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Exploring Experiential Assessment in Mechanics of Materials: A Departure from Traditional Examinations

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Abstract

Mechanics of Materials is a pivotal junior-level course that is essential for various engineering disciplines (including Civil, Mechanical, Material Science, Biomedical, and Manufacturing Engineering) at the University of Connecticut. The class had an enrollment of 130 students in the Fall of 2023. This course is being conducted in a state-of-the-art active learning classroom, distinguished from traditional lecture halls by its setup, featuring 34 six-seat tables with rolling chairs, accommodating up to 204 students. This unique environment fosters hands-on activities and efficient interaction between students and instructor. This research aims to shed light on the potential of experiential learning assessments in enhancing engineering education and accommodating diverse learning needs.

The Mechanics of Materials course underwent a substantial redesign in the Fall of 2020, focusing on inclusive teaching methods to support neurodiverse learners. The adoption of experiential learning empowers students to apply theoretical knowledge in real-world scenarios, thereby deepening their comprehension of complex engineering concepts [1]. This approach effectively bridges the gap between theory and practice.

To cater to diverse learning preferences, facilitate visualization, promote real-world applications, and implement experiential learning, a variety of methods have been integrated over the past decade in this course. These methods include augmented reality (AR), discussions using real-world example pictures, and interactions with physical models—both through student engagement and instructor demonstrations.

Research has indicated that some students may not fully demonstrate their learning within the constraints of standardized exams [2]. Traditionally, the course has employed standard exams in which students answer four textbook-based problem-solving questions within a 60-minute timeframe. This study aimed to replace one of the traditional midterm exams with an experiential assessment to explore the impact on students' performance and their preference for this format over the traditional setting. In this experiential assessment, students were tasked with designing and building a built-up beam using foam materials and sewing pins during the exam (60 minutes). The objectives of the exam encompassed calculating the loading of a beam from a floor plan, drawing shear force diagram, bending moment diagram, recognizing maximum shear force and bending moment on the beam, determining beam section properties, reporting the maximum normal stress due to bending, and specifying the fastening tools (pin spacing) in response to shearing stress in beams. Finally, the students assembled the beam and submitted both calculations and the physical model. Several exam versions were distributed at each table to deter cheating.

The effectiveness of this experiential assessment was studied by comparing the distribution of exam grades within this class cohort (the experiment group) and previous cohorts (the control group). An anonymous survey was conducted during the Fall of 2023 semester to gather student feedback on this innovative assessment method and its effectiveness in showcasing their

knowledge. The implementation method for this experiential exam and findings of the survey are shared and discussed in this paper.

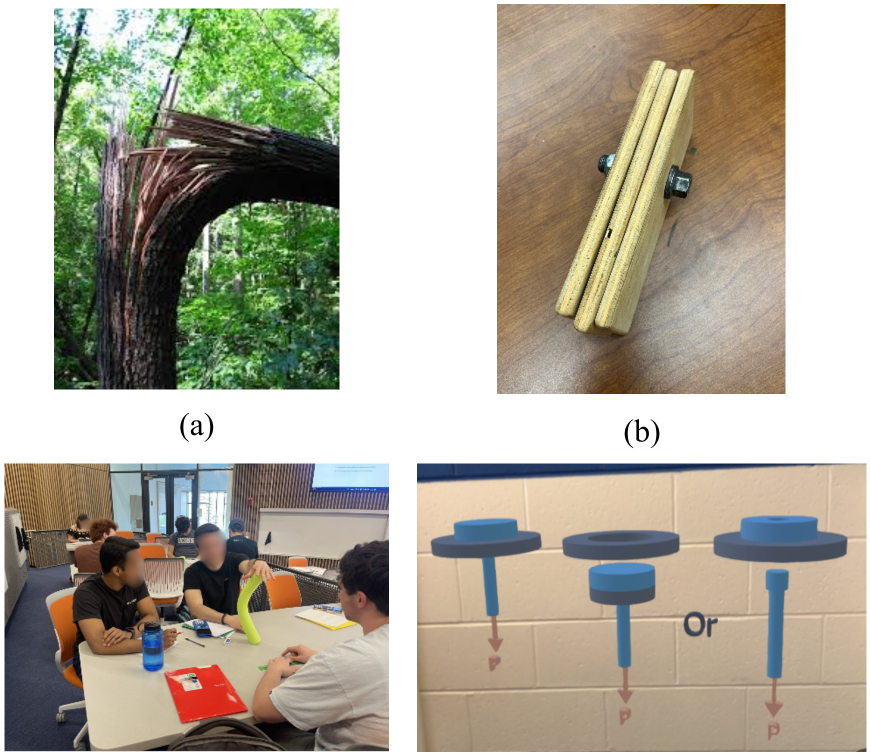
Background

Mechanics of Materials is a required course for several engineering majors, including Civil, Mechanical, Biomedical, Material Science, and Manufacturing Engineering. It is typically taken by sophomores or juniors. Each section of the course usually has between 100 to 130 students, with a total of around 400 students taking the course each academic year.

In this course, students learn different methods to calculate stress and strain in structural elements like beams, columns, and shafts. The course is delivered in a "flipped" format, where each topic is covered through two videos: one explains the concept and the theory, and the other shows how to solve 2 or 3 problems step by step. Each class is 50 minutes long, and it meets three times a week. Class time includes a brief lecture from the instructor about the day's topic and related real-world examples, followed by a session where students solve problems.

In the summer of 2020, the Mechanics of Materials course was chosen to undergo a redesign as part of the "INCLUDE, Beyond Accommodation: Leveraging Neurodiversity for Engineering Innovation" research project. This project was supported by the Engineering Education Centers of the National Science Foundation. Its goal was to revolutionize engineering education and foster an inclusive environment that supports learners with neurodiversity. While universal design principles can make courses accessible to everyone, additional measures are needed to make them inclusive for neurodivergent students [3]. This involves enabling students to recognize and apply their unique abilities within engineering. Research has indicated that neurodivergent students, including those with ADHD, dyslexia, and autism, often excel in visualization, spatial thinking, and hands-on activities [4], [5], [6],[7]. Previous findings suggest that the ability to accurately visualize objects in three dimensions (3D) enhances spatial understanding, which is crucial for success in engineering fields [8], [9]. This skill not only helps students grasp material more effectively but also boosts their creativity. One method to improve visualization and spatial abilities is to provide students with chances to use handheld models [10].

The course instructor employed a variety of methods to enhance visualization and hands-on experiences, as shown in Figure 1, which highlights some approaches used over the past six years in this class. These methods included demonstrations with foam models, the use of real-world example pictures, applying augmented reality (AR) for 3D models, and engaging students with pool noodles to explore different types of loading and to predict stress, strain, or load capacity [11], [12].



(a) (b)

(c) (d)

Figure 1. Varity of methods using visualization a) real world example of tree under bending, b) wooden model to demo double shear, c) students' interaction with pool noodle for buckling, d) augmented reality (AR) to show punching.

Student Evaluation of Teaching (SET) results from previous study [11] showed that more than 70% of students found real-life pictures helpful in their learning and said that:

> *"Real life examples showcased how theory applies in the world around us, making concepts more understandable".*

The instructor noticed that students struggled to understand the beam configuration, spacing and pattern of nails in built-up beams because they couldn't visualize it well. The instructor's previous research on using augmented reality showed that 79% of students using a 3D model felt comfortable with understanding the problem's geometry. In contrast, only 37% of students using 2D models felt the same [12].

The goal of the experiential exam was to evaluate if students could manage the entire process of designing a built-up beam, from determining the beam's load to its construction, using designated course materials. The assumption was that an experiential assessment, offering real-world scenarios, visualization, and hands-on experience, might enhance student engagement and learning. The study also explored whether students would prefer this experiential approach to a traditional examination.

This paper outlines the execution of the experiential exam, covering the required materials and exam problems, student performance and feedback, and compares the average exam scores between two groups of students: those who participated in the experiential exam (experiment group - Fall 2023) and those who underwent a traditional test (control group - Spring 2023).

Hypotheses and nature of data

This study aims to determine whether providing hands-on exam experiences can increase student engagement, enhance their learning experiences, and improve average exam scores. It does not, however, explore changes in student learning outcomes. To test this hypothesis, data from an anonymous survey filled out by participants and observations made by the instructor are presented and examined. The research methods involved the "systematic collection of information about the activities, characteristics, and outcomes of programs to make judgments about the program, improve effectiveness, and inform decisions about future development," as defined in reference [13]. Therefore, an IRB (Institutional Review Board) approval was not sought for this study.

Implementation

<u>Exam overview</u>

This hands-on exam was designed for the second part of the course, which concentrates on analyzing and designing structures subject to bending, eccentric axial loads, and shear forces.

The exam aimed to holistically design a beam within a floor plan, considering point load, distributed load, and a moment (couple) within 60 minutes. This approach mirrored a real-world project, where the outcome of each exam section informed the next. The idea was that focusing on a single, comprehensive problem, rather than four separate ones, could make better use of students' efforts and time. However, a potential downside of this method is that an early mistake could affect all subsequent parts of the exam. To mitigate the impact of such sequential errors, the exam grading focused on the correct application of concepts rather than the precise numerical results. Students were also asked to construct the designed beam with foam sheets (representing beam sections) and sewing pins (as fasteners). This hands-on part of the exam helped students verify the feasibility of their designs and whether their calculations were practical. Students could earn extra points if they could determine the maximum normal stress on the beam with an eccentric axial load on its cross section (bonus problem). In the traditional exam (spring 2023), similar exam objectives, exam policy (exam time and bonus problem) were offered. The exam objectives are detailed in Table 1. The problem statements for one version of the experiential and traditional exams are shared in Appendix A.

Table 1. Experiential exam objectives

Exam Objectives
Identifying the amount of distributed load on the beam based on the snow load (psf-pound per square foot) and the beam location on the floor plan.
Calculating reactions at the beam supports
Drawing shear force diagram
Drawing bending moment diagram

Recognizing the maximum shear force and bending moment on the beam
Locating the location of neutral axis for the given cross section
Calculating the second moment of inertia for the cross-section respect to the horizontal and vertical axes
Indicating if the beam is bent respect to horizonal or vertical axis on the cross section
Reporting the maximum tensile and compressive normal stress due to bending
Calculating the shearing force capacity of pins (fastening tools)
Designing the required pin spacing in the top and bottom flanges
Calculating normal stress due to an eccentric axial load applied on the cross section (Bonus)
Assembling beams based on given cross section configuration and calculated pin spacings

To prevent cheating in an active learning classroom where four students sit around a table, different versions of the exam were created. Each version had variations in the beam's location on the floor plan, the values and locations of loadings, the beam's cross section, the ultimate strength of the fastening tool (pin), and the factor of safety. Figure 2 provides an example of the floor plan, beam loading, cross section, and perspective. The geometry and load values were chosen to ensure that the calculated pin spacing is practical for assembling the beam.

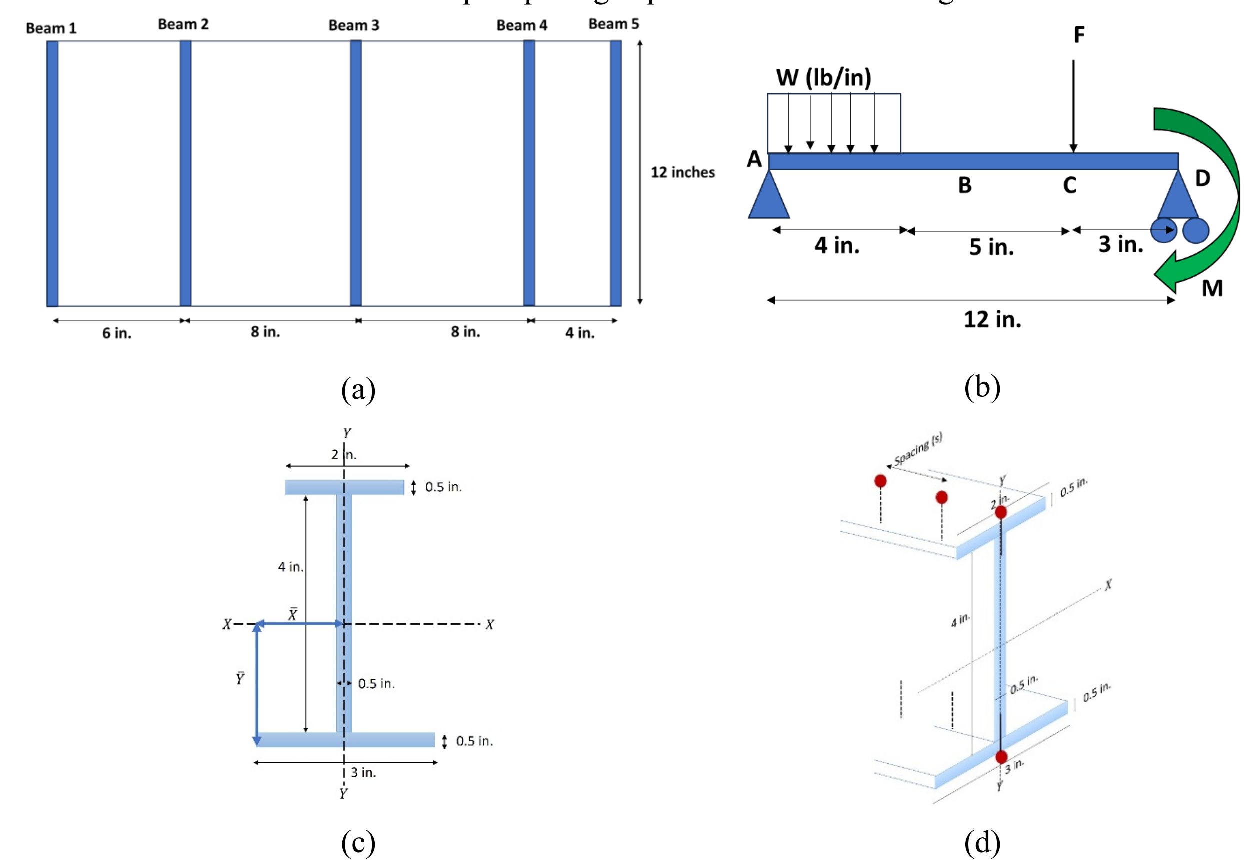


Figure 2. a) the floor plan, b) loading on the beam, c) cross section overview, d) beam perspective

The beam cross section configurations are shown in Figure 3. The cross-section properties such as location of neutral axis, the second moment of inertia, and the first moment of area were variable.

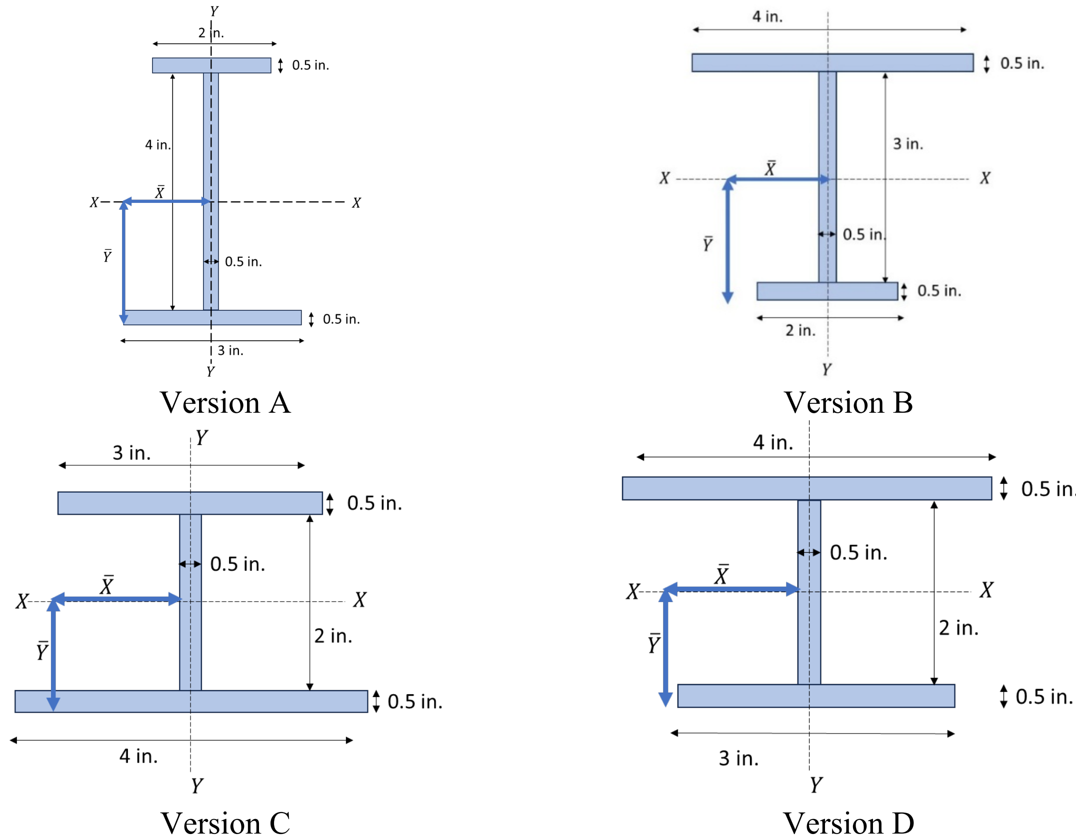
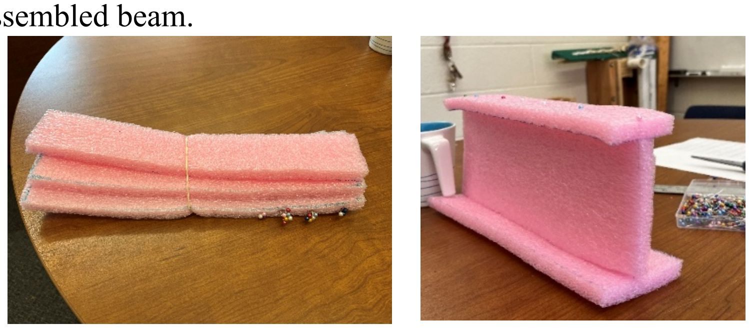


Figure 3. Beam cross sections in the versions A through D of the exam

Each student was given eighteen sewing pins and three sheets, each 12 inches long and ¼ inch thick, in varying widths of 2 inches, 3 inches, and 4 inches. Figure 4 displays the materials provided and the assembled beam.



(a) (b)

Figure 4. a) Provided kit to each student and b) final beam configuration.

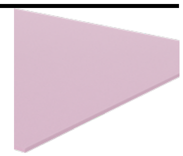
The exam consisted of two parts: the written calculations, which made up 95% of the grade, and a photograph of the assembled beam, accounting for the remaining 5%. At the end of the test, students submitted their written calculations and later uploaded the beam photo to the Learning

Management System (LMS), Blackboard. Students were informed about the exam setting ahead of time and the picture requirement using camera (cellphone).

Materials

Table 2 lists the materials used in the exam, including foam, sewing pins, detailing their quantities, costs, and images. The class had 130 students, and the total cost to supply everyone with the necessary materials was approximately $318. This breaks down to a cost of $2.45 per student. Preparing the materials, including cutting the foam sheets and assembling the material packages, took about 4 hours. Both the instructor and the teaching assistants volunteered their time for this process. After the exam, the materials were collected from the students and stored in the instructor's office to be reused in future classes.

Table 2: Amount and cost of materials (Fall 2023)

Item	Detail	Total price	Image
Cushioning Polyethylene Foam (1/4" thick)	100 sqf	$298	
Sewing Pins	2400 pins	$19.92	

Exam Preparation Resources

Since it was the first time the experiential exam was introduced, a sample exam for a different beam configuration was shared with the students to help them understand the exam format and its goals. The students could complete this practice exam and then discuss their work and get assistance from the instructor or teaching assistants before the real exam. Many students mentioned that the sample exam was very helpful in preparing and doing well on the exam. Similar resources (sample exams) were also given to other groups of students taking traditional exams in previous semesters.

Active Learning Classroom

Implementing this experiential exam was crucial in the active learning classroom setting. This classroom has thirty-four rectangular tables, each with six rolling chairs, accommodating up to 204 students. With an enrollment of 130 students, this setup allows for about four students per table. Each table features a small whiteboard, encouraging group work and brainstorming. The room is tiered across four levels, ensuring everyone can see the podium and the main screen no matter where they sit. This contrasts with traditional classrooms, where interaction is difficult for students in middle seats. In this setup, every student is easily reachable. Figure 5 displays the exam day in the active learning classroom.

Figure 5. Exam day in the active learning classroom

Results

A survey was done anonymously to get students' opinions on their experience with this hands-on exam. The survey's findings would help the instructor decide if this exam format should be used again and what improvements could be made for the students' experience and performance.

Out of 130 students, 120 took the hands-on exam, and 58 of those students responded to the survey, making the response rate 48.3%. There were 10 students in the class with approved accommodation from the Center of Students with Disability (double time for exam). It was unknown to the instructor if these students are identified as neurodivergent. The impact of an experiential exam on students with neurodiverse characteristics is being studied in a separate study (with an approved IRB) which the results will be shared in future papers.

Table 3: Students' feedback about experiential assessment

	Percentage (%)				
	Extremely Agree	**Agree**	**Neutral**	**Disagree**	**Extremely Disagree**
I was able to effectively demonstrate my knowledge about beam analysis in the Experiential Exam	34.5	39.7	12.1	5.2	8.6
I would prefer a traditional exam (4 questions from textbook) over experiential exam	6.9	17.2	31.0	31.0	13.8
The exam time (60 minutes) was appropriate for the experiential exam 2	5.2	29.3	17.2	41.4	6.9
I recommend the instructor to transform other midterm exams to an experiential format in future	12.1	32.8	39.7	13.8	1.7

Table 3 displays students' answers to questions about their preferred exam format, timing, and whether they recommend applying this experiential format to other midterm exams.

Over 74% of respondents either agreed or strongly agreed that the test format lets them show their knowledge. Around 24% of students would rather have a traditional exam, while about 45% preferred the experiential exam. Some students felt there wasn't enough time for the exam, feeling rushed or unable to finish, and calling for more time. This need for more time was echoed by over 48% of students who disagreed or strongly disagreed that the exam timing was right. The majority, 45%, agreed or strongly agreed with using experiential assessment in other courses, with only 15% opposing. Most respondents liked the format and shared positive feedback. Below are some comments from students about the test.

> *"I really liked the format. I enjoyed doing a bunch of calculations that led to the creation of a beam, rather than 4 separate questions. Translating my numbers into a real life thing actually helped me catch some mistakes I had made. The only problem with the exam was I felt I did not have enough time. I felt like I had to rush at the end. I think only 15 - 20 minutes more would be needed."*

> *"I really appreciated that I was able to go through the problem and fully analyze the case as the exam format. I find it really hard to access all the concepts that I need when looking at 4 siloed exam questions. I found it really helpful to be able to use all the concepts to work together to solve one cohesive problem with many steps. I can't think of ways that it would actually be improved."*

The survey asked students to name factors that could improve their exam scores or had a negative effect on their performance. Many students said using different study aids, such as practice exams, going to office hours, joining study groups, and watching sample solving videos, greatly helped them prepare and do well on the exam. Some students directly related their success to how much time they spent studying. Everyone agreed that the test format made it easier to understand and use the concepts being tested. The practice exam was often named as an important tool that helped students know what to expect and better understand the material.

Some students said that the exam's timing in the academic calendar made it hard for them to prepare. They had other exams or not enough time the day before the test. Many mentioned that not being able to study enough due to these scheduling problems affected their performance. There were also comments about how mistakes made early in the test negatively influenced the rest of it. They suggested a test format that makes it easier to correct early mistakes. However, it's important to note that the instructor's grading approach was mentioned positively. They did not deduct points for mistakes unless they showed a misunderstanding of the concept.

Table 4 shows the exam 2 grade range for students in two groups: those from Spring 2023 who took the test in a traditional format, and those from Fall 2023 who took it in an experiential format. Each group had the same number of students, 130, and both classes were conducted in the active learning classroom.

Table 4: Midterm exam-2 grade range for students enrolled in Spring 2023 (traditional exam) and Fall 2023 (experiential exam).

	Spring 2023		Fall 2023	
Grade Range	**Number of students**	**(%) of class**	**Number of students**	**(%) of class**
90 - 100	34	26.2	50	38.5
80 - 89	11	8.5	18	13.8
70 - 79	12	9.2	11	8.5
60 - 69	18	13.8	8	6.2
50 - 59	17	13.1	10	7.7
40 - 49	8	6.2	8	6.2
30 - 39	6	4.6	8	6.2
20 - 29	6	4.6	4	3.1
19- 10	2	1.5	3	2.3
0 - 9	6	4.6	0	0.0

In the Fall of 2023, over 38% of students who were evaluated through experiential assessment scored above 90, compared to only 26% of students who took traditional exams in the Spring of 2023. It's important to mention that the instructor's grading approach and the resources given to students to prepare for the exams were consistent between the two groups. In this grading approach, major points are given when students demonstrate the application of mechanics' concepts correctly in the exam. Students may lose a few points for numerical error in this grading scheme.

Table 5: Average and median of the midterm exam grades (exam-2) for students in Spring-Fall 2023.

	Spring 2023	Fall 2023
Average	67.1	75.65
Median	68.25	82

The failure rate (scores below 60) was 34.6% in Spring 2023, which decreased to 25.4% in Fall 2023. Table 5 reveals that the experiment group (Fall 2023) had an average exam grade of 75.65, which is 12% higher than the control group's average of 67.1. The median grade in the experiment group also saw a 20% increase. These findings suggest that experiential assessment may be a more effective method for students to showcase their learning.

Conclusion

A traditional midterm exam was switched out for an experiential assessment to see how it affected student performance and whether they preferred this new method to the usual one. In this practical exam, students had 60 minutes to design and construct a beam made of foam

materials and sewing pins. This test aimed to encourage the use of real-world examples, improve visualization skills, and provide hands-on experience in evaluating the course.
The survey results revealed that the majority of students (74%) found the experiential exam allowed them to showcase what they had learned effectively. Over 48% of students felt the time given for the exam was insufficient, suggesting that an extra 10 minutes could have been beneficial. In traditional exam setting, 60 minutes allocated time seemed sufficient. The average and median grades for the experiential exam in Fall 2023 were higher compared to those of the traditional exam in Spring 2023. Additionally, a greater number of students achieved satisfactory grades, scoring above 90 or between 80 and 90. The practice exam, office hours, and sample solution videos were identified as useful tools that helped prepare students for this exam.

Acknowledgements

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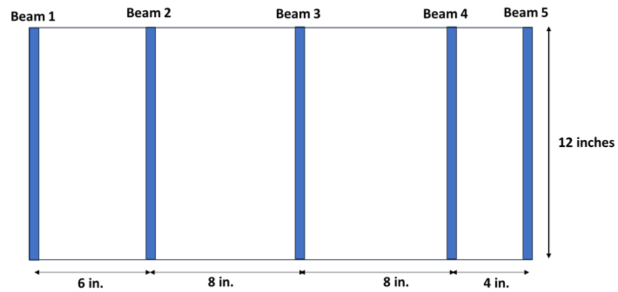
<u>**Appendix A**</u>

Experiential exam problem statements (Fall 2023)

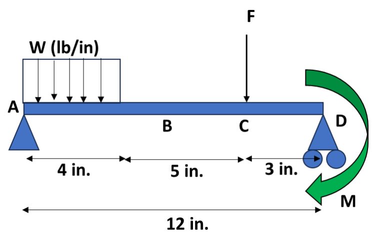
You are tasked to design Beam 1 for a floor plan below.



Top view of floor plans

a) Determine the **distributed load of W** for beam 1 if the snow load on the floor is 3 lb/in^2. [5 points]

b) Determine **reactions at supports A and D** if F=10 lbs and M=20 lb.in. Use the magnitude of W that you calculated in the previous part (part a). [8 points]

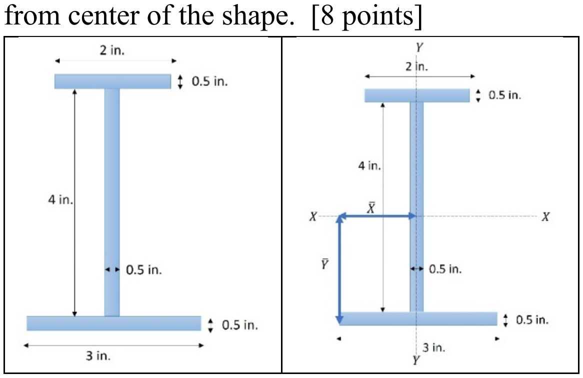


Beam 1

c) Draw **shear force diagram** for the beam. Identify the **maximum shearing force on the beam Vmax**. [10 points]

d) Draw **bending moment diagram** for the beam. Identify the **maximum moment on the beam Mmax**. [10 points]

e) For the beam cross section shown below, **calculate location of ybar and xbar** (N.A) passing from center of the shape. [8 points]



Beam cross section

f) Calculate 2nd moment of inertia respect to horizontal axis (**I_X**). [10 points]

g) Calculate 2nd moment of inertia respect to vertical axis **(I_y).** [5 points]

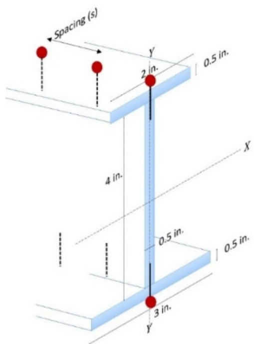
h) Indicate if the bending due to vertical loading is about x axis or y axis on the cross section. [4 points]

i) **Calculate the <u>maximum normal stress due to bending</u>** in **<u>tension</u>** and **<u>compression</u>**. Note: Use M_{max} from part d. [10 points]

j) To make this built-up beam sewing pins are used that each has diameter of 0.02 inch and shearing strength of 70 ksi. Calculate **<u>the shearing force capacity of one sewing pin</u>**. [5 points]

k) Using maximum vertical shearing force applied to the beam Vmax from part c and the shear force capacity of each pin, calculate the **<u>required spacing between pins for the top flange of beam</u>**. [10 points]

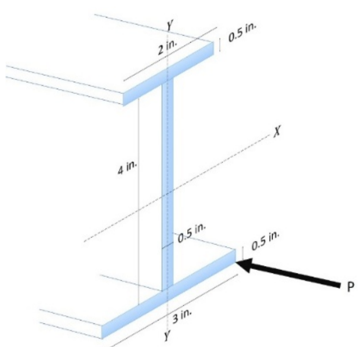
l) Using maximum vertical shearing force applied to the beam V_{max} from part c and the shear force capacity of each pin, calculate the **<u>required spacing between pins for the bottom flange of beam</u>**. [10 points]



m) Assemble your beam and **<u>take a picture</u>** of it. **<u>Upload</u>** the picture to HuskyCT under Exam-2 on the left menu by the end of the day. [5 points]**Note: Submit your calculation along the foam/pins package (the same way that you received it).**

<u>Bonus problem (5 points)</u>

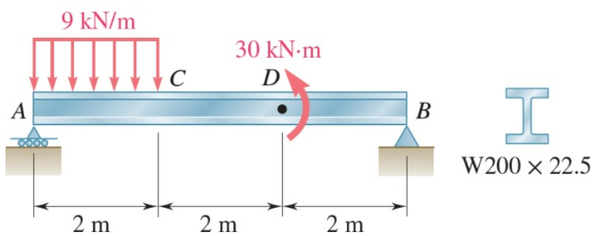
a) Assume that beam cross section is under an eccentric axial loading that is applied at the lower right corner as shown below. **<u>Calculate the maximum compressive normal stress</u>** due to this eccentric load P= 15 lbs. **<u>Does your beam fail under this stress, if the allowable normal stress of foam is 25 psi?</u>**



Traditional exam problem statements (Spring 2023)

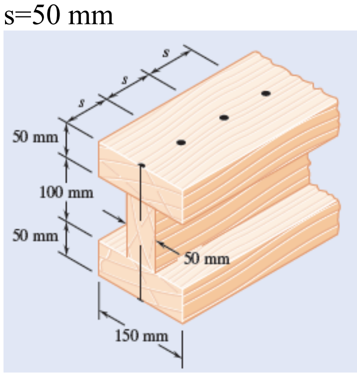
Problem 1 (25 points): For the beam shown below:

a) Draw the shear diagram.
b) Draw the moment diagram.
c) Calculate the maximum normal stress. The properties of W200×22.5 can be found in the provided table.

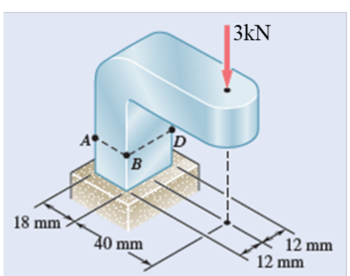


Problem 2 (25 points): For the beam shown below, determine the largest permissible shear force given the following information:

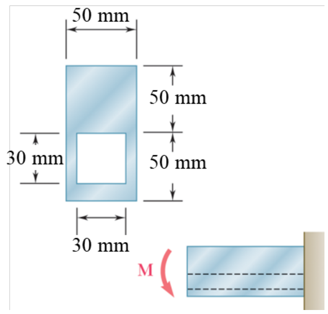
- Ultimate shear strength of nails = 90 MPa
- Factor of safety of 3
- Area of nail = 20 mm^2
- s=50 mm



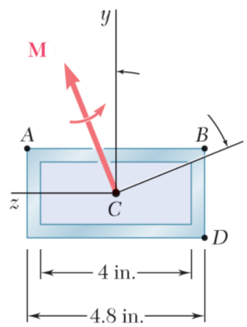
Problem 3 (25 points): Determine the stress at point A.

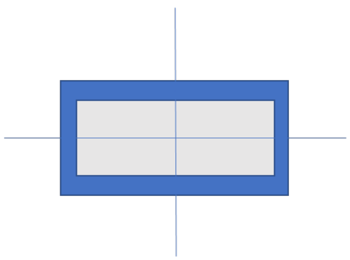


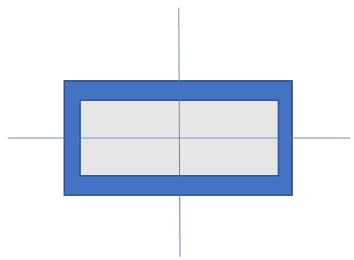
<u>Problem 4 (25 points):</u> For the extruded beam shown, the allowable stress is 120 MPa in tension and 150 MPa in compression. Determine the largest couple M that can be applied.



<u>Problem 5-1 (Optional - 3 points BONUS):</u> For the following shape, draw the Mz and My components on the blank cross sections shown and show which portions are under tension and compression. (2 pts)







a) What point experience the highest compressive stress (A, B, or C)? (1 pt)

<u>Problem 5-2 (Optional - 2 points BONUS)</u>

For the following shape subjected to vertical shear, show where you would make cuts and shade the area where you would calculate Q to find the stress at point a.