects. The main differentiating quality that respondents highlighted was that the link design project was more mathematically precise or rigorous than similar projects they have done in the past. Prior experiences primarily relied on a "guess and check" method to test design quality, an approach they found ineffective for designing their links. Several written responses to the question are shown below:

- *It was different in that we had to explain, in detail our design process, and there were specific numeric constraints for success and failure past "did it break?" It was harder because we had to actually calculate forces, angles, and sizes rather than guessing or eyeballing it.*
- *This project was very challenging to approach it from a more analytical view rather than "guess and check." I've been taught and have used "guess and check" all throughout high school and especially in First Robotics.*
- *I did a balsa wood bridge competition & this was more challenging. I think a lot of it came from the need to be more precise. The bridge needed good structure but I didn't run any calculations. The link had to be proven efficient.*
- *This was the only project I've done before relying on your own math for creation of the final product.*

In response to the question, "Did the competition element of the project add value?", 25 students indicated that it did add value, 3 indicated that it did not add value, and the remaining 5 responses were a mix of positive and negative features of the competition experience. Overwhelmingly, the most common reason students cited for valuing the competition was that it created a necessary incentive for them to try optimizing their design. In a similar vein, some students indicated that the added incentive actually forced them to use statics knowledge to complete the project rather than simply choosing a heavy but safe design. Also common was the impression that the competition was fun, exciting, or rewarding, and students enjoyed seeing the different links all their classmates had created. Some respondents also mentioned that the competitive aspect made the project feel more real and meaningful. For those who thought the competition did not add value or had mixed feelings, the most common reason was that the grade-based incentive to create a better design than other teams was not actually that attractive given that they could still score reasonably well on the project by creating a heavier design with a greater likelihood of success. Below are a few representative responses from survey respondents:

- *Yeah, it just made it a little more fun and pushed a little to have the best link you could.*
- *Yes, there were stable models that were guaranteed to work but had a significant amount of mass due to the factor of safety. The competition drove us to find the most*

optimal, not just the one that worked within the parameters.

- *It absolutely made it more interesting. I do wish my design could've been more competitive. Balancing confidence and competitiveness with the impact it would have on our grade was hard.*
- *Yes because it made the project more realistic, and forced our group to actually calculate the optimal link instead of just going as safe as possible.*
- *Personally, it did not. The concept is good, but if your grade in the class is already good, 6 points will not matter too much.*

Instructor C: This instructor received only four comments about the project (out of 48 students enrolled) in their most recent course evaluations, all of which have been presented below verbatim:

- *... the way the professor set up the class project was unusual and different from other statics professors.*
- *He completely ruined the final project for the class. By creating a class average of the link design there is no pride or enjoyment in the final project. Please ... let every person create there [sic] own link or at least have groups.*
- *Group projects instead of full class project would be an improvement.*
- *The project was a bit confusing to know what to be done, but after having it explained a bit more one on one I understood what to do.*

Clearly there are a few students who prefer the project approach taken by other instructors. Of the four relevant comments, only two are specifically critical. Such critical feedback might be coming from competitive-minded students who would have been enthusiastically motivated by competition. Another possibility is that some students lost motivation when their link was averaged into the class link, disconnecting them from the creative process. Yet, students who might have felt like they did not belong when their link was substantially oversized or undersized might not be able to articulate this perspective in the course evaluations. These are significant concerns to balance. What works for some students does not work for all. Creating a class environment and assignment structure that maximizes learning for everyone continues to be a challenge when teaching students with different motivations and experiences. A possible improvement is for Instructor C to explain the reasoning behind their class average project approach.

Conclusions

We have presented the technical and logistical details of a linkage element design project for a landing gear mechanism that is an important component of our Statics and Mechanics of Materials I course in this paper. We have also discussed the similarities and differences in our approaches to the project along with a detailed assessment of its effectiveness from our experience and that of the students. On the balance, student feedback and our own observations suggest that this project provides a positive learning experience for most students even with our differences in implementation.

While this is the design project that has been most commonly utilized in this course over the past decade, it is not the only one. Variations on this project have included designing a linkage element for a can crusher or a weightlifting mechanism. Regardless of the application, the underlying combination of treating the element as a two-force member and combining the concepts of static moment equilibrium, normal stress, and factor of safety is shared between these projects. We would be happy to share more information with any reader who is interested in implementing any of these projects in their class.

References

[1] D. E. Allen, R. S. Donham, and S. A. Bernhardt, "Problem-Based Learning," *New Directions for Teaching and Learning*, vol. 2011, no. 128, pp. 21–29, 2011.

[2] J. G. Sullivan, "Integrated Problem-Based Learning: Framing Cube," in *2012 ASEE Annual Conference & Exposition*, (San Antonio, Texas), ASEE Conferences, June 2012.

[3] B. Ramadan and K. Nasr, "Implementation of Problem Based Learning into Engineering Thermodynamics," in *2005 Annual Conference*, (Portland, Oregon), ASEE Conferences, June 2005.

[4] W. Zhang, "Problem Base Learning of Multi Core Programming," in *2010 Annual Conference & Exposition*, (Louisville, Kentucky), ASEE Conferences, June 2010.

[5] C. G. Drake, "A Low-Cost Project Course to Enhance Learning in a Statics and Strength of Materials Course," in *2011 ASEE Annual Conference & Exposition*, (Vancouver, BC), ASEE Conferences, June 2011.

[6] X. Le, R. L. Roberts, G. G. Ma, and H. Connors, "A Team Build-Test-Redesign Project in an Engineering Statics Course," in *2020 ASEE Virtual Annual Conference Content Access*, (Virtual On line), ASEE Conferences, June 2020.

[7] G. Chang and W. Peterson, "Bridge Design Project: A Hands On Approach to Statics and Strength of Materials Learning," in *2009 Annual Conference & Exposition*, (Austin, Texas), ASEE Conferences, June 2009.

[8] M. Pike, "Design and Test Project in a Statics Course," in *1996 Annual Conference*, (Washington, District of Columbia), ASEE Conferences, June 1996.

[9] S. Liu, "Implementing Project-Based Learning in Physics and Statics Courses," in *2014 ASEE Annual Conference & Exposition*, (Indianapolis, Indiana), ASEE Conferences, June 2014.

[10] N. A. Brake and F. A. Adam, "Integrating a 3-D Printer and a Truss Optimization Project in Statics," in *2016 ASEE Annual Conference & Exposition*, (New Orleans, Louisiana), ASEE Conferences, June 2016.

[11] L. Fredette and M. Kennedy, "Work in Progress: Reformulation of a Truss Competition Course Project to Improve Educational Outcomes," in *2022 ASEE Annual Conference & Exposition*, (Minneapolis, MN), ASEE Conferences, August 2022.

[12] N. DeJong, K. V. Treuren, D. Farris, and C. Fry, "Using Design to Teach Freshman Engineering," in *2000 Annual Conference*, (St. Louis, Missouri), ASEE Conferences, June 2000.

[13] R. A. Marlor, "Incorporating a Truss Design Project into a Mechanics & Statics Course," in *2007 North Midwest Section Meeting*, (Houghton, MI), ASEE Conferences, February 2021.

[14] R. A. Marlor, "A Design Project for a Mechanics & Statics Course," in *2011 ASEE Annual Conference & Exposition*, (Vancouver, BC), ASEE Conferences, June 2011.

[15] M. Hennessey, “Statics and Dynamics Projects Emphasizing Introductory Design and Manufacturing,” in *2008 Annual Conference & Exposition*, (Pittsburgh, Pennsylvania), ASEE Conferences, June 2008.

[16] E. Treadway, J. E. Swenson, and A. W. Johnson, “Open-Ended Modeling Group Projects in Introductory Statics and Dynamics Courses,” in *2021 ASEE Virtual Annual Conference Content Access*, (Virtual Conference), ASEE Conferences, July 2021.

[17] K. Billiar and K. A. Marengo, “Canine Hip Forces: The Ups and Downs of Project-Based Learning of static equilibrium,” in *2017 ASEE Annual Conference & Exposition*, (Columbus, Ohio), ASEE Conferences, June 2017.

[18] J. Kadlowec, M. Amadoro, and A. Osta, “A Statics and Dynamics Project Infusing Entrepreneurial Mindset,” in *2021 ASEE North Central Section Conference*, (University of Toledo, Ohio), ASEE Conferences, March 2021.

[19] E. Constans, K. Dyer, and S. Sangelkar, “A New Method for Teaching The Fourbar Linkage and its Application to Other Linkages,” in *2019 ASEE Annual Conference & Exposition*, (Tampa, Florida), ASEE Conferences, June 2019.

[20] J. Lahmann, B. Halsey, A. Danesh-Yazdi, S. Sangelkar, and E. Constans, “Comparison of Two Teaching Methods for Analyzing Fourbar Linkages,” in *2022 ASEE Annual Conference & Exposition*, (Minneapolis, Minnesota), ASEE Conferences, June 2022.

Appendices

A Example Memo Template and Grading Rubric

MEMO

To: Prof. *your professor's name*

From: Your Team Number (*Member Name 1*, *Member Name 2*, *Member Name 3*)

Date: *Date when the memo is due*

Re: Link Design for Landing Gear Device, Course X, Section Y

Write a coherent memo that discusses and explains your link's performance by addressing these questions at minimum. Clearly communicate what your team did and convince me that you knew what you were doing (at least in hindsight). Do not exceed one page.

Results. Did your link survive or fail on testing day? If your link survived, how did it place in the mass ranking? If it failed, how did it fail (fracture, elongation, failure to assemble)? If your link failed, what was the reason (incorrect technical analysis, FOS chosen to be too small, incorrect assembly measurements)?

Design Process Summary. Describe your link design process and general approach. Did you attempt to design the lightest link or a "safe" design? How did you choose an assembly hole? How did you choose the rough link shape? How did you choose the thickness? What material properties did you use for your calculations? Include the force you predicted your link would carry (even if it was incorrect). Reference your attachments for the work documentation showing the complete engineering analysis performed, but do not talk through your equations. This paragraph should make sense to me—being familiar with the project, but not having participated in your group discussions and decision-making process.

Suggested Design Modifications. If you were to redesign the link, how would you approach the analysis differently? Were there important concerns that you should have considered? What did you assume about the link manufacturing and testing conditions that was not correct? If your analysis was flawed, did your mistake result in a design that was safer or less safe?

Signatures

Expected attachments & grading rubric

General notes:

- The memo must be typed (not handwritten).
- Attachment 1 must be created in a drafting package. Hand-drawings are not allowed.
- Attachment 2 may be handwritten on green engineering paper if you write clearly and use sufficient space for diagrams and explanations. All assumptions must be clearly stated. Illegible or poorly documented work will be considered missing.
- Each attachment must start on a new page and have a clear title.

Link geometry details (attachment 1)

A fully dimensioned engineering drawing of the link, including thickness and material specification. This should be printed on white paper from SolidWorks or a similar drafting package. This is NOT the dxf file you submitted to get the part cut on the laser cutter.

Link engineering analysis details (attachment 2)

A complete engineering analysis of the expected loads on the link and the calculations used to decide the link dimensions. Clearly stated system boundaries and FBDs are expected. Show your FOS for failure in the main link body as well as near the holes. Use sentences, paragraphs, and appropriate equilibrium equations, *as if you were writing an example problem in the textbook*. Give enough detail for someone to understand how you arrived at your link design and why you made your design choices—use words, phrases, annotations, and sentences. No design decisions should be made without justification.

Grading rubric

Memo [12 pts]	[0] Memo is missing or substantially incomplete. Poor or rushed attempt.	[4] Parts of the memo make sense, but some expected information is missing.	[8] Memo makes sense with mostly clear writing. All expected information is included.	[12] Memo makes sense with clear writing. All expected information is included.
Attachment 1 [8 pts]	[0] Link geometry not shown, or hand-drawn.	[4] Link geometry shown with an attempt at relevant standards, but much is missing.	[6] Link geometry given according to relevant standards, almost sufficient for manufacture.	[8] Link geometry given according to relevant standards, sufficient for manufacture.
Attachment 2 [30 pts]	[6] Explanation barely attempted, appears to be scratch work, or fundamental technical errors exist.	[14] Explanation of link analysis and design is lacking, moderate technical errors exist. Or very unclear handwriting.	[22] Good-quality explanation of link analysis and design, but something's unclear or a small technical error exists.	[30] Textbook-quality explanation of link analysis and design. Correct technical analysis.