AR-Classroom Usability: Implications for UX Research on AR-enabled Educational Technologies for 3D Matrix Algebra Learning

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***Abstract*— This research full paper describes the augmented reality (AR) application AR-Classroom that combines a physical and virtual environment to teach 3D geometric rotations in an engaging and simplified manner. The AR-Classroom contains a virtual workshop where users can perform rotations by manipulating the application's X, Y, and Z-axis sliders to rotate a virtual LEGO model and a physical workshop where users perform rotations using a physical LEGO model. Guided by previous findings and an iterative approach to usability, the present usability study focused on assessing the usability of the AR-Classroom in its most recent version using a new physical LEGO model (i.e., airplane) and reflecting on how discoverability and usability can be assessed using different types of user experience measures and qualitative analysis. Participants were 22 undergraduate students who completed a pre-test with demographic information, watched a video on geometric transformations, and were randomly assigned to interact with either workshop. While interacting with the AR app, participants were instructed to provide feedback and a single ease-of-use question score. Participants then completed a post-test with two measures of usability. Descriptive statistics of the UX measures were explored, and a thematic analysis was conducted to identify and code themes in human-computer interaction. Findings suggest that the AR-Classroom has reached satisfactory usability, and users can navigate the app's features effectively. Discussion includes insight into which aspects of the app need improvement, how to promote self-directed support in the app, the development of future app efficacy experiments, and how to evaluate the usability of AR technology for learning.**

***Keywords*— Augmented Reality, Educational Technology, Usability Testing, Spatial Transformation, Matrices.**

I. INTRODUCTION

Strong spatial and math abilities are essential for STEM performance. However, previous research identifies two critical difficulties underlying spatial skill development in three-dimensional (3D) geometry: visualization and mental rotations [1][2][3]. Previous researchers have investigated the utility of educational technologies for mediating the challenges students face when developing their spatial and math abilities [4][5][6]. In particular, the use of augmented reality (AR) in educational contexts has gained increased interest as research has demonstrated the potential to positively influence students' learning process for abstract and theoretical educational content [7][8][9][10].

AR's technological abilities provide a unique context to engage students, facilitate the collaboration between instructor and students, and enhance students' spatial ability through direct interaction with 3D objects in virtual space [11]. AR technology can provide a variety of virtual dynamic 3D structures to work with as it can increase understanding of concepts to improve students' learning [12]. AR can potentially enhance teaching and learning, especially for subjects that require students to visualize abstract content [13], such as 3D matrix algebra and their geometric transformations. AR technology incorporates virtual materials into a real-time situation by augmenting reality using 3D technology, creating a layer of information for the user's sensory view of the natural world [14]. However, the usability of AR-enabled educational technology for developing spatial and math skills needs to be critically investigated as implementing such technology, particularly in higher education, is still a novel approach.

The present study investigates the usability of AR educational technology, specifically the AR-Classroom application for learning 3D rotations and their underlying matrix algebra. The usability test aims to uncover user experiences with the app, identifying which features are accessible and which pose challenges. The insights from this study are crucial for informing future research on the usability of AR-enabled educational technologies for learning 3D matrix algebra and other mathematical representations of spatial transformations. These findings hold significant implications for the development and implementation of AR technology in educational settings, particularly in the context of higher education.

II. Research Background

User Experience (UX) is a person's perceptions of and responses from using a product or system (ISO 9241-210, 2010), often called usability. The International Organization for Standardization (ISO) in Standard # 9241-11 conceptualizes usability as "*the extent to which specified users can use a product to achieve specific goals with effectiveness, efficiency, and satisfaction in a specified context of use*" [15]. Usability is often assessed via a usability test, which asks participants to interact with a product, perform tasks related to the product's functionality, provide feedback on their experience, and answer questions about their perceptions, all of which allows the researchers to gain information about the product's ease of use or areas of difficulty [16].

Usability testing can inform researchers' and developers' understanding of users' experience interacting with their products [17]. Usability testing typically involves five broad research aims: (1) Investigate the participant's ability to complete specific tasks successfully, (2) Identify how long or how easy or difficult it is to use to complete specific tasks, (3) Examine how satisfied participants are with the product, (4) Formulate recommendations for changes required to improve user experience, and (5) Analyze the performance to see if it meets the usability objectives.

Usability is essential for understanding human-computer interactions, particularly for educational purposes. Learning using educational technology is greatly affected by perceived usability [18]. Though a wide range of research has evaluated user interactions with traditional systems such as web interfaces, computer software, and mobile devices, less is documented about assessing usability for AR-enabled educational technology.

A. *Usability of AR Technology in Education*

AR technology in education is particularly beneficial as it can enhance the learning environment by enabling the visualization of abstract concepts and providing students with an engaging format [19][20]. Visualization of theoretically complex concepts, such as 3D matrix algebra, considerably improves the understandability of abstract concepts [21], which are difficult to grasp for learners. As its popularity continues to grow, AR has been extensively studied, and researchers have formally begun to evaluate AR applications for educational purposes. User studies of AR technologies are still challenging as developers and researchers must ensure that AR experiences for education are properly designed experiments and appropriate evaluation methods are used [22].

III. AR-Classroom

The AR-Classroom is an AR-enabled application designed to create an engaging and interactive learning environment for students, development is further described in [23]. Its primary goal is to improve students' comprehension of spatial transformations and their mathematical representations through innovative features and hands-on experiences. The app's key feature is its ability to allow students to manipulate 3D physical models, like a LEGO space shuttle, to perform physical spatial transformations while simultaneously visualizing the process in AR and displaying the corresponding mathematical representation.

When a physical model is detected in the camera image, the app superimposes a wireframe on the model in the computer display. Two sets of virtual coordinate frames, each with X, Y, and Z axes, are attached to the physical model and the wireframe. To illustrate a rotation, the wireframe rotates around one of the three axes, and a virtual arc is drawn between the two coordinate frames. The angle and matrix of the rotation are also displayed on the screen, providing a comprehensive visual representation of the transformation process.

The app offers two distinct workshops, Workshop 1: Virtual Object Rotation and Workshop 2: Physical Object Rotation, each focusing on different approaches to spatial transformation. In Workshop 1, students select an axis (X, Y, or Z) and use a rotation angle slider in the user interface to perform spatial rotations around the chosen axis on a 3D virtual model (Fig 1). In contrast, Workshop 2 allows students to manipulate the physical model, selecting an axis and performing spatial rotations using their hands (Fig 2). The app detects and visualizes the physical rotations, providing immediate feedback and displaying an error message (i.e., False Rotation!) if the rotation is not around the selected axis.

The hands-on approach in Workshop 2 is designed to deepen students' understanding of spatial transformations by allowing them to observe changes in visualization as they rotate the physical model. The app is specifically structured to create a seamless learning progression from Workshop 1 to Workshop 2, enabling students to build upon their spatial transformation knowledge and enhance their learning experience through embodied learning.

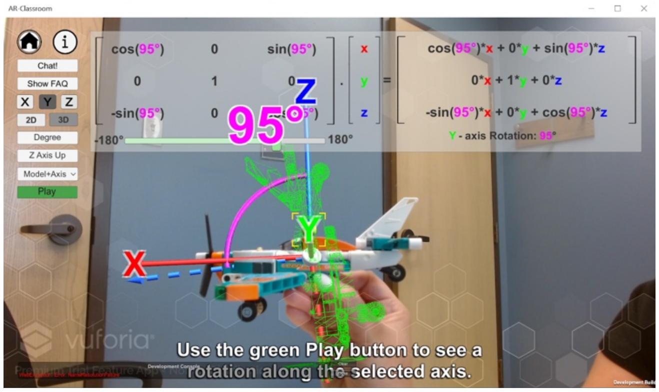

Fig 1. AR-Classroom Workshop 1: Virtual Object Rotation.

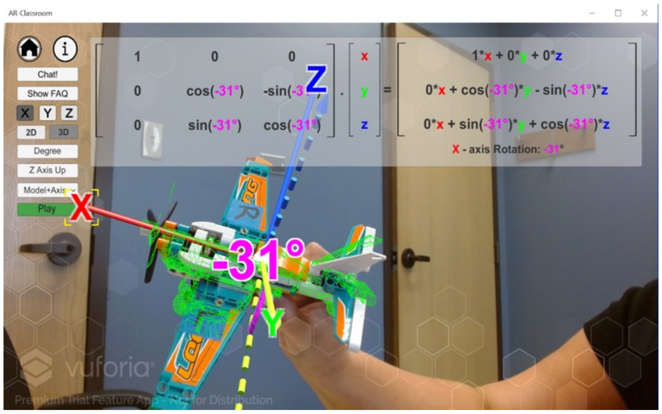

Fig 2. AR-Classroom Workshop 2: Physical Object Rotation.

A. Previous Usability and Learning Experiments

Aligned with standards for evaluating the usability of AR technology, usability tests of related AR technology [24] and numerous previous usability studies on the AR-Classroom app have been conducted at various stages of the product's development. First, the initial usability tests [25] of the AR-Classroom in its starting version were conducted, and findings were used to formulate recommendations to address issues and enhance users' experience. After implementing these changes, the second usability test was conducted to investigate the impact of changes made based on previous usability findings and identify any persistent usability issues. Based on the second usability test results, there were still salient issues in user-app interactions. This led to the third usability test [26] to investigate the cumulative impact of changes made to the AR-Classroom. The AR-Classroom was deemed satisfactory through this iterative approach to usability testing, and an initial learning experiment on its efficacy was conducted.

The findings from the initial learning experiment [27] [28] suggest that matrix algebra learning interventions delivered by AR-Classroom may be helpful and improve mathematical skills. After repeatedly using the AR-Classroom, students recognized the patterns and similarities between types of spatial rotations and demonstrated a fundamental understanding of the mathematical theory underlying 3D spatial rotations. The findings from the learning experiment were then used to develop a new version of the app that targets the identified strategies students use to learn matrix algebra, which is discussed in the present study.

IV. The Present Study

Guided by previous findings and an iterative approach to usability, the present usability test focused on assessing the usability of the AR-Classroom in its most recent version released in December 2023 using a new physical LEGO model (i.e., an airplane) and reflecting on how discoverability and usability can be assessed using different types of user experience (UX) measures and qualitative analysis. The test focused on descriptive statistics and qualitative data to answer three research questions on the AR-Classroom's usability:

1. What do users discover about the workshops?
2. What features of the workshops are accessible versus challenging?
3. How can the study's procedures inform future research about usability of AR-enabled educational technologies for learning 3D matrix algebra?

V. Methods

Participants were recruited via a research sign-up system in the Department of Psychological and Brain Sciences at Texas A&M University. The experiment took 1 hour, and participants received research credit for participation. Participants were 22 undergraduate students randomly assigned to either the virtual (N = 11) or physical conditions (N = 11).

A. Procedures

A The usability test conditions (virtual and physical) followed similar procedures, except for completing different workshops. Participants completed a pre-test with questions regarding demographic information, previous experience with matrix algebra, and a measure of math abilities and confidence. After completing the pre-test, participants watched an introductory video on matrix algebra that provided a brief overview of key concepts and terminology as a primer for students. After watching the videos, the AR-Classroom application was run on the desktop computer with a webcam, and participants were given the LEGO airplane model.

While interacting with the AR app, participants completed several tasks related to the app's functions. Both usability conditions completed the following tasks:

1. Take 5 minutes to try out the AR-Classroom's features (i.e., discoverability period).
2. Use the LEGO airplane to demonstrate a 90° clockwise rotation about the x-axis with 3D (3x3 rotation matrix) visualization.
3. Use the LEGO airplane to demonstrate a 30° counterclockwise rotation about the y-axis with 2D (2x2 rotation matrix) visualization.
4. Use the LEGO airplane to demonstrate a 0.5$\boldsymbol{\pi}$ radian clockwise rotation about the z-axis with 3D (3x3 rotation matrix) visualization.
5. Use the AR-Classroom to match the matrix (Fig 3).

5. Use the AR Classroom to match the following matrix.

$$\begin{bmatrix} \cos(45) & 0 & \sin(45) \\ 0 & 1 & 0 \\ -\sin(45) & 0 & \cos(45) \end{bmatrix}$$

Fig 3. Usability Test Task #5.

While completing these steps, participants were instructed to think aloud, explaining what they were trying to do, whether it was easy or challenging, and any thoughts related to their experience using the app. While participants are thinking aloud two researchers took notes on participants' reported experience using the AR-Classroom. After completing each task, participants' post-task metrics were measured. After the participant had completed the task, as they reported a single ease-of-use (i.e., SEQ) score from 1 (*very difficult*) to 7 (*very easy*). SEQ scores demonstrate how challenging each task is for a user and provide insight into task related difficulties when using a product [29]. Higher SEQ scores mean that the user rated the task as easy to complete using the AR-Classroom, indicating higher perceived usability.

After interacting with the AR-Classroom, participants completed a post-test with the same math abilities and a confidence measure as well as two measures of usability: the 16-item Post-Study System Usability Questionnaire (PSSUQ) [30] and the 4-item Usability Metric for User Experience Lite (UMUX-Lite) [31][32]. The PSSUQ is measured on a 5-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*) and provides an overall score (similar to the system usability score) by averaging all 16 items. However, it also has three subscales: System Usefulness (items 1–6), Information Quality (items 7–12), and Interface Quality (items 13–15). Similarly, the UMUX is measured on a 5-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*) and averages all four items for the overall UX score.

VI. Results

Descriptive statistics for the usability measures of SEQ for each task, the PSSUQ, and the UMUX-Lite were reviewed, however, statistical significance could not be determined due to small sample size ($N<30$). Thus, descriptive statistics were used to contextualize the findings of the thematic analysis.

Thematic analysis methodology was used to identify meaningful patterns and themes in user-reported experiences while interacting with AR-Classroom. Thematic analysis followed a 6-step process [33][34]: familiarization, coding, generating themes, reviewing themes, defining and naming themes, and writing up. First, two research assistants reviewed all participant observation notes to familiarize themselves with the data. Data was then analyzed to document codes (i.e., short labels) that describe the interaction experience. Next, the codes were reviewed, patterns were identified, and the research team developed themes. Themes were reviewed and revised to ensure that they accurately represented the data. Once the themes were finalized, they were defined, and their utility in data interpretation was considered to describe user experience iterating with the AR-Classroom.

A. Descriptive Statistics

Descriptive statistics of the post-test metrics PSSUQ and UMUX-Lite were explored using the AR-Classroom to see general user experience ratings. First, the PSSUQ overall mean score was 3.67 (SD = .97), with the subscales of System Usefulness (M = 3.72, SD = 1.07), Information Quality (M = 3.67, SD = .97), and Interface Quality (M = 3.52, SD = 1.10). Next, the UMUX-Lite average total score was 2.99 (SD = .37).

B. Thematic Analysis

Task #1 (Discoverability). During the initial free play period, three key themes were identified based on user-app interaction: *Initial confusion due to app 'clutter', usefulness of instructions*, and *ease of understanding*. For discoverability, SEQ scores showed that participants on average rated this task a 4.48.

At the beginning of the discoverability period, it was observed that participants needed help orienting themselves to the app when first introduced to the instructions page (Fig 4). A few believed it was overwhelming when they initially opened the app. The home page was described as "cluttered" and confusing to some participants (N = 3). Several participants (N = 5) would ask, "*Do I hit start?*" or "*Where do I start?*" to the research team after reviewing the instructions as they expressed confusion on whether to read instructions more thoroughly or start exploring the app.

Most participants (N = 18) read the instructions to understand better what they expected to do. Participants often spent a long time on the instruction page while other participants tried out the buttons first, returned to the instruction page to read it, and then returned to trying different buttons. When participants were given a few minutes of free play, they found navigating and using the app easier after reading the instructions thoroughly. Though participants may have appeared apprehensive when first seeing the instruction screen, they overwhelmingly noted that the instructions were helpful and referenced them at points during the usability test. Nine participants used the instructions to understand better what they were expected to do. These instructions were helpful to several participants as they mentioned that using the AR-Classroom during this discoverability period was "*pretty straightforward after reading instructions*." Meanwhile, nine other participants found navigating and using the buttons easier after reading the instructions thoroughly, sometimes even more than once.

Participants also reported difficulty maintaining registration (alignment between the virtual and physical models), meaning that the camera on the computer did not easily recognize the airplane held in front of the screen. Participants found it hard to hold the plane steady, kept moving it out of frame, or lost registration during the discoverability period and had to re-

register a few times (N = 8). Moreover, some participants (N = 7) had difficulty understanding axis rotations or registering the model (N = 8). It was observed that participants believed they were doing the correct rotations on the selected axis, but the app would display a "False Rotation." The registration of the model was continuously lost as participants attempted a rotation. It was noted that the app was considered "*very sensitive*" as it was difficult for participants to keep the model on a particular axis.

The AR-Classroom provided an easy understanding, particularly for visual learners. Some participants (N = 3) liked how the matrix was shown, and being able to interact live was helpful. One participant expressed their enjoyment of "*I think it's pretty cool…it shows you exactly what's happening like the rotations*," While another stated that "*measurements were accurate and the model provides good understanding for those who may not be as receptive about the concepts. AR model simplifies it, easier to learn for visual learners*".

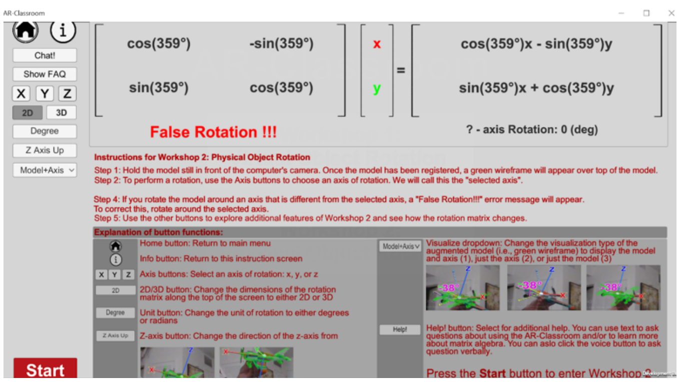

Fig 4. AR-Classroom Workshop 2: Instructions Page.

Task #2. For the second task of performing a 90° Clockwise Rotation About the X-axis with 3D Visualization, SEQ scores showed that participants rated this task an average of 5.48. The themes related to this task were the *ease-of-use manipulating slider, not intuitive to switch between dimensions, the ability to rotate about the X-axis* and *mixed experience with AR tracking.*

Most participants in the virtual condition (N = 8) immediately went to change the buttons and use the slider to change the angle. They expressed that this step was easy to grasp, with one participant stating that "*Slider is pretty straightforward and makes it easy to see where the thing [augmented model on screen] should go*." Several participants (N = 7) would not switch from 2D to 3D unless prompted by the researcher. Otherwise, participants will remain on the 2D viewing option. When it was time to rotate on the x-axis, the participants rotated the model correctly on the x-axis without help. Participants (N = 6) would need clarification on clockwise or counter-clockwise but would figure it out and rotate correctly. Almost all participants in the virtual condition were able to register the model and rarely had to re-register the model (N = 10); however, a few physical condition participants (N = 3) had difficulty with the AR tracking as they would rotate correctly, but the AR tracking would not follow while others were able to register.

Task #3. By the time participants began the third task of performing a 30° counter-clockwise rotation of the Y-axis with 2D visualization, they had begun to demonstrate a growing understanding of the app. The SEQ score rating of 5.67 demonstrated their growing knowledge of how to use the app's virtual and physical workshops. Given participants' ability to effectively interact with the AR classroom, the only theme identified for this task was *understanding of app functionality*.

Most participants (N = 16) had become familiar with the app, and its usage was becoming less challenging for them to navigate. Additionally, participants began to connect what they learned from prior tasks as they picked the correct dimension setting by selecting the 2D and y-axis before rotating the model. One participant noted, "*As I keep messing with it [the AR-Classroom app], it gets easier*."

Task #4. Task four of performing a .5π Radian Clockwise Rotation About the Z-axis with 3D visualization highlighted some challenges users had accessing app functions. Participants rated the task a 5.3 overall with findings revealing the themes of *confusion switching between degrees and radians* and *unfamiliarity with Z-axis rotations.*

Ten participants noted that they had trouble switching from degrees to radians in the app. Participants often did not know how to find the radians or would forget to change to the radian setting until after they performed the rotation. One participant stated, "*you have to realize you need to change the degree to radians but once you do that you're fine*." Additionally, some participants had to read the FAQ and check the Help button to learn what to do. After being prompted (N = 4) by the research team to switch to radians, participants were able to complete the task, and one participant expressed that they did not realize the button would switch them to radians. Another participant tried to change degrees to radians in their head until given a hint. "*I don't know what that [radians symbol] is….Once I figured it out it was easy*." Moreover, when performing a Z-axis rotation, many participants in the physical condition (N = 5) were confused. They stated they were unsure what a Z-axis rotation looked like and had difficulty moving the model around.

Task #5. The final task asked participants to rotate the airplane model using the AR-Classroom to match a 3x3 matrix printed on paper (Fig 3). Overall, participants rated this task a 5.52, with identified themes such as *the ability to manipulate the matrix on screen* and *trial and error of axis selection.*

Almost all participants (N = 18) demonstrated adaptability by seamlessly switching between 2D and 3D matrices without any hints or reminders. Their ease in this transition was evident, with some students even mentioning using what they remember from the introduction video to help them decide how to set up the matrix on screen. The majority of participants (N = 15) were able to switch between axes with ease. If they did not know what axis rotation to perform, they would try opposing rotations and switch through the buttons for the axis until the columns looked similar to the matrix shown to them on paper. A participant stated they knew they needed to "*...match the picture to what is on the screen. I knew this format [the matrix on paper] and knew how to switch everything*."

While there was no specific theme formulated for the final tasks related to the app's AR tracking, it was evident that eight participants in the physical condition encountered significant challenges. They required assistance in maintaining registration as they attempted to match the matrix as the airplane model frequently lost focus, disrupting their process. These participants candidly shared their struggles, stating, "*It's really difficult to keep it balanced*" and that "*Once you lose track, it's very challenging to regain your bearings*."

VII. Discussion

Based on an exploration of the descriptive statistics and thematic analysis findings we were able to answer our driving research questions: (1) What do users discover about the workshops?, (2) What features of the workshops are accessible versus challenging?, and (3) How can the study's procedures inform us about the usability of AR-enabled educational technologies for learning 3D matrix algebra?

First, after initial interaction with the instructions page, users can easily navigate the instructions page and retrieve relevant information as needed. Users can also rotate about the X-axis more quickly than the Y or Z axes, likely associated with their familiarity with this axis in the two-dimensional space. Finally, after performing several tasks with the AR-Classroom, users could manipulate the app's settings and the matrix on the screen either through physical or virtual rotation to match a 3x3 matrix (i.e., task #5), either on their first try due to their knowledge of what a rotation would look like based on the matrix or by trial-and-error where they clicked several buttons on screen and tried multiple directions of rotation. In both approaches, users can interact with the AR-Classroom in a way that allows for self-directed learning, as defined by Knowles [35] as "*a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes"* (p. 18).

Next, as indicated by SEQ scores, we found that the 90° Clockwise Rotation About the X-axis with 3D Visualization (i.e., task #2, M = 5.48), performing a 30° counter-clockwise rotation of the Y-axis with 2D Visualization (i.e., task #3, M = 5.67), and rotating the airplane model using the AR-Classroom to match a 3x3 matrix printed on paper (i.e., task #5, M = 5.52) were the most straightforward tasks for participants to complete. These tasks may have been more accessible for users after task #1 of five minutes of the discoverability period, which allowed users to become familiar with the app before performing sequential tasks, as noticed by the low rating of the first task (M = 4.48) compared to the following. Beyond task #1, participants also had particular difficulty performing a Z-axis rotation with radian notation (M = #4), which is unsurprising as participants were less familiar with what a Z-axis rotation would look like in a real-world situation. Additionally, we documented that participants could perform a rotation using the AR-Classroom based on a matrix provided to them by the final task. These findings suggest that as users continue to use the app and become familiar with AR-Classroom, it is easier to visualize a 3D rotation across the X and Y axes.

Finally, considering the current findings and reflecting on our team's previous usability studies on the AR-Classroom, evaluating the usability of AR-enabled educational technologies for learning 3D matrix algebra provides unique challenges as researchers must consider the user's previous knowledge of the content, their familiarity with AR technology, and the efficacy of the data collection methods. As AR is a new and emerging technology, users may be uncomfortable with it. It is essential to provide participants with a tutorial or training exercise to learn the device's controls before evaluating the application. Researchers can work this into their experimental design by including a dedicated time to practice using the AR-Classroom and similar devices between discoverability or training prior to the test sessions.

Another consideration for UX tests on AR-enabled technology for learning is that researchers must intentionally include multiple data points, including qualitative and quantitative methods. Using task metrics during the test, including SEQ scores, provides immediate feedback and response to the task rather than a retrospective recall during the post-test. Aligned with immediate and direct feedback, having users' think out loud' while performing tasks using the AR-enabled app allows users to express their experience in real-time with their own words, which is particularly important for ensuring the accessibility of a product. Additionally, including observational data provides a non-verbal context of users' qualitative feedback, so while a user may rate a task low on ease of use, their qualitative feedback may reveal which specific part of the task is contributing to difficulty in completion. Moreover, the subjective questionnaires given during a post-test can be used to gather users' quantitative perceptions about a product, which can be helpful as they are typically quick to administer and can be used to compare multiple versions of products against each other. Incorporating task metrics, questionnaires, user-reported feedback and observation in usability testing provides more robust interaction findings.

A. Limitations

The present study evaluates the AR-Classroom's current usability with a multi-method approach to assessment, including UX tasks with SEQ scores, user-reported feedback, researcher observations, and two post-test UX measures. However, a noted limitation of the present study may be its small sample size, which impacted the author's ability to determine statistical significance. However, previous research has established that the sample size for usability differs from other empirical studies. The mathematical model of problem discovery rates in usability testing [36][37] demonstrates that most usability problems are detected with the first three to five subjects; running additional subjects during the same test is unlikely to reveal new information, and return on investment in usability testing is maximized when testing with small groups using an iterative test-and-design methodology. Thus, our sample of twenty-two participants, with eleven in each condition, provides saturation in the findings of usability of the current version of the AR-Classroom.

Moreover, when evaluating the usability of AR-enabled technology, such as the AR-classroom, metrics gathered during usability testing, such as time on task, task success, and user-reported experience [38], need to be documented. These can be collected by observing the participant and noting their behaviors and feedback. However, observing a participant's screen when using an AR application can be difficult. To mitigate this issue, two research assistants were present for every usability test, and both documented observations of what the participant was doing on screen (e.g., clicking the correct button, using the slider to rotate, etc.) during the user-app-interaction period.

Future research on the AR-Classroom's usability will be conducted as new app versions are released. Each usability test will continue to focus on reported user experience using a multi-method approach and iterative process to derive recommendations to enhance the app's development. As each version of the AR-Classroom app meets satisfactory usability, learning experiments will further investigate the app's efficacy in teaching 3D matrix algebra. After each learning experiment, new features are then added to the app as deemed fit by the results of prior experiments to meet targeted learning goals. Then, the process of conducting usability tests and learning experiments continues. By following this process of usability and efficacy evaluations, the authors can provide other researchers guidance on how to create effective AR-enabled technology for learning, ensure validity in the app's abilities, provide data-driven solutions to UX issues, and support students learning of 3D matrix algebra using the AR-Classroom.

VIII. Conclsuion

In summary, the present study on the current version of the AR-Classroom app explored the app's usability using qualitative and descriptive statistics. Findings were used to understand what users discover using the app, what features are easy or difficult to use, and provide recommendations for future research on AR-Classroom and similar technologies. By following the process of usability and efficacy evaluations, the authors can provide other researchers guidance on how to create effective AR-enabled technology for learning, ensure validity in the app's abilities, provide data-driven solutions to UX issues, and support students learning of 3D matrix algebra using the AR-Classroom.

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