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Using Augmented Reality to Eliminate Common Misconceptions for Students in Core Mechanical Engineering Courses

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Abstract

An Augmented Reality (AR) tool was designed to address common mistakes and misconceptions that usually stem from poor three-dimensional visualization skills in students in core Mechanical Engineering courses. The AR aid is designed in the form of visual tips that students can see and interact with when looking at a printed exercise though their phone and AR app. This paper also provides the instructions to create these AR tools as well as sample problems that the readers can interact and experiment with. The effectiveness of the approach was verified through comparison of final exam questions on the topic of combined loading in Mechanics of Materials over four semesters with a control class. Significant improvement was observed in elimination of the typical mistakes that stem from visualization. Furthermore, the tool was very easy to initiate by the instructor and students, and generated student enthusiasm and favorable feedback.

Introduction

From the experience of multiple instructors shared in course coordination meetings for Mechanics of Materials and Machine Design, it was observed that students particularly struggled with different stages of working with combined loading. This struggling included fundamental prerequisite issues on drawing the correct free-body diagrams in three dimensions, connecting the loads with their respective normal and shear stresses, and resolving the correct directions and stress distributions for combining the calculated stresses.

The issue is particularly important because the topic is a fundamental building block for Machine Design and any solid design project that engineers tackle. Furthermore, the issue was particularly deemed hard to resolve because it persisted even after placing special emphasis on the topic of combined loading and allocating more sessions to its practice in class.

It was proposed by the instructors that the issue may have roots in lack of student visualization of three-dimensional loading. In that case, it would make sense that simply allocating more practice time to the topic would not significantly help the students. An approach was needed to specifically work on three-dimensional visualization skills and connecting it with the combined loading problems.

AR presented a promising technology for designing a study aid to improve 3D visualization skills in students, while at the same time enhance their engagement with the homework and improve their learning and retention in general.

Related work

In this section, evidence is presented on effectiveness of visual tools in general and AR technology in particular, in learning.

Evidence of effectiveness of visual tools for learning. Based on theories of visual awareness [1], one way to involve the higher cortical areas of the brain needed for learning, is through directing attention to an image. Directed attention is key in this process. While watching an image or video in passing does stimulate the visual cortex, without directed attention, it will not stimulate the higher cortical areas. This is the reason why watching an educational video while being engaged in other activities at the same time usually doesn't lead to deep learning. However, directing attention to an image is a proved brain pathway to involving the thinking cortex, and hence facilitating the learning.

Even before fMRI (functional Magnetic Resonance Imaging) made the pathways of visual learning visible, the experiential evidence had proven visual thinking to be very effective in increasing student engagement, class participation, language skills, writing skills, and visual literacy [2, 3].

Although evidence for the learning-enhancement effect of visual thinking has been available for a long time (a review of older research is available in [4]), its usage in teaching, especially in higher education, has been largely overlooked. The enhancing connection between reading comprehension and visual imagery was shown for children in third grade throughout their educational career in [5]. Similar results were confirmed for fifth graders in a separate study [6], and for learning-disabled students [7]. Another study, [8], showed that first graders learned and retained at a significantly higher rate when imagery was used, and further, the students showed higher level of creativity with usage of imagery [9], a result that can be exploited in higher-education problem-solving. A more recent study [10] reports the effect of using visual thinking software to improve writing skills of students with mild disabilities, and another one [11] provides a practical best practice example on how visual thinking is used to enhance student background knowledge.

Although, these studies were performed at the level of elementary schools, they are readily applicable to higher education classrooms, since the underlying brain pathways remain the same for children and adults [1].

Effects and challenges of using AR tools in teaching. In [12], AR was used as a magic mirror to teach human anatomy. Once the user looked at this mirror, the three-dimensional internal organs were shown superposed on the person's image. The system was shown to be favored by most of medical students, boosted autonomous learning, and is expected to reduce laboratory material and cost, however, the authors mentioned that for the full potential of the AR tool to be realized, academic methodologies need to be changed to fit the available technology.

In [13], an AR app was designed to test students' understanding of metabolic pathways by 3D visualization of molecular structures in substrates and products and showing changes in the molecules and exchange of energy through metabolic reactions. It was observed that several desirable skills were improved in students while working with the app. These skills included enhanced engagement in academic debate, peer review, collaborative learning, meaningful learning and development of visual literacy. The AR tool in this study was used mostly as an assessment tool for prior learning and no study was performed on the tool's effect on learning itself.

In [14], a study was presented on the efficacy and student satisfaction of using AR in design of cavity preparation for students of dentistry. The authors found the technology to be a stimulus for students, and although it did not improve the gaining of theoretical knowledge, it did improve the skills that needed visualization.

In [15], a review of the user experience of AR was presented and its usage in a blended English course offered at Osaka University was studied. For the most cases the tool was favored by students [16] except when technology glitches and the overhead effort made it hard to use.

Based on the work mentioned above, AR presents a promising tool for enhancing 3D visualization skills in students, while at the same time boosting motivating, engagement, and overall learning satisfaction, provided that low overhead robust apps are used.

System model

To study the effect of AR as an aid for student performance in combined loading, an AR tool was designed and introduced to students in a one-session pilot module in Fall 2017 to observe and understand the students' reaction to the tool. The students interacted with the tool and wrote feedback about their experience. Based on favorable feedback, a package of AR problems was designed for the full experiment in Spring and Fall of 2018. Data from two instructors in six other classes was used as control.

To assess the effect, the instructors used the number and type of mistakes students made in the final exam questions on combined loading. These mistakes were organized into the following six categories.

1. Could not correctly draw the free-body diagram or did not draw one
2. Could not correctly relate the loads and their respective stress resultants (e.g., used applied torque in calculating a bending moment)
3. Could not correctly calculate the stress resultants (e.g., used the wrong moment arm)
4. Could not correctly apply the distribution of the stress (e.g., calculated stress due to transverse shear force stress at a point where it should be zero)
5. Could not correctly resolve the direction of the stress (e.g., tension/compression)
6. Minor calculation errors

Errors in calculating section properties such as moment of inertia were assigned to category 6, and if a student turned in a blank solution it was considered a category 2 mistake.

Hypotheses. The authors hypothesized that improving visualization skills using the AR tool could potentially improve student performance in categories 1-5, since category 6 was mathematical accuracy and unrelated to visualization. Based on related work presented in the above sections, the instructors also expected to see a boost in engagement and motivation of the students.

The AR tool. The AR aid package contained a set of AR guided problems, one for each of the major topics covered in the course. These problems were used as part of the homework sets for students. Each weekly homework set contained one guided problem, followed by 7 or 8 textbook problems. The students were instructed to work on the guided problem first, since the AR tips referred to and reinforced the important concepts and procedures. Later, guided problems were graded for accuracy and detailed feedback was given to students individually based on their solutions.

Each guided exercise contained a trigger image. This was usually the figure that depicted the problem. When students looked at the problem image through their smartphone app, they would see AR tips superimposed on the problem image. The tips included questions to guide the thought process, clarifying images such as 3D visualization of the problem, reminder of important concepts both in text and image form, partial free-body diagrams, clues on where to make sections, references to relevant passages and examples in the textbook, stress distributions, an occasional intermediate answer to double-check with, and anything that the instructor wanted to emphasize. Two examples are provided in the appendix.

The tool was designed such that it repeated over the course of the semester, the thought process to help students visually build a habit of inquiry that would lead from a problem statement to a problem solution.

The AR exercises were created using HP Reveal [17], which is a cloud-based AR creation and management studio. This application was selected because of the following features:

1) Ease of use for students, as the literature shows technology with high overhead or slow learning curve distracts from learning rather than help it [16]. HP Reveal can be initiated with students within five minutes while in class. All the students need to do is to download the app on their phones, make a free account, and follow the class channel. The sequence of steps is provided in the appendix.
2) Ease of use for creators, as HP Reveal is very user-friendly. No programming is needed, and the assignment creation amounts to uploading the problem image and all the overlay tip images (or solid models and videos) to the studio and arranging their appearance and interactions.
3) The application is free of charge for students and for creators.
4) The application is robust and works with most smartphones and devices. Over the three semesters of experimenting with students, the instructors ran into no technical difficulty or device incompatibility issues.

Results and discussion

Final exam questions on combined loading from two instructors over four semesters (eight total classes) were analyzed to count the occurrence of each of the 6 mistake categories for each class. One of the instructors used the AR tool for two semesters, while the other instructor did not. The two classes that used the AR tool for the entire course were labeled "AR" and the other six classes which did not use the AR tool were labeled "Control." Both instructors used the same textbook [18] and course pack [19].

Statistical Analysis. ''R'' software, version 3.1.2 was used for all statistical analysis in this study. Tukey's Honestly Significant Difference (HSD) following an analysis of variance (ANOVA) test was used to differentiate the two methods labeled "AR" and "Control" (Agricola package, $\alpha = 0.05$). Tukey test differentiates the means that are significantly different from other sets of means [20]. *p*-value has been widely used to determine if there is a meaningful relation between two measured values [21]. A common threshold for the p-value is 0.05 which can be considered as the significant level (α) of the test [22]. The relation between two measured values is considered to be meaningful (significant) if the *p*-value is smaller than that defined significant level (usually at $\alpha = 0.05$).

Summary of the Results. Figure1 shows the comparison of "AR" classes with "control" classes. Classes 1-4 are in chronological order representing semesters of Fall 2016 (38 students), Fall 2017 (35 students), Spring 2018 (45 students), and Fall 2018 (77 students) for instructor 1; classes 5-8 are in chronological order representing Spring 2017 (51 students), Fall 2017 (57 students), Spring 2018 (56 students), and Fall 2018 (54 students) for instructor 2. The significance of the differences, from the statistical analysis, is presented in detail below.

Total mistakes per student-excluding category 6 mistakes, was significantly lower ($p = 0.03$) in "AR" method (average = 0.89 ± 0.03) than "Control" method (average = 1.52 ± 0.30).

Total mistakes per student was also lower ($p = 0.04$) in "AR" method (average = 1.18 ± 0.05) than "Control" method (average = 1.76 ± 0.29).

Category 5 mistakes were significantly lower ($p = 0.02$) for "AR" (average = 0.05 ± 0.01) compared with "Control" (average = 0.23 ± 0.08).

No statistical difference was observed between the two methods for the other categories of mistakes individually. *p*-values for categories 1, 2, 3, 4, and 6 were found to be 0.8, 0.23, 0.25, 0.13, and 0.43, respectively.

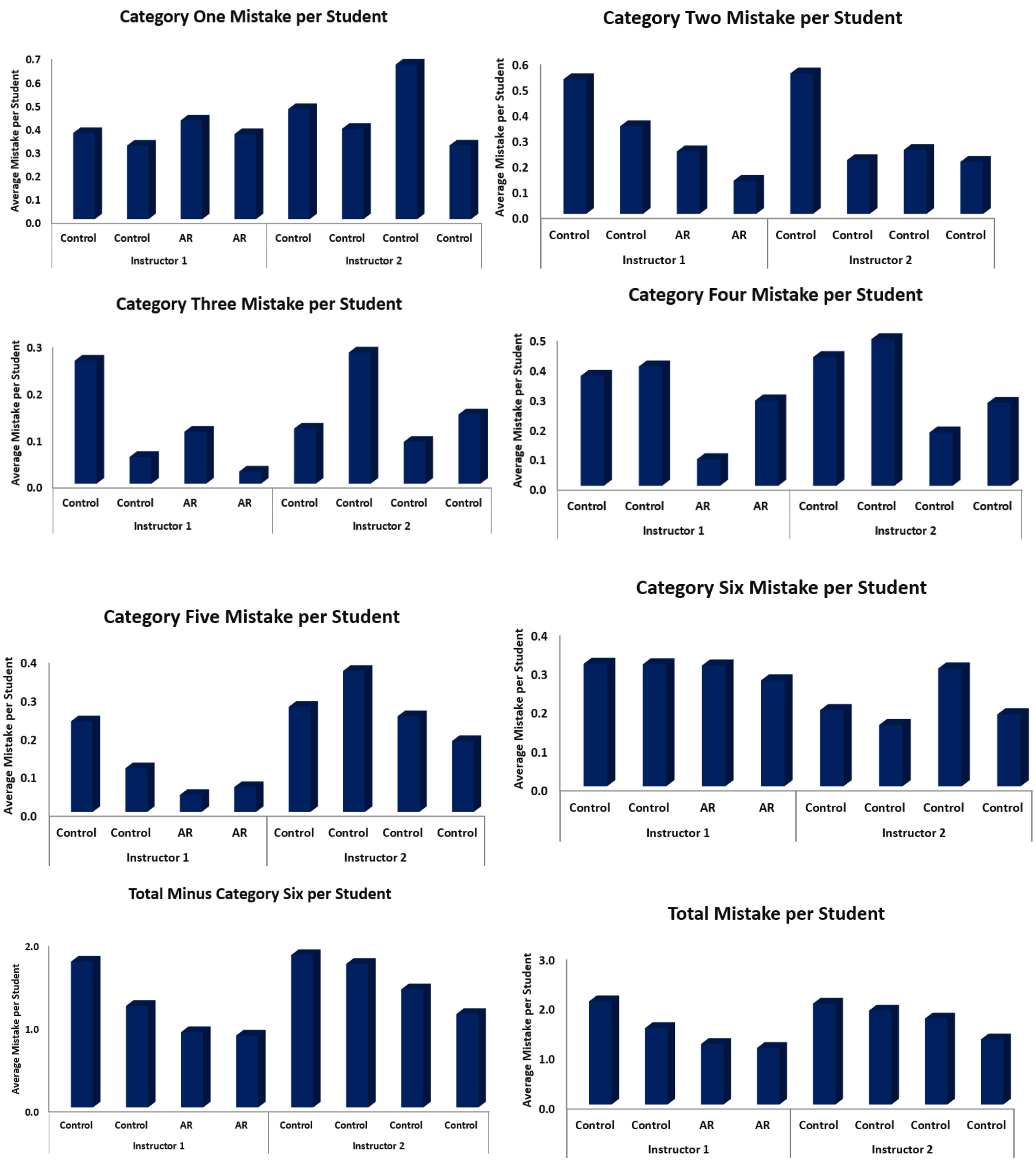

Figure 1: Comparison of mistakes per student for the eight classes

Other observations. Mistake type 2 shows a significant reduction with time for instructor 1. However, this is attributed not to AR, but to the collaborative problem-solving that was part of Instructor 1's teaching method. This effect relates to fundamental conceptual learning achieved from peer teaching and has been studied in a separate work of the authors. [23]

Mistake type 6 was generally lower for instructor 2. This effect is related to specific emphasis placed on accuracy in instructor 2's teaching method, also addressed in detail in the authors' previous study [23].

For both instructors, total number of mistakes per student shows a reduction with time, confirming the effectiveness of applying intervention strategies and suggesting this type of observation of mistakes and data analysis as a good self-assessment tool for instructors to analyze and improve their techniques.

Qualitative observations. Although data was analyzed in detail for combined loading problems only, it was also observed that for axial loading problems, the common mistake of sectioning at the point of application of the load or at the location of abrupt geometry change was nearly completely eliminated, using the AR tool.

On multiple occasions, the students expressed appreciation about the AR tool. They mentioned that it helped them feel more confident about being able to work the problem.
Although the authors have not gathered data regarding this, a general tendency was observed toward the students starting the homework problems earlier rather than later. This was observed from the students showing up in office hours as early as half an hour after class and asking meaningful questions about the AR guided problem.

The authors have received no complaints of any sorts, in person, or in evaluations regarding the AR tool.

Discussion and future work. Based on the results, the AR tool has been effective in helping students make less mistakes overall in combined loading problems. Further, significant reduction of category 5 mistakes shows improvement in students better visualizing stress directions.

The mistakes related to free-body diagrams (category 1) did not significantly improve. However, the authors suspect it would if a similar tool was introduced to the pre-requisite Statics course, activating visual thinking in students in relation with free-body diagrams.

Categories 2-4 also did not show significant improvement. Closer examination shows that performing well in these categories involves not only visualization skills but also conceptual learning and metacognition, skills that, based on the literature [14], are not necessarily improved by usage of AR.

Future work can also include:

- Adding more interactive items to the exercises, such as solid models and distributions that are presented in 3D.
- Exploring with teamwork and collaboration using AR software that allow multiple users to interact in the same virtual space.

Conclusions

An AR tool was used successfully in improving student performance in Mechanics of Materials class. A statistical analysis showed that the tool significantly reduced the number of typical mistakes that students made. Further, the tool was favored by students, and based on student comments, it generated enthusiasm and boosted confidence in their own ability to work the problems. It is, however, worthwhile to mention that the tool showed no significant improvement in the areas relating to conceptual learning and metacognition. As such, this AR tool is most effective in the areas where enhanced and repeated visualization leads to improved performance.

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Appendix

This appendix contains two of the thirteen guided problems from the AR tool used in this study. Instructions for downloading the AR app:

1. Download HP Reveal app on your phone or other camera-enabled personal device.
2. Create a free account.
3. While logged into the app, open your web browser, go to http://auras.ma/s/9UkPC, and click on "Follow" to gain access to this study's channel.
4. Open the app, tap the icon , and look at the exercise image through your smartphone. The first AR tip should appear. Tapping each tip will bring up the next tip. The image of the tiger means you have reached the end of the tips.

Sample AR-guided problems. The following provides sample AR-guided problems on the two topics of axial loading and combined loading. Please note that the white space under each problem's image is needed for the app to recognize the trigger image.

Example 1. Axial loading

Find the maximum stress within the aluminum bar and the total length change when the loads are applied. The dimensions are inches. Each segment is 10 inches long. Use E = 10e6 psi.

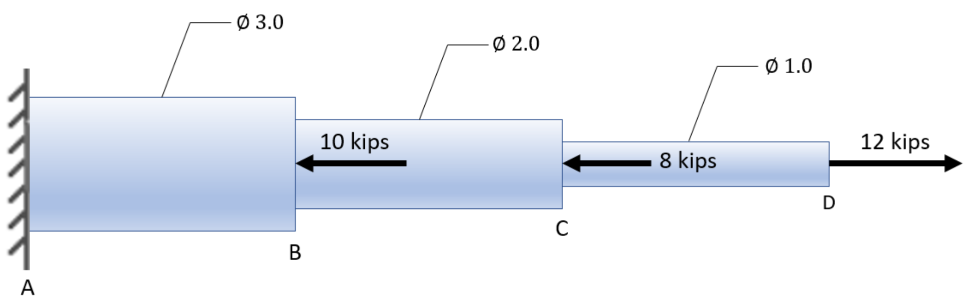

Figure 2: Sample AR-guided exercise for axial loading (Note: the white space under the image is needed for the app to recognize the trigger image.)

Figure 3 and 5 provide photos of some of the AR tips created for the axial loading and the combined loading problems, respectively.

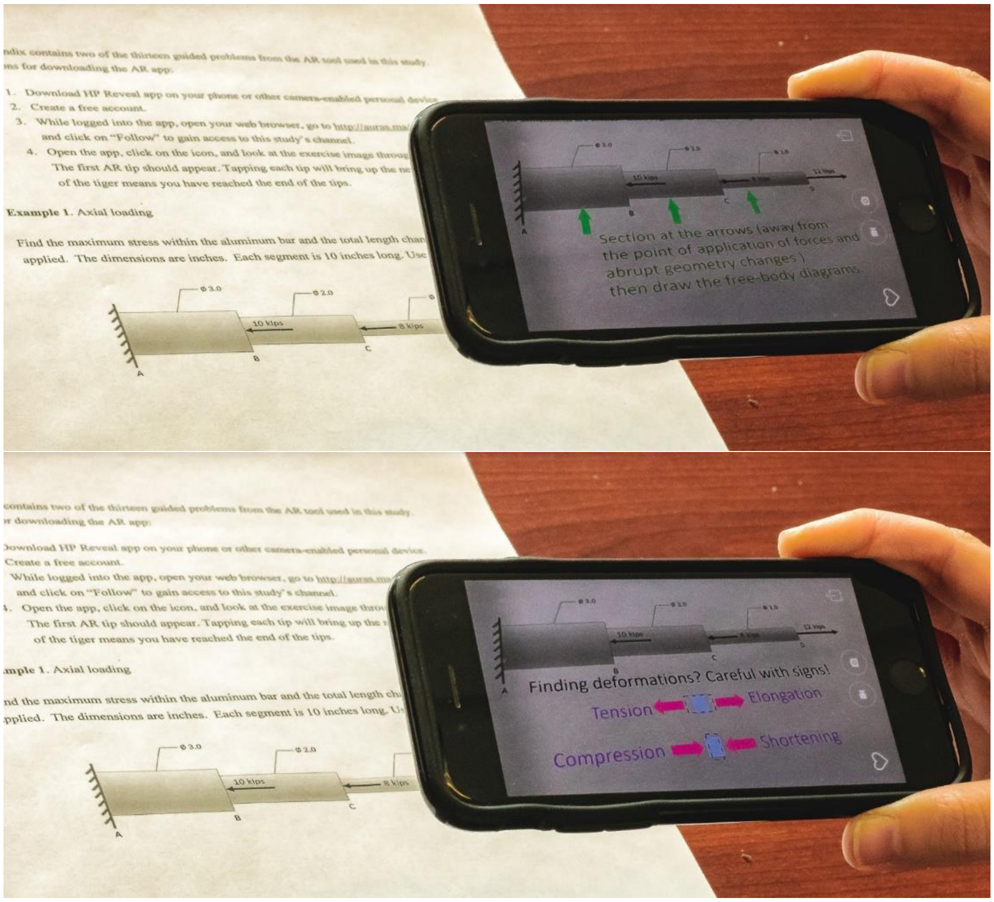

Figure 3: Sample AR tips for the axial loading exercise

Example 2. Combined loading

The given solid circular shaft is fixed at the AB end and loaded as shown. The shaft diameter is 2 inches. Determine the state of stress at points A and B.

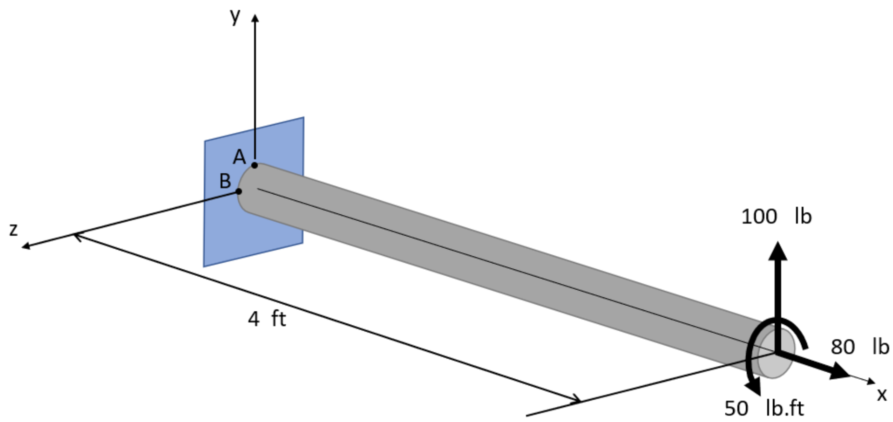

Figure 4: Sample AR-guided exercise for combined loading (Note: the white space under the image is needed for the app to recognize the trigger image.)

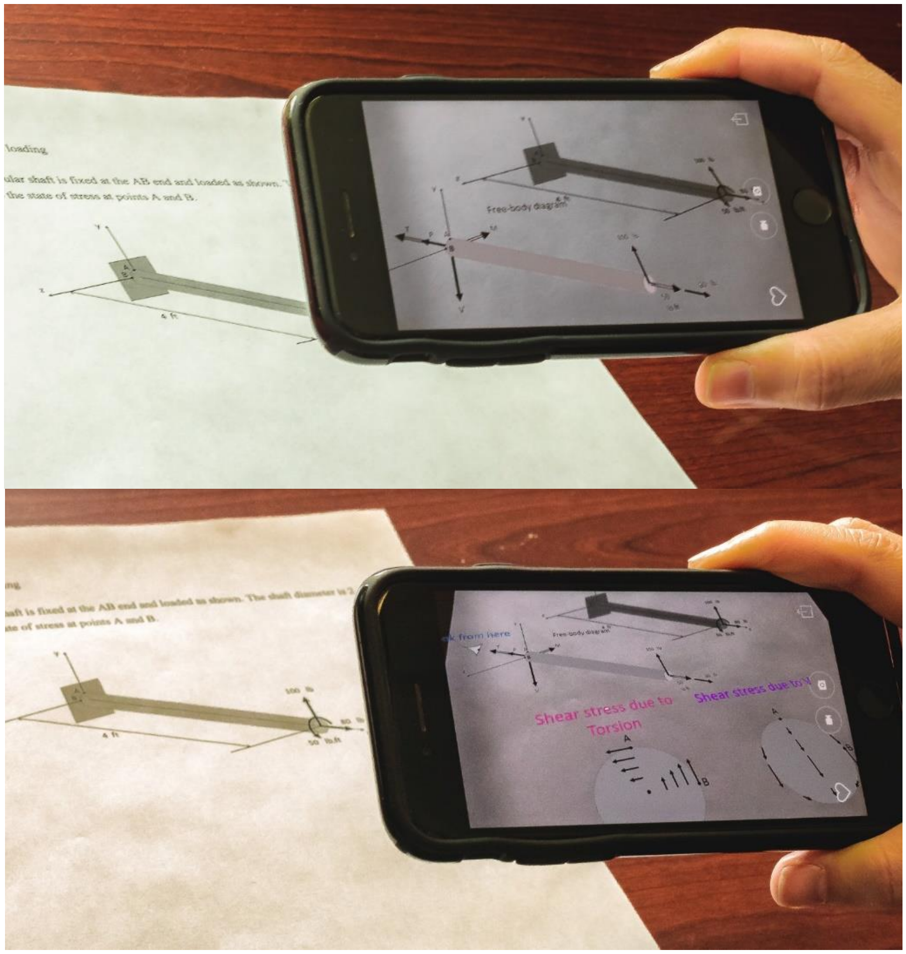

Figure 5: Sample AR tips for the combined loading exercise