Evaluation of Augmented Reality as a Visualization Tool to Enhance Undergraduate Engineering Students' Performance in an Entry-Level Course

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Abstract

The ability to predict spatial elements based on two-dimensional figures, evaluate engineering elements, identify expected deformations, and predict possible failure mechanisms are critical for engineers. However, in applied mechanics courses, many undergraduate engineering students struggle with applying these skills to engineering problems. Previous studies have shown that three-dimensional (3D) visualization can help students to improve spatial understanding, learn material more permanently, and improve their creativity. Building on this phenomenon, interactive 3D models using Augmented Reality (AR) were incorporated in a Mechanics of Materials course. This course is an entry-level course and major requirement for different engineering disciplines including Civil, Mechanical, Biomedical, Materials Science, and Manufacturing Engineering. To evaluate the effectiveness of 3D models in students' performance, a study was conducted with students in the course. In the study, one group only had access to a traditional, two-dimensional (2D) schematic, while the other group had access to a 3D model. The experimental and control groups were then swapped for the second problem. The results of this study revealed that 3D models improve student performance. This paper reviews the design and results from the study, with the expectation that showing the impact on students' performance will help institutions add similar activities to their engineering courses to improve students learning.

Keywords: Augmented Reality (AR), 3D models, visualization skills, engineering education, postsecondary education

Background

For engineers it is critical to recognize the actual shape of elements from 2D drawings, identify potential loading scenarios on structural elements, and predict expected deformations and possible failure mechanisms. The ability to visualize and manipulate objects in one's mind is a vital skill in engineering (Metz et al., 2016). Previous studies have shown that accurately visualizing objects in 3D improves spatial understanding which has been associated with success in engineering programs (Schuchardt & Bowman, 2007). However, students often struggle with 3D visualization due to a lack of training or aphantasia (Milne et al., 2012). One option for improving visualization and spatial skills is providing opportunities for students to interact with handheld models; however, instructors often lack sufficient time or resources to facilitate student interactions with handheld models in large classes (Sorby, 2009). In recent years, virtual reality (VR) and augmented reality (AR) have emerged as promising methods of incorporating 3D visualization in the classroom (McGrath, 2019) (Duarte et al., 2020) (Mystakidis et al., 2021; Semerikov et al., 2021; Wang et al., 2018). This visualization can help students learn course material permanently and improve their creativity (Carey, 2015). The rapid advancement of new technologies — combined with the exponential increase in the computation power of personal computers and devices — has presented our education system with a unique opportunity for widespread adoptions of such creative educational methods that were out-of-reach less than a decade ago.

Experiences such as AR/VR have significant potential to transform undergraduate engineering education by providing learning experiences in which students interact with complex engineering problems in an immersive, low-risk environment (Flaig, 2017). Using AR/VR in education is an alternative option to improve learning through increased engagement and immersion (Merchant et al., 2014). Interacting with 3D models, which simulate the real-world, is an exceptionally powerful educational tool because it mimics how the human perceptual system processes real space (Steuer, 1992). While both technologies have a multitude of applications within higher education, AR is particularly attractive at an undergraduate level due to the low cost required for implementation (Papakostas et al., 2021). VR completely immerses users in a virtual world, which requires the use of a headset. Not only does this add cost, but it can be prohibitive in classes of larger size with limited meeting time and space. AR technology superimposes virtual objects upon the physical world, often using computing device with both a camera and a viewing screen (Behmke et al., 2018) (Carmigniani et al., 2011). Today, most cellphones have the hardware and operating systems required for supporting AR applications. Using readily available technology enables the widespread application of this technology in the classroom.

To build on this phenomenon, interactive 3D models using AR were incorporated in a flipped-style Mechanics of Materials course. This entry-level undergraduate course is taken by most engineering majors (Civil, Mechanical, Biomedical, Material Science and Management, and Manufacturing Engineering). To evaluate the impact of using AR models on student performance, an IRB-reviewed study was conducted with students enrolled in the course. The study compared the performance of two groups solving two engineering problems. For the first problem, one group was given a 3D AR model (Experimental Group) showing the geometry of the subject of the problem, while the other group received a 2D representation of the same problem (Control Group). For the second problem on the assignment, the experimental and control groups were swapped. A series of analytical and conceptual questions were presented to students. They also responded to survey questions at the end of each problem related to their confidence level in solving different aspects of the problems. Statistical analysis was used to interpret the results of the study.

The course targeted for implementation of AR was Mechanics of Materials, which was selected for numerous reasons including: 1) high enrollment, 2) diverse engineering disciplines, and 3) the flipped nature of the course. The flipped class — developed in 2013 — offers this opportunity to target higher learning objectives, such as analyzing, evaluation, and creation based on Bloom's taxonomy (Bloom, 1956; Herreid & Schiller, 2013). In previous course offerings, the instructor noticed that students may judge an engineering problem poorly due to lack of 3D visualizations skills. In previous years, different methods were employed to strengthen this skill including using simple foam models and displaying pictures of real-life applications of engineering topics or catastrophic designs (Motaref, 2020). While students rated the aforementioned methods positively in course evaluations, it was still challenging for some students to accurately visualize problem geometry in 3D.

As an alternative method to enhance student's visualization skills, 3D computer models, along with AR, were employed to display basic engineering concepts, real life examples, and complicated structures. AR offers the opportunity to look at the models from different views, zoom in on some parts of the structure and interact with

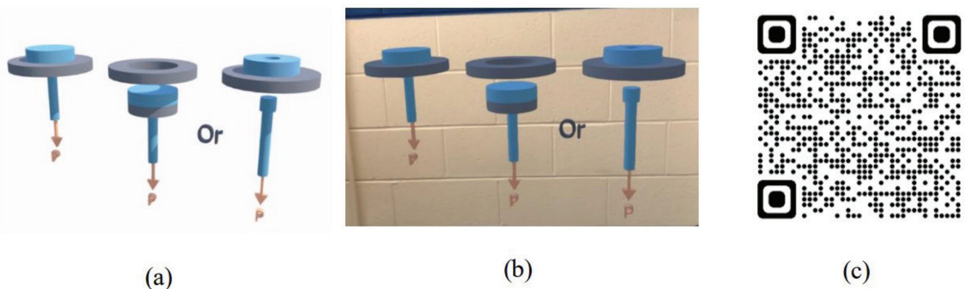

Figure 1. Sample visualization of viewing a 3D model in Sketchfab using a) the online viewer and b) the AR phone application.

models in a real environment. This allows for students to interact with realistic digital objects when the bounds of the traditional classroom environment may not allow for such exploration (Vincenti, 2010).

Throughout the course, the Sketchfab application was used to share 3D models with students and offer them the opportunity to interact with models in AR. This application allowed students to move, rotate and enlarge the model with their devices. A sample of an AR model from the course being viewed on a computer, in AR, and the QR code to access the model are shown in Figures 1a, b, and c respectively. To encourage others to implement 3D models in their courses, it is important to discuss the process of creating and accessing these models. In this course, all models were created using SketchUp and then imported to Sketchfab. While the process was free for students to access the models via Sketchfab, it is worth noting that the export options are limited in the free version of SketchUp. Therefore, the instructors used a professional academic version of the software to create and export the models, which costs $55 annually. The impact of implementing 3D models in Sketchfab on students' performance is evaluated in this study.

This paper reviews the motivation for incorporating interactive 3D modeling in the course and major findings from the study on the effectiveness of AR. It is anticipated that demonstrating the impact on students' performance will help other institutions add similar activities to their engineering courses to improve students learning.

Hypothesis

The goal of this study is to objectively evaluate the effect of using AR visualization methods on the performance of undergraduate engineering students in Mechanics of Materials. It is hypothesized that providing AR models showing the 3D geometry of specimens improves students' ability to visualize the project geometry, identify key parameters, apply the relevant mechanics concepts, and this results in higher scores. For all components of the two problems, the null hypothesis was that students with the 3D AR condition perform no better than students in the 2D condition, at a 5% significance level (95% confidence level).

Study Design

To evaluate the effectiveness of AR models in improving student understanding of problem geometry and potential failure modes, a study was conducted midway through the course offering. The optional study took place during one 50-minute class period and involved solving two multi-step engineering problems. Students were instructed on how to use and interact with AR models using their cellphone earlier in the semester. Participants were split into two groups (Group A and B) to balance for major, academic year, and their existing level of performance in the class (based on self-reported Exam 1 grade). The two groups were asked to solve the same engineering problem with the same problem description. One group was given only a 3D AR model showing the geometry of the subject of the problem while the other received only a 2D drawing. Examples of the 2D and 3D visualizations for Problem 1 and 2 are shown below in Figures 2 and 3, respectively. For the second problem, the visualization tool (AR vs 2D) was switched between the groups to swap the experimental and control groups. The engineering problems were multi-part to evaluate if students were able to 1) identify and apply the engineering concept, 2) recognize key parameters in the problem and their corresponding values from the problem statement, 3) predict the failure point based on the location of maximum stress/strain, and 4) obtain the final correct answer for the problem. A subset of questions and survey responses directly related to visualization will be presented.

	Materials					
Group	Mechanical	MEM	Science	Biomedical	Civil	Other
A	43	3	2	3	6	3
B	41	5	3	4	9	2

Table 1. Breakdown of participants in groups by major.

Group	Sophomore	Junior	Senior
A	4	51	5
B	3	54	7

Table 2. Breakdown of participants in groups by academic level.

Group	A	B	C	D	F
A	22	21	6	8	3
B	20	17	14	5	8

Table 3. Breakdown of participants in groups by grade on Exam 1.

The demographics of the participants in each group are shown below in Tables 1-3. An effort was made to balance for GPA, major, and performance on Exam 1. Four participants who took part in the study were excluded from the results. The exclusion criteria were if a participant did not attempt either question 1 or 2 and did not provide any survey responses for the corresponding questions. The total number of participants in Group A and B were 60 and 64, respectively.

The two problems given to students were based on course material they were tested on earlier in the week during their midterm exam. The questions focused on different topics to ensure having the 3D model for one question would not affect their performance on the other question. Both questions will be briefly reviewed to contextualize the results.

Problem 1 focused on eccentric loading. The problem description was "the crane shown in the model is lifting an 8 kN object. It is installed on a concrete foundation with length of 4 m, width of 3 m, and depth of 2.4 m. The total weight of the crane itself is 18 kN and it is being applied at the center of the crane's tower. "Views of the visualizations provided to Group A and B are shown in Figure 2a and b, respectively. The specific questions studied were, 1-1: "calculate the overturning moment due to the eccentric load," 1-2: "calculate the total stress at the edge that experiences a larger compressive stress due to the vertical axial load and the overturning moment," and 1-3: "if this crane lifts a load larger than its capacity, list the possible modes of failure that may occur (list what comes to your mind)." Parts 1-1 and 1-2 were scored based on the percent of the question answered correctly and part 1-3 was scored based on the number of correct failure modes identified by students, i.e., the number of points awarded equaled the number of correct failure modes listed.

Problem 2 focused on shear flow. The problem description was "the horizontal beam, AB, support three swings. The beam is made of three pieces of wooden planks. All the planks are 2" × 6". Two nails are used to connect each flange to the web. Nailing is repeated with spacing of 1.5" along the length of beam." Views of the visualizations provided to Group A and B are shown in Figure 3a and 3b, respectively. The specific questions studied were, 2-1: "draw the cross section of the beam and show the nailing details on that," 2-2: "calculate the second moment of inertia of the beam," and 2-3: "calculate the shear flow (q) at the interface of the flange to web connection." Problem 2-1 was scored by assigning either 0, 0.5, or 1 based on if the students got the problem incorrect, partially correct, or correct. Partial credit was given if students drew the cross section correctly but did not correctly identify the nailing detail. Parts 2-2 and 2-3 were scored based on the percentage of the questions answered correctly.

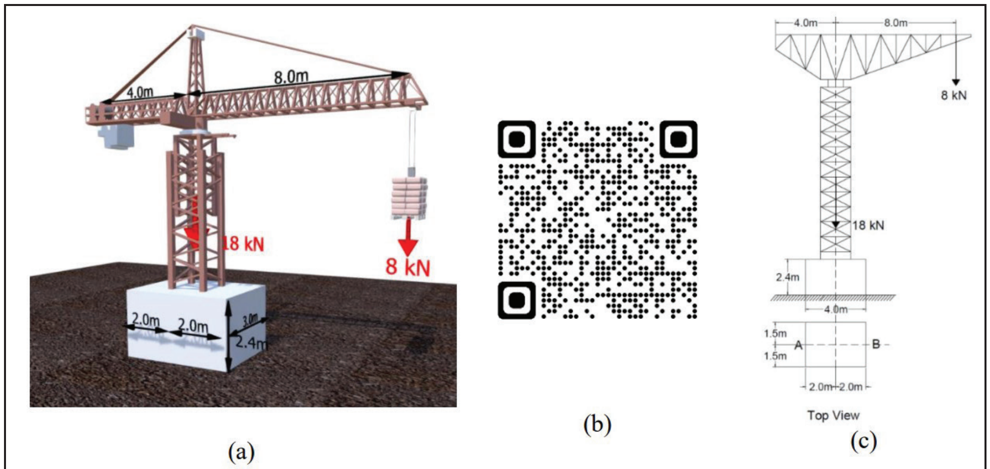

Figure 2. View of visualizations provided for problem 1 including (a) screen shot of 3D model given to Group A, (b) QR code to access 3D model for Group A, and (c) 2D schematic given to Group B.

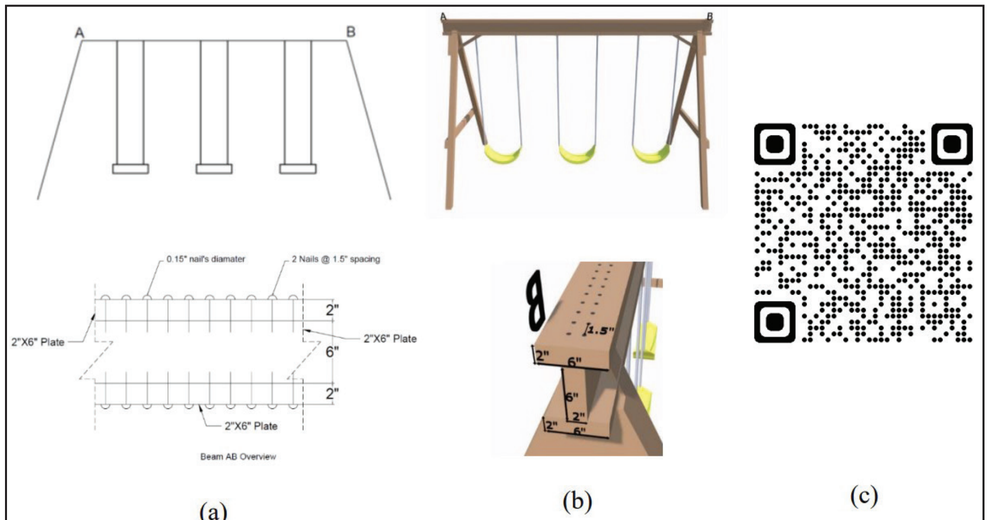

Figure 3. View of visualizations provided for problem 2 including (a) 2D schematic given to Group A and (b) screen shot of 3D model given to Group B and (c) QR code to access 3D model for Group B.

Results

In this section, we begin by discussing the feedback provided by students on their level of comfort in understanding the project geometry on the questions. This feedback helps to understand the student perceptions of the visualization tools. Subsequently, we analyze the performance of the students on the two problems and subproblems to determine the effectiveness of the AR tool in improving student performance.

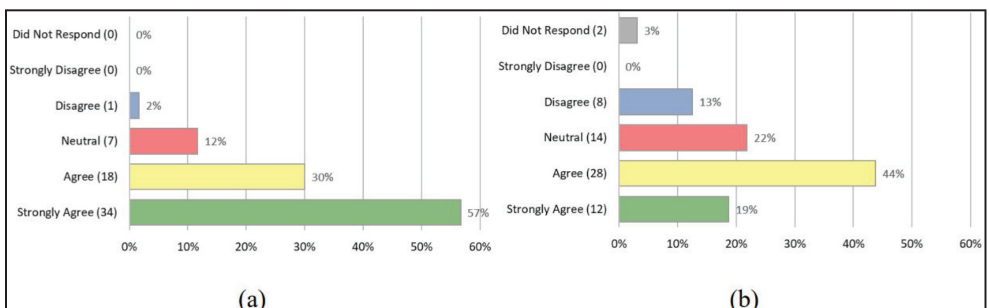

Figure 4. Survey responses from Problem 1 noting the ease of understanding the project geometry for a) Group A with the 3D model and b) Group B with the 2D model.

Student Feedback

Problem 1

In addition to answering the problems, students were asked to rank their level of comfort in understanding the project geometry. The survey responses to the question for Groups A and B are shown in Figure 4a and b, respectively. In general, a total of 87% of students in Group A noted they either agreed or strongly agreed that it was easy for them to understand the geometric parameters. Only a total of 63% of students from Group B found it easy (agreed or strongly agreed) to comprehend the problem by having access to 2D model.

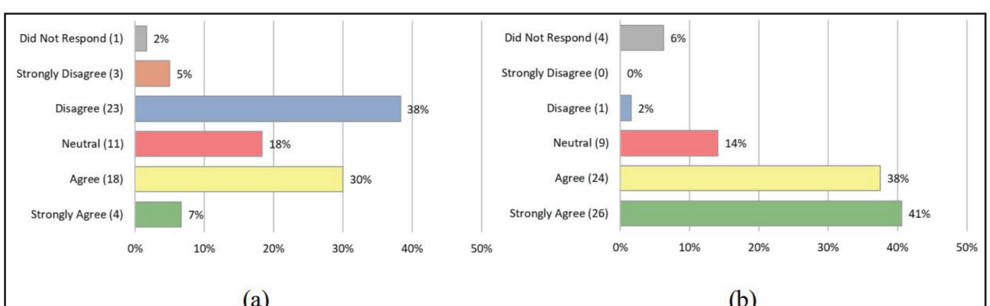

Figure 5. Survey responses from Problem 2 noting the easy of understanding the project geometry for a) Group A with the 2D model and b) Group B with the 3D model.

Problem 2

For Problem 2, the survey responses for Group A and B are shown in Figure 5a and b, respectively. Students in Group B were more confident in understanding the project geometry compared to Group A, which was reflected in their respective scores on the problems. A total of 79% of students in Group B noted they either agreed or strongly agreed that it was easy for them to understand the geometric parameters. Only 37% of students from Group A found it easy (agreed or strongly agreed) to comprehend the problem by having access to 2D model. The survey also showed that Group B participants were quite confident in their understanding, despite many of the students making minor errors in understanding the nailing details in the problem.

Students Performance on Problems

The individual study responses for both problem 1 and problem 2 were scored independently by two graders using the same rubric. Both scorers have PhDs in structural engineering and have taught Mechanics of Materials. The interrater reliability was evaluated using both Pearson's correlation coefficient and the Kappa statistic. For questions 1-1, 1-3, and 2-1, the Kappa statistic was used to evaluate interrater reliability because students were expected to receive the same rating. The Kappa values for these questions were 0.715, 0.98, and 0.639, respectively. For all questions, Pearson's correlation coefficient was used to assess interrater reliability. The Pearson's correlation coefficients ranged from 0.825 to 0.996.

Based on the Kappa statistic and Pearson's correlation coefficient, there was good interrater reliability for all questions. Therefore, the scores from the different raters were considered reliable, and an average of the scores was used for the analysis. This approach ensures that the final analysis reflects the collective judgment of the raters, rather than the opinion of a single rater.

The Mann-Whitney U test was used to analyze the results of each question. This analysis tests for differences between two groups on a single variable with no specific distribution (McKnight & Najab, 2010). A t-test was not used as the data did not have a normal distribution.

Problem 1

Problem 1-1

Problem 1-1 asked students to determine the overturning moment due to the eccentric load. The results from the Mann-Whitney U test are shown in Table 4. The table includes a number of variables including N - the total number of cases in each group, or the sample size, the mean rank - the average of the ranks for all observations within each sample, sum of ranks - the sum of the ranks for all observations for each sample, the U test statistic, the Z score - a standard test statistic, and the p value - the probability value.

	Group A (3D)	Group B (2D)
N	60	64
Mean Rank	68.32	57.05
Sum of Ranks	4099	3651
Mann-Whitney U	1571	
Z	-2.296	
Exact Sig. (1-tailed)	**0.01****	
*5% significance level, ** 1% significance level		

Table 4. Mann-Whitney Test Results for Problem 1-1.

	A's		B's		≤C	
	Group A (3D)	Group B (2D)	Group A (3D)	Group B (2D)	Group A (3D)	Group B (2D)
N	22	20	21	17	17	27
Mean Rank	20.64	22.45	20.60	18.15	27.44	19.39
Sum of Ranks	454	449	432.50	308.50	466.5	523.5
Mann-Whitney U	201.0		155.5		145.5	
Z	-0.786		-1.268		-2.196	
Exact Sig. (1-tailed)	**0.238**		**0.177**		**0.014***	
*5% significance level, ** 1% significance level						

Table 5. Mann-Whitney Test Results for Problem 1-1.

The results show that there is a statistically significant difference between the scores of the two groups, with Group A (3D model) outperforming Group B (2D sketch). Correctly solving for the overturning moment required the students to select the correct load and lever arm. The results suggest that the 3D model helped students visualize these elements, leading to the correct selection.

Notably, Group A had a slightly higher average score on exam one (2.85 vs 2.56, on 4.0 GPA scale). To ensure the higher score did not impact the results, the analysis was completed for subgroups with similar grades on Exam 1 to isolate the impact of the group (*i.e.*, 2D vs. 3D model). The scores on Exam 1 were separated into three approximately equal groups: students who received A's, students who received B's, and students who received C's or lower. The results for the different subgroups are shown in Table 5.

An interesting finding emerges: the only time the use of the 3D model made a significant difference was for students who performed below average (score of C or lower) on Exam 1. This may suggest that 3D models are more effective for students who struggle in the course. Further research is needed to substantiate this finding.

Problem 1-2

Problem 1-2 asked students to calculate the total stress at the edge that experiences a larger compressive stress due to the vertical load and the overturning moment. The results from the Mann-Whitney U test are shown in Table 6. No points were deducted for errors carried through from Problem 1-1. For this problem, there was no statistical significance in the scores of the groups. This was not a surprise, as most challenges came from students forgetting to add the contribution of normal stress from the weight of crane, which is a problem with the concept of combining stresses from an axial load and moment, not an issue with understanding problem geometry.

Problem 1-3

Problem 1-3 asked students to list potential failure modes should the crane lift too large of a load. The problem was scored based on the number of correct failure modes noted. Students listed anywhere between 0 and 6 modes. The analysis of the results from problem 1-3 are shown in Table 7 below.

The findings suggest that the 3D model was beneficial in the students reporting a larger number of correct potential failure modes. To adjust for the impact of higher Exam 1 scores, the analysis was repeated for the different subgroups following the same approach used for Problem 1-1. The results are shown in Table 8.

The results are similar to those for the overall evaluation of Problem 1-3, where the impact of the 3D model is significant. The model is not significant for students who

	Group A (3D)	Group B (2D)
N	60	64
Mean Rank	67.74	57.59
Sum of Ranks	4064.5	3685.5
Mann-Whitney U	1605.5	
Z	-1.575	
Exact Sig. (1-tailed)	**0.058**	
*5% significance level, ** 1% significance level		

Table 6. Mann-Whitney Test Results for Problem 1-2.

	Group A (3D)	Group B (2D)
N	60	64
Mean Rank	70.76	54.76
Sum of Ranks	4245.5	3504.5
Mann-Whitney U	1424.5	
Z	-2.53	
Exact Sig. (1-tailed)	**0.006****	
*5% significance level, ** 1% significance level		

Table 7. Mann-Whitney Test Results for Problem 1-3.

	A's		B's		≤C	
	Group A (D)	Group B (2D)	Group A (3D)	Group B (2D)	Group A (3D)	Group B (2D)
N	22	20	21	17	17	27
Mean Rank	21.23	21.80	23.19	14.94	27.09	19.61
Sum of Ranks	467.0	436.0	487.0	254.0	460.5	529.5
Mann-Whitney U	214.0		101		151.5	
Z	-0.154		-2.339		-1.922	
Exact Sig. (1-tailed)	**0.444**		**0.009****		**0.029***	
*5% significance level, ** 1% significance level						

Table 8. Mann-Whitney Test Results for Problem 1-3.

Group	0 (Incorrect)	0.25	0.5	0.75	1 (Correct)
A	31	2	16	1	10
B	6	0	10	27	21

Table 9. Breakdown of scores on problem 2-1 by group.

received an A on Exam 1, but is significant for those who received B's and a C or lower. This is similar to the findings from problem 1-1, which may suggest that 3D models are more effective for students who struggle in the course. Further research is needed to substantiate this finding. In addition, the student's grade in the overall course, or performance on all exams, would be more beneficial as a baseline, as there are a multitude of factors that could impact performance on Exam 1 such as amount of time spent studying, other course demands, and test anxiety.

Problem 2

For the second problem, the visualization tool (AR vs 2D) was switched between the groups to swap the experimental and control groups. Problem 2 required students to visualize and correctly identify the cross section based on the visualization and problem statement provided. They then needed to use the correctly identified cross section to complete parts 2-2 and 2-3. Problem 2 was more challenging to score, as correctly identifying the cross sections was critical in determining the moment of inertia and shear flow. In future renditions of this study, the authors intend to modify the questions so that an incorrect answer on one part does not impact scoring of subsequent sections.

Problem 2-1

The results for Problem 2-1 are shown below in Table 9. It is immediately clear that students in Group A struggled with the problem, with over 50% of the students getting zero credit. The results of the Mann-Whitney Test are shown in Table 10. Given the P-value of <0.001, we can conclude the difference in median score is statistically significant between the two groups.

As Group A had the higher average score on Exam 1, it is more telling that Group B (3D model) substantially outperformed Group A on this question. This may also suggest 3D models are most-beneficial on problems with more complex geometries. Consistent with the approach used for Problem 1, the Mann-Whitney test was repeated for students who received the same score on Exam 1 (A's, B's, C's or lower) (Table 11). The results show that the 3D model consistently resulted in significant differences between Group A and B for each set of Exam 1 scores.

Another interesting finding from this Problem concerns how the partially correct answers differed between groups. In Group A with the 2D drawing, all students who received partial credit only showed one nail in the top and bottom flanges. For Group B, students received partial credit for a variety of cases including only showing the nails on the top flange (most common, over 50%), showing an incorrect spacing of the nails, showing one nail on the top and bottom flanges, or not showing any nails. The most common mistake for Group B was not including the nails connecting the bottom flange to the web, even though the problem statement noted that "two nails are used to connect each flange to the web." This may suggest that having the 3D model could make students feel overly confident in the answer and pay less attention to the problem statement or think less critically. This also suggests that the students did not fully examine the model, which included nails along the bottom flange.

Problem 2-2

Problem 2-2 asked students to calculate the second moment of inertia of the beam. The statistical analysis was only conducted for students who answered Question 2-1 partially correct or completely correct, as it is impossible to calculate the moment of inertia without having the correct cross section. The correct nailing detail was not required as this does not impact the moment of inertia calculation. The results are shown in Table 12. As anticipated, the results were not significant as the students' challenges were namely due to conceptual issues rather than visualization.

Problem 2-3

Problem 2-3 asked students to calculate the shear flow between the web and flange. The statistical analysis was only conducted for students who received full credit on Question 2-1 as the correct cross section and nailing detail was required. The results are reported in Table 13. It is likely that the results are not significant as this is mainly a conceptual issue rather than a problem visualizing the section. However, due to the minimal number of observations from Group A, N=10, the findings require further research.

Conclusions

This study has made several important conclusions regarding the impact of augmented reality on student performance and understanding of project geometry. The results indicate that students who had access to 3D models performed better in identifying failure modes and project geometry (i.e., cross section) compared to those who had access to 2D models. The improvement was particularly evident for students who had lower scores on Exam 1. However, in order to better understand the full impact of 3D models on student performance, it is recommended that future studies include additional information on students' performance in the course such as their final grade or score on Exam 2.

The study also found that students who were provided with 3D models felt more comfortable and confident in understanding the project geometry for both problems. For Problem 1, 87% of students with access to the 3D model found it easy to understand the geometric parameters, compared to only 63% of students with access to 2D models. Similarly, for Problem 2, 79% of students with the 3D model reported being comfortable with the problem geometry, compared to only 37% of those with the 2D model. However, the difference in responses between

	Group A (2D)	Group B (3D)
N	60	64
Mean Rank	44.59	79.29
Sum of Ranks	2675.5	5074.5
Mann-Whitney U	845.5	
Z	-5.550	
Exact Sig. (1-tailed)	**<0.001****	
*5% significance level, ** 1% significance level		

Table 10. Mann-Whitney Test Results for Problem 2-1.

	A's		B's		≤C	
	Group A (2D)	Group B (3D)	Group A (2D)	Group B (3D)	Group A (2D)	Group B (3D)
N	22	20	21	17	17	27
Mean Rank	17.11	26.33	12.81	27.76	14.29	27.67
Sum of Ranks	376.5	526.5	269.0	472.0	243.0	747.0
Mann-Whitney U	123.5		38.0		90.0	
Z	-2.579		-4.283		-3.508	
Exact Sig. (1-tailed)	**.005****		**<0.001****		**<0.001****	
*5% significance level, ** 1% significance level						

Table 11. Mann-Whitney Test Results Separated by Grade on Exam 1 for Problem 2-1.

	Group A (2D)	Group B (3D)
N	27	58
Mean Rank	42.28	43.34
Sum of Ranks	1141.5	2513.5
Mann-Whitney U	763.5	
Z	-0.201	
Exact Sig. (1-tailed)	**0.419**	
*5% significance level, ** 1% significance level		

Table 12. Mann-Whitney Test Results for Problem 2-2.

	Group A (2D)	Group B (3D)
N	10	21
Mean Rank	13.30	17.29
Sum of Ranks	133.0	363.0
Mann-Whitney U	78.0	
Z	-1.213	
Exact Sig. (1-tailed)	**0.117**	
*5% significance level, ** 1% significance level		

Table 13. Mann-Whitney Test Results for Problem 2-3.

the two problems suggests that 3D models may be most beneficial for problems with greater complexities.

While the 3D model did have a significant impact on student performance on problems related to visualization, the impact was shown to be insignificant on multiple problems that relied heavily on an engineering concepts rather than visualization, such as solving for stress, moment of inertia, and shear flow. As many students struggled with these concepts, the researchers recommend repeating the study later in the semester when these concepts may be clearer to students, to see how this impacts the findings.

To ensure the validity and generalizability of the findings of this study, it is recommended that future studies be conducted with additional problem sets to provide more robust data. Additionally, we plan to collect data on students' spatial cognition scores to examine how it interacts with the use of 3D models in teaching project geometry. This will help us to better understand whether spatial cognition moderates the impact of 3D models on student performance and understanding of project geometry. By including a larger number of participants in future studies and examining the interaction between spatial cognition and 3D models, we can contribute to a more comprehensive understanding of the impact of AR on student performance and understanding of project geometry. Ultimately, this will provide greater insight into the viability of replication and the potential for widespread implementation of AR technology in engineering education.

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