WIP: Using Augmented Reality to Improve Time to Mastery of Moments in Statics

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Abstract

The integration of augmented reality (AR) has emerged as an innovative approach to support student engagement, understanding, and visual-spatial skill development in engineering mechanics education. This Work-in-Progress (WIP) paper reports on the design, implementation, and preliminary evaluation of an AR-based learning module created to support student learning of moments in an undergraduate Statics course. Moments are widely recognized as a challenging foundational concept in Statics. Mastery requires students to interpret three-dimensional spatial relationships, connect physical behavior with mathematical representations, and apply vector and scalar formulations to reason about the magnitude and direction of forces and resulting moments in space. These cognitive demands are associated with persistent misconceptions and extended time to mastery.

The developed module employs a mobile AR application that projects a three-dimensional virtual scene of a billboard sign mounted on a fixed frame and subjected to a force representing wind pressure. Students manipulate both the magnitude and direction of the applied load throughout the learning experience and calculate the resulting moments. Guided tasks prompt students to apply vector and scalar formulations, use the right-hand rule, and verify their numerical results against AR-generated values. This approach enables students to investigate an authentic mechanics scenario that is difficult to replicate with physical models while moving beyond contrived textbook examples. Unlike traditional computational modeling tools, the AR environment provides immediate, visually anchored feedback without prerequisite modeling skills, such as understanding support conditions, mechanics of materials, and analysis methods beyond the scope of Statics.

The instructional intervention was implemented with 22 students working in small groups of two to five members, each completing a 45-minute activity in a controlled lab environment. Preliminary results from a post-activity survey indicate high levels of engagement, with 77% of students rating the experience as *"very engaging"* (+4 or +5 on a -5 to +5 scale), and 82% reporting increased confidence in their understanding of moments. In addition, students who participated in the AR activity demonstrated earlier mastery of the Moments module, reaching mastery a median of two weeks sooner than other students in both the same-year and prior-year comparison cohorts. Ongoing work continues to examine mastery trajectories and downstream learning effects across subsequent topics. This study aims to inform the development of AR-based instructional tools that enhance conceptual understanding, foster visual-spatial skill development, and contribute to the growing body of research on technology-enhanced mechanics instruction.

1. Introduction

Students in Statics often struggle with vector-based reasoning involving moments and equilibrium. In this work, these challenges are examined through a spatial visualization lens [1], [2]. Mastery of moments requires students to interpret three-dimensional geometry, reason about force direction and magnitude, and connect mathematical operations to physical behavior; these demands are often associated with misconceptions and delayed mastery early in the Statics sequence.

Traditional instruction in Statics relies heavily on textbook diagrams and contrived problem settings, which provide limited support for the development of visual-spatial reasoning. Although computational modeling tools can offer realistic representations, they typically require previous knowledge related to boundary conditions, material behavior, and system idealization that exceeds the scope of early Statics coursework. Physical demonstrations can support visualization but are often instructor-led, difficult to scale for hands-on individual student engagement, and limited in their ability to provide precise and adjustable loading conditions. Consequently, many students struggle to connect analytical procedures with physical interpretation. These limitations motivate the need for instructional tools that provide authentic contexts and immediate visual feedback while remaining accessible to novice learners.

Augmented reality offers an opportunity to address these challenges by enabling students to interact directly with three-dimensional representations of mechanical systems. By visualizing forces and moments in real time and verifying analytical results within an interactive environment, AR has the potential to support both conceptual understanding and visual-spatial skill development.

This study examines the design and preliminary impact of an AR-based learning module focused on moments in Statics. It contributes to the limited body of research examining AR-based interventions in core mechanics topics, with a particular focus on supporting students who require additional time to achieve mastery within a mastery-based learning framework.

Guided by spatial visualization development and authentic learning perspectives, this WIP study addresses the following research questions:

- ***RQ1:*** How do participating students perceive the AR module with respect to engagement, usability, and confidence in understanding moments?
- ***RQ2:*** Among students who did not demonstrate mastery of moments within the first two assessment attempts, how is participation in the AR module associated with time to mastery compared with same-year and prior-year comparison groups?

2. Theoretical Framework

Spatial visualization skills play an important role in student success in engineering and related technical fields; however, many students enter engineering programs with underdeveloped three-dimensional spatial skills [3], [4]. Tasks such as identifying moment arms, reasoning about vector direction, and applying cross products place substantial demands on students' ability to mentally manipulate objects in space. Research indicates that spatial skills are malleable and can be improved through training, with durable and transferable effects. This motivates the design of learning activities that intentionally scaffold spatial reasoning when teaching conceptually demanding mechanics content [5].

Effective learning environments situate instruction within realistic contexts that support meaningful connections between formal representations and physical interpretation. Authentic learning environments promote deeper understanding and knowledge transfer by helping learners connect formal representations to relevant applications [6], [7]. In mechanics education, such contexts are particularly valuable for abstract concepts like moments, where students must reconcile numerical solutions with physical interpretation.

In this study, spatial visualization and authentic learning perspectives jointly informed the design of an AR-based learning module that allows students to interact with a realistic structural system while engaging in analytical problem solving. The AR environment was designed to provide immediate, visually anchored feedback without introducing modeling complexity beyond the scope of Statics.

3. Related Work

Prior research has examined the use of augmented and virtual reality in STEM education, reporting benefits such as increased student engagement, improved visualization of abstract phenomena, and positive learning outcomes, while also identifying challenges related to cognitive load, usability, and instructional design [8], [9]. Despite this growing body of work, relatively few studies have focused on the application of AR to core topics in engineering mechanics, and fewer still have examined targeted interventions designed to support students who require additional time to demonstrate mastery in mastery-based learning environments.

Many reported AR implementations rely on simplified representations or require modeling and analytical expertise that may be inaccessible to students early in the Statics sequence [8], [9]. The present study contributes to the literature by presenting an AR-based learning module that emphasizes authentic mechanics contexts, accessibility for novice learners, and direct integration with traditional solution methods.

4. Module Design and Implementation

4.1 Instructional Design

The AR environment was custom developed using the Unity game engine and deployed on mobile devices, enabling real-time visualization and interaction. The module was designed to promote active engagement, support spatial reasoning, and maintain analytical rigor. A central design goal was to allow students to manipulate forces of known magnitude and orientation within a controlled and realistic geometry. Unlike physical models, which can be costly, difficult to scale, and limited in adjustability, the AR environment allows students to independently explore multiple loading scenarios while maintaining consistent system parameters.

The module employs a mobile AR application to project a three-dimensional model of a billboard sign mounted on a fixed frame and subjected to a force representing wind pressure (Figure 1). Students vary both the magnitude and direction of the applied load, including horizontal and vertical angles, and observe the resulting moment vector in real time. The application also displays numerical values that students use to verify their calculations.

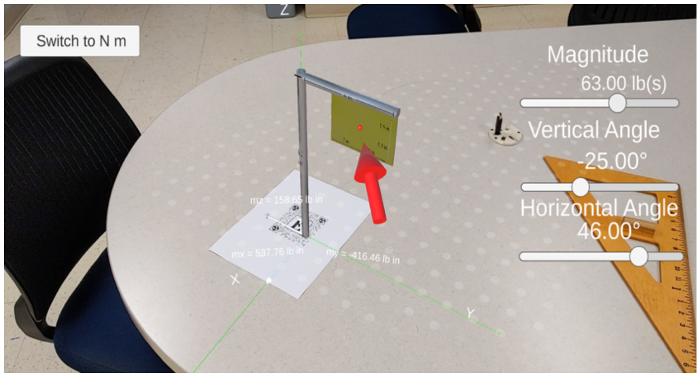

Figure 1. Augmented reality scene depicting the billboard sign mounted on a fixed frame and subjected to a force representing wind pressure.

4.2 Learning Activity

Students worked in small groups of two to five and completed a 45-minute guided activity in a lab setting. The activity was conducted after the second assessment opportunity and before the third. Each group received a printed handout outlining the tasks and a mobile device with the AR application installed. Guided prompts asked students to calculate moments using vector and scalar formulations, apply the right-hand rule, and compare their results with values generated by the application. The instructor provided logistical support during the activity.

5. Methods

5.1 Course Context and Participants

The study was conducted in a sophomore-level undergraduate Statics course structured using a mastery-based learning framework. Students completed weekly assessments for individual modules and demonstrated mastery by earning an A (perfect solution) or A- (one minor non-conceptual error). Students were allowed multiple attempts (one per week) to demonstrate mastery.

The Moments module was the second module introduced in the course and was first assessed during Week 3 of the semester, with a second assessment opportunity during Week 4. The Moments assessment consisted of two problems including a three-dimensional problem requiring calculation of the moment of a force about a point using Cartesian vector notation, and a two-dimensional problem assessing students' ability to analyze a couple. Correct solutions required appropriate use of position vectors, force resolution, vector cross products, correct sign conventions, and consistent units.

The AR group consisted of students who had not demonstrated mastery of moments within the first two assessment attempts and who voluntarily participated in the AR learning activity. Two comparison groups were included, a same-cohort comparison group of students who did not participate in the AR activity, and a prior-cohort comparison group drawn from a previous offering of the course taught using the same instructional structure. For both comparison groups, the analysis included only students who had not demonstrated mastery of moments within the first two assessment attempts. Because participation in the AR activity was voluntary, the AR and comparison groups may differ in motivation or engagement, representing a potential source of selection bias.

5.2 Data Collection and Analysis

Data sources included post-activity survey responses, assessment records documenting week of mastery, and final course outcomes measured as total modules mastered by the end of the semester.

Mastery outcomes were analyzed using cumulative mastery curves and descriptive statistics. For each group, cumulative percentages of students achieving mastery by week were calculated beginning with Week 5, the first assessment opportunity following the AR intervention. Time to mastery was characterized using the median week of mastery and the weekly percentage of students achieving mastery.

The survey included Likert-scale items and open-ended prompts addressing engagement, usability, and perceived learning value. Survey data were summarized using descriptive statistics, including means, medians, and percentages of responses in the highest agreement categories. Open-ended survey responses were reviewed and grouped into common themes related to visualization, engagement, and conceptual understanding.

Exploratory analyses of total modules mastered were conducted using descriptive statistics to examine potential downstream effects of earlier mastery of Moments. Given the optional nature of the intervention and the targeted group of students requiring more than 2 attempts to demonstrate mastery, inferential claims were made cautiously and framed as preliminary.

6. Results

6.1 Mastery Outcomes

Cumulative mastery curves indicate that students who participated in the AR intervention achieved mastery earlier than comparison groups (Figure 2). By Week 6, corresponding to the second assessment opportunity following the intervention, 54.5% of AR participants had achieved mastery, compared to 18.8% of non-participating students from the same cohort and 17.2% from the prior cohort (Table 1).

The median week of mastery was Week 6 for AR participants, compared to Week 8 for both comparison groups. Notably, 22.7% of AR participants achieved mastery on the first assessment following the intervention, whereas no students in the same cohort comparison group did so at that time.

Because final course grades depended on the total number of modules mastered, this metric was examined as an exploratory downstream outcome. Students who participated in the AR intervention mastered a median of 7.5 modules by the end of the semester, compared to 6.0 modules for non-participating same-cohort students (Table 2). This difference suggests that earlier mastery of the Moments module may have allowed AR participants more time to focus on subsequent topics. Given the targeted and optional nature of the intervention, these results are interpreted cautiously and are not used as primary outcome measures.

The interquartile ranges in Table 2 were similar across groups, suggesting comparable variability in final mastery outcomes rather than differences in outcome dispersion.

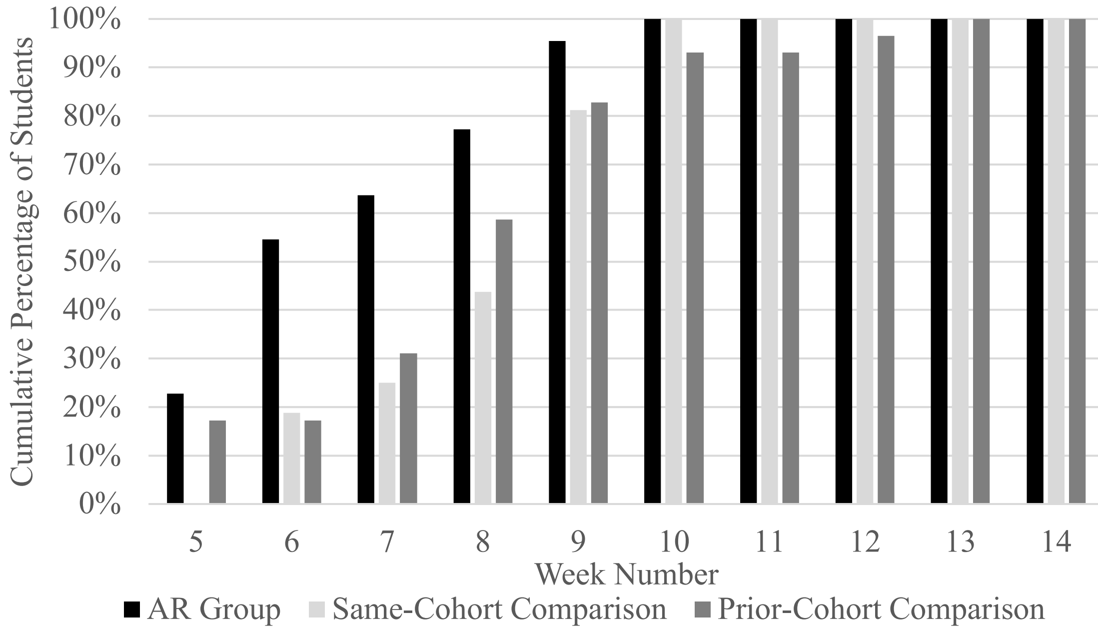

Figure 2. Cumulative percentage of students achieving mastery of the Moments module by week.

Table 1. Mastery Outcomes by Student Group.

Group	***n***	***Median Week of Mastery***	***% Mastered by Week 6***
AR Group	22	6	54.5%
Same-Cohort Comparison	16	8	18.8%
Prior-Cohort Comparison	29	8	17.2%

Table 2. Total Number of Modules Mastered by End of Semester.

Group	***n***	***Median Modules Mastered [IQR]***	***Mean ± SD***
AR Group	22	7.5 [3.8]	7.68 ± 2.42
Same-Cohort Comparison	16	6.0 [4.0]	6.62 ± 2.53

6.2 Student Perceptions

Survey results indicated strong engagement and perceived learning value. About 77% of students rated the activity as very engaging, and 82% reported increased confidence in their understanding of moments (Table 3). Qualitative comments reinforced these findings, particularly with respect to visualization and conceptual understanding. One student noted, *"I enjoyed the 3D example, and it really helped me understand the topic more,"* while another commented that the activity made it easier *"to visualize the object to better understand how it would physically react."* Several students also emphasized that the AR environment allowed them to focus on conceptual understanding rather than procedural complexity, with one student observing, *"the math was simple and our learning was more focused on the concepts and visualization of moments."*

Table 3. Student Perceptions of the AR Learning Module (n = 22).

Survey Item	***Mean***	***SD***	***% Rating +4 to +5***
Engagement	4.1	0.9	77%
Ease of Use	3.8	1.1	73%
Confidence in Understanding Moments	4.0	1.0	82%
Helpfulness of Visualization	4.2	0.8	86%
Likelihood of Recommendation	4.3	0.7	91%

7. Discussion

The findings suggest that the AR-based learning module supported both affective outcomes and earlier demonstration of mastery for students learning moments in Statics. Increased engagement and confidence reported by students were accompanied by earlier mastery on formal assessments, indicating that perceived learning gains were reflected in performance outcomes. A likely mechanism for this effect is the ability of the AR environment to externalize spatial relationships that students would otherwise need to construct mentally. By providing real-time visual feedback and enabling direct manipulation of force vectors, the module reduces cognitive load associated with spatial reasoning and allows students to focus on conceptual understanding. Alongside this, final mastery distributions exhibited comparable variability across groups, suggesting that the intervention influenced the timing of mastery rather than the overall spread of end-of-semester outcomes.

These results are consistent with prior research demonstrating the importance and malleability of spatial visualization skills in engineering education and the potential of interactive visual tools to support their development [3], [5]. By situating moments analysis within an authentic structural context and providing immediate feedback, the AR module appears to support students who require additional time to master this concept without altering overall performance variability.

Several limitations should be noted. Participation in the AR activity was optional, and the control group did not engage in a parallel hands-on activity. As a result, observed differences may reflect the benefits of structured interactive engagement rather than AR technology alone. These limitations inform directions for future research.

8. Conclusion and Future Work

This Work-in-Progress study examined the design and preliminary impact of an AR-based learning module for teaching moments in Statics. Addressing RQ1, student perceptions indicated high levels of engagement and increased confidence in understanding moments. With respect to RQ2, students who participated in the AR module and had not demonstrated mastery within the first two assessment attempts achieved mastery earlier than same-year and prior-year comparison groups, suggesting an association between AR participation and accelerated time to mastery.

Future work will explore the development of deformable AR models that incorporate basic physics to support learning in Mechanics of Materials. Subsequent studies will examine retention and transfer of learning across later mechanics topics and compare AR-based activities with alternative interactive instructional approaches.

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