# AR-Classroom: Integrating Conversational Artificial Intelligence with Augmented Reality Technology for Learning Spatial Transformations and Their Matrix Representation


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***Abstract*—This research full paper describes the AR-Classroom application that utilizes augmented reality (AR) and physical and virtual manipulatives to enable undergraduate students to build intuition about the relation between spatial transformations and their mathematical representations. To further build on the app's usability and functionality, additional features are being prototyped to continue improving the user-app interaction with the AR-Classroom. Some of the challenges the students faced when using AR-Classroom were recalling basic matrix operations without geometric context, basic trigonometric functions and their applications in the two-dimensional space, loss of AR registration for not understanding the AR environment, and User Interface (UI) issues. To address these issues, a conversational Artificial Intelligence (AI)-based multi-sensory and interactive assistance has been added to the AR-Classroom. Integrating sophisticated language processing and response generation of AI with immersive three-dimensional capabilities of AR can create a more engaging learning experience than the previous versions of the app. This integration focuses on creating a symbiosis between AR and AI. It creates an elevated user experience by offering real-time, personalized assistance to students dealing with issues related to understanding mathematical concepts and functionalities of the app. A qualitative exploratory usability study was done to assess the user's interaction with the AI implemented in the AR-Classroom, aiming to explore the AI's ability to guide students in using AR technology and aid in introductory matrix algebra learning, to effectively serve the students' learning. Based on the thematic analysis of the user experiment we found four main themes related to users' perceptions of AR-Classroom AI features usability : (1) AI chatbot ease-of-use, (2) Need for answer elaboration from AI, (3) Desire for visual information, and (4) Increased understanding of the content area. The scores of ease of use indicate AI's ability to guide complex tasks in an AR environment using AI features with less concern for the cognitive load. The overall result suggests the need for further investigation on incorporating AI-guided visual cues in an AR environment.**



***Index Terms*—Augmented Reality, Conversational AI, Spatial Learning, Educational Technology**

## I. INTRODUCTION

Understanding mathematical concepts (such as translation, rotations, and matrices) significantly contributes to aerospace engineering, mechanical engineering, civil engineering, computer graphics, civil engineering, architecture, and other Science, Technology, Engineering, and Mathematics (STEM) fields. Several students in their first year of undergraduate studies in the STEM discipline face difficulties in visualization and drawing tasks despite having several resources of Computer Assisted Learning (CAL) in geometry, spatial transformations, and related mathematics [1]. Many students who studied drawing in secondary school, have not developed their spatial ability sufficiently and they have serious difficulties with mentally manipulating figures in space [2]. Some of the issues are: understanding the symbolic notation of linear algebra, generalizing geometric ways of reasoning [3], and switching to matrix representations of the transformations resulting in a lost intuitive connection [4].

Language can encode type vs token distinction, quantificational relation, and taxonomic relation which are invisible to spatial representation [5]. Spatial representation can encode detailed geometric features that language cannot [5]. The audiovisual multi-sensory approach can provide effective teaching and learning [6] which can be utilized for spatial learning. Many educators advocate for the integration of visualization technologies in teaching and learning mathematics [7]. AR in the learning process can improve spatial abilities in the domain of architecture education [8].

Natural Language Processing technology enables machines to comprehend, analyze, and interpret natural human languages and generate human-like responses. This ability has made this technology widespread for getting quick answers to a wide variety of questions and topics [9]. Integrating sophisticated language processing and response generation of AI with immersive three-dimensional capabilities of AR can facilitate a more engaging spatial learning experience [10]. This ability is also useful for resolving usability difficulties by giving relevant and reliable information and removing cognitive load and physical effort. This research focuses on an exploratory approach to create a symbiosis between AR and conversational AI for spatial learning by offering real-time, personalized interactive assistance and a multi-sensory immersive experience.

This research intends to identify an efficient system for learning rotation matrices using AR and conversational AI-assisted embodied learning, with a focus on evaluating the efficacy of AI-guided instruction. In this paper, we discussed the following research questions.

(a) How conversational AI can be incorporated in an AR environment to teach complex mathematical concepts (i.e. transformation matrices) to undergraduate students and to reduce the limitations of the previous version of AR-Classroom?

(b) What are the processes and outcomes of exploratory usability test to evaluate the effectiveness of conversational AI to answer complex mathematical questions and successfully guide the students using the AR environment?

(c) What are the limitations of the conversational AI and AR integration in AR-Classroom and the directions of future improvements in the application?

This paper is divided into the following sections. Section II presents a brief literature review. Section III discusses the first question mentioned above by describing our implemented features. Section IV discusses the details of user study and the results of the thematic analysis. Subsections IV-A and IV-B examine the second question and Subsection IV-C explores the third research question. Lastly, Section V concludes our paper with directions for future works.

## II. LITERATURE REVIEW

Research has shown that embodied learning, using physical manipulatives combined with quality instruction, can support mathematical understanding [11]. This approach can also change students' perception of mathematical concepts compared to using purely virtual manipulatives [12]. The capability to understand transformations as both visual representation and mathematical functions is essential for developing a critical comprehension of the mathematics of transformations. This understanding is influenced by the APOS (Action-Process-Object-Schema) Theory of mathematical learning, but it remains a challenging task for many students [13]. Dynamic math software can aid in learning transformations effectively. There are several applications and online resources available for students on top of traditional mathematics books. For example, GeoGebra is an open-source dynamic math software that links interactive geometry with algebra and helps students get an intuitive feeling and visualize adequate math processes [14].

The use of AR-based technologies can reduce the cognitive load of users required for spatial learning by superimposing virtual instruction on the real world. AR has three distinguishing features: combination of real and virtual; interaction in real-time; and registration in three dimensions [15]. Education in many STEM fields requires students' learning experience within well-designed instructional approaches. AR-based systems can provide this experience through experimental practices and tasks with high representational accuracy and realistic simulation [16]. Using AR in education has several positive impacts: increased content understanding, learning spatial structures, language associations, long-term memory retention, improved collaboration, and motivation [17]. Using AR-powered embodied learning for spatial translation and representation of corresponding matrices has already shown significant improvement in the participants' math scores [18]. The project AR-Classroom uses embodied learning and novel AR features to visualize spatial rotation and their mathematical representation, and the usability tests that were completed using the application showed promising results [19]. The benchmark test and updated usability test done on 24 participants have shown significant improvement in usability scores [20].

AI and machine learning are now commonly used to power AI chatbots, which can provide an engaging and useful user experience. Using conversational AI in education is one of the major approaches to enhancing and promoting a more personalized learning experience [21]. A well-designed chatbot can leverage the neural network of AI to create an engaging and beneficial user experience [22]. Combining these AI applications with AR can bring about many benefits. For instance, in a training scenario, an intelligent chatbot can act as a mentor, providing additional guidance and feedback to the trainee, thus enhancing the training process [23]. A novel early education platform that combines smart voice commands and AR technology is introduced in [24]. The platform is embedded in a storage box, making it convenient for use in homes and kindergartens where preschool education is provided. This project enhances the integration of these technologies in educational settings. The use of AR technology and speech recognition to support productive vocabulary among students has shown user satisfaction when parents and teachers were interviewed [25]. Some of the issues are the inherent nature of AI algorithms that are prone to bias and the possibility of increasing the already-existing inequalities in the educational system [9]. Generative conversational AI faces mixed reviews about its relevance and usefulness in practical applications being prone to errors such as the provision of biased or fake information, inaccuracies, and vagueness [26]. Based on the study above, this work aims to establish a synergy between AR and conversational AI to enhance the understanding and visualization of complex mathematical concepts like rotation matrices. In this research, we utilized AR-Classroom as a testbed to implement and develop an effective integration between AR and conversational AI.

## III. AR-CLASSROOM

### *A. Augmented Reality*

AR-Classroom uses AR technology to provide students with an interactive experience to learn spatial transformations. A student can hold and manipulate a 3D physical model (e.g. Airplane LEGO Model) to rotate it along the X-, Y-, and Z-axis and view the corresponding augmented mathematical representation. There are two workshops in AR-Classroom to provide a continuous learning experience: Workshop 1 and Workshop 2. In Workshop 1, the students utilize the UI component (a rotation angle slider) to perform the spatial transformation by rotating a 3D virtual model (Figure 1). In Workshop 2, the students use their hands to rotate the 3D physical model to perform the spatial transformation (Figure 2). Workshop 2 is more challenging for students because of the hand motion but it also brings more opportunities associated with AR (e.g., detection of false rotation).

At the beginning of both workshops, students go through a tutorial session that introduces the AR application. After the tutorial session, the student has to hold the model in front of the camera to register the 3D physical model. We used "Model Target" from Vuforia to detect and localize the model with the help of a trained 3D model-based recognition database of the

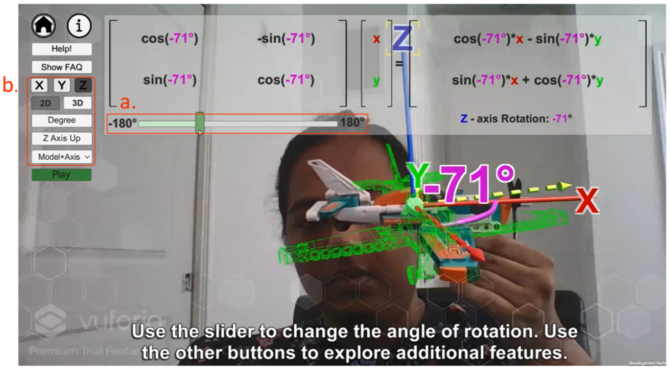



Fig. 1. Workshop 1: Virtual Model Rotation. (a) Slider for rotation (b) UI elements to visualize 2D vs 3D, radian vs degree, Z-axis up vs Z-axis down.

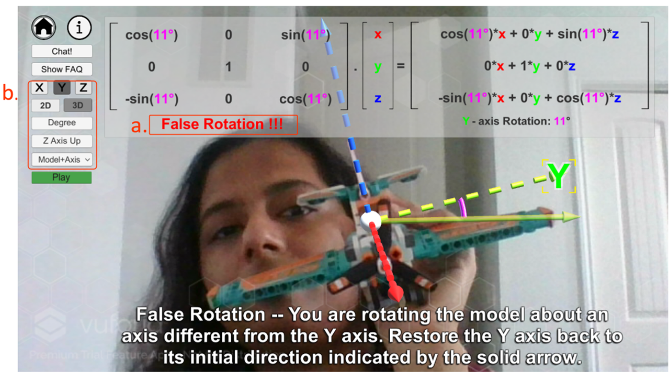



Fig. 2. Workshop 2: Physical Model Rotation (a) False rotation flag (b) UI elements to visualize 2D vs 3D, radian vs degree, Z-axis up vs Z-axis down.

3D physical model [27]. After the recognition is achieved, a virtual wireframe model is superimposed over the physical model and the registration is complete. After the registration is successful, the student chooses an axis (from X-, Y-, and Z-axis) to start the rotation process. The display shows the following components (Figure 1, Figure 2) during the rotation process-

1) a physical model that shows the state before rotation
2) a 3D reference frame coordinate with X-, Y-, and Z-axis represented by red, green, and blue solid arrows attached to the physical model
3) a 3D wireframe model which shows the state after rotation
4) a 3D reference frame coordinate with X-, Y-, and Z-axis represented by red, green, and blue solid arrows attached to the 3D wireframe model.

After selecting one axis, students can perform the rotation. We assigned the wireframe model to be the body frame in Workshop 1. Students can rotate the wireframe model using a slider in Workshop 1 and observe the corresponding equation on the panel (Figure 1a). In Workshop 2, the 3D physical model is assigned as the body frame and the wireframe model is the reference frame. Students use their hands to rotate the physical object along the selected axis and observe the corresponding equation. If the students make a mistake during Workshop 2, a “False Rotation” flag is displayed to the students (Figure 2a). There are several UI elements in the display that the students can utilize during the rotation. These UI elements reflect the mathematical changes in the matrix rotation equations on the display panel. Students can use toggle buttons to make the following changes: 2D vs 3D, radian vs degree, and Z-axis up vs Z-axis down (different conventions used in different fields such as architecture vs aerospace) (Figure 1a, Figure 2a).

### *B. Limitations of AR*

After the qualitative study from the usability test and learning test of the previous version of AR-Classroom [20], we encountered the following issues that needed to be addressed.

1) Some of the students had forgotten multiple basic mathematical concepts related to matrices, algebra, and trigonometry that constitute rotation matrices. Without background knowledge, it is very difficult to comprehend the concept of matrix equations for rotations. The students sometimes need personalized instruction to remind them of the forgotten concepts as the depth of knowledge of different students varies significantly.
2) Students face difficulties registering the 3D physical model as some of them struggle to hold it properly in front of the camera of the AR device (a computer with a webcam running AR registration). When interacting with the application, if the 3D physical model is removed from the view of the camera, the tracking of the physical model stops. To continue using the application, the model needs to be brought in front of the camera again which is difficult for some students to understand.
3) After selecting an axis, students face difficulties performing the rotation, especially during the hand rotation in Workshop 2, undesired rotations inevitably happen. Even though the rotation around a wrong axis is conveyed to the students by the “False Rotation” flag, some of the students struggle to correct it.
4) Some students avoid using UI buttons that help to observe corresponding versions of matrix equations. It happens because they forget about the instructions on UI when they are conducting the rotation.

### *C. Conversational AI Integration*

To solve the challenges mentioned above we integrated conversation AI to provide each student personalized guidance. Conversational AI can power automated messaging and speech-enabled applications, enabling human-like interactions. This involves a combination of art and science, incorporating language detection and machine learning to recognize speech and text, understand intent, and interpret languages to respond appropriately. Context, personalization, and relevance are crucial elements in creating natural-sounding conversations that can help each student in their learning process [28]. For this purpose, we integrated a conversational AI-powered bot to engage in vocal or textual communication with the students in real-time. Voice bots engage in two-way communication with users by understanding natural language. They utilize various methods to listen, comprehend, and learn throughout their usage which is essential for increasing the flexibility of communication [29].

We used ChatGPT through OpenAI API as the conversational AI integrated with the UI of AR-Classroom. The AI learned the knowledge of the AR-Classroom UI, registration process, and rotation techniques at the back end through the documentation of the app. It can also retrieve general mathematical knowledge from the OpenAI database to help the students with basic concepts. For multimodal communication between AI and the user, we implemented both voice and text options and the user can choose either one of them. The voice feature is more helpful when the student is holding the 3D model while communicating. The text feature is helpful in a noisy environment, or the student is unable to use voice for some reason.

When the user chooses to use the voice option, the audio is recorded and converted to text by utilizing “Audio Transcription” features and the Whisper model from OpenAI [30]. For each step of the user journey, we created a custom prompt based on the information about the application and previous user study data. We utilize these custom prompts and questions asked by the user for text generation. We used the “Chat Completion” features and “gpt-3.5-turbo-1106” model from OpenAI for text generation [30]. After receiving the text from the AI, we convert it from text-to-speech using Amazon Polly [31]. This option has an added advantage because the students do not need to read the text when they are focusing on the matrix equation. Both text replies and voice replies are presented to the student to enhance communication flexibility. In Figure 3, we can see the information flow during user interaction with conversational AI.

The conversational AI could answer mathematical questions related to the understanding of matrix rotation equations from its training data. We provided information that is directly related to our application to provide comprehensive knowledge to the students. We provide the following information for Workshop 1.

1) Frequently asked questions and answers prepared based on the previous user testing of Workshop 1
2) Description of AR features of Workshop 1
3) Description of the functionality of each UI element
4) Physical model registration guidance
5) Rotation guidance for Workshop 1 along the X-, Y-, and Z-axis

We provide the following information for Workshop 2.

1) Frequently asked questions and answers prepared based on the previous user testing of Workshop 2
2) Description of AR features of Workshop 2
3) Description of the functionality of each UI element
4) Rotation guidance for Workshop 2 along the X-, Y-, and Z-axis
5) Correction Guidance for false rotation

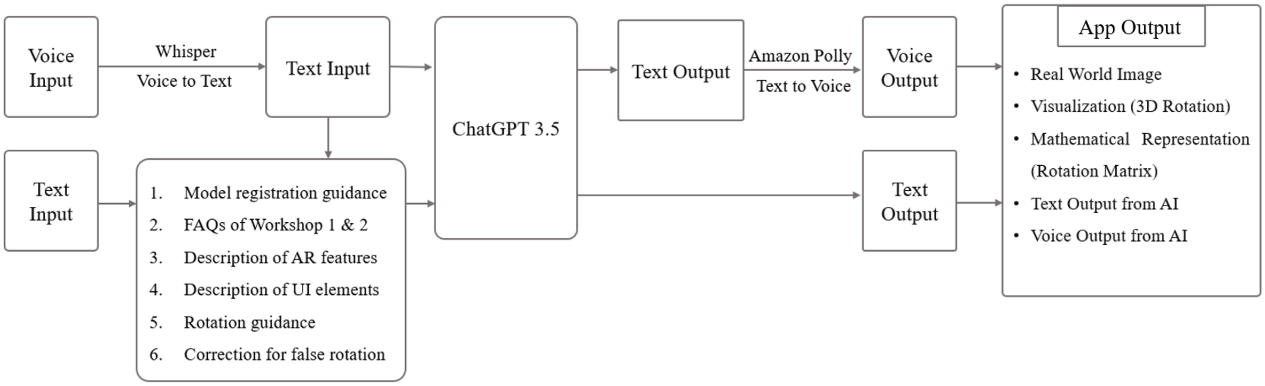



Fig. 3. Conversational AI Information Flow.

6) Physical model registration guidance

### D. *User Interface of Conversational AI*

We included a button named "Chat!" that is visible after the students choose a workshop to initiate the conversational AI feature (Figure 4a). After clicking the button students can view a scrollable panel (Figure 4b), a text input area, Send button (Figure 4c), and a Voice Record button (Figure 4d). The scrollable panel visualizes the conversation between the user and the AI. The text input option and Voice Record button are utilized by the students for asking questions. We limited the answer length to 50 words to keep the communication concise and efficient.

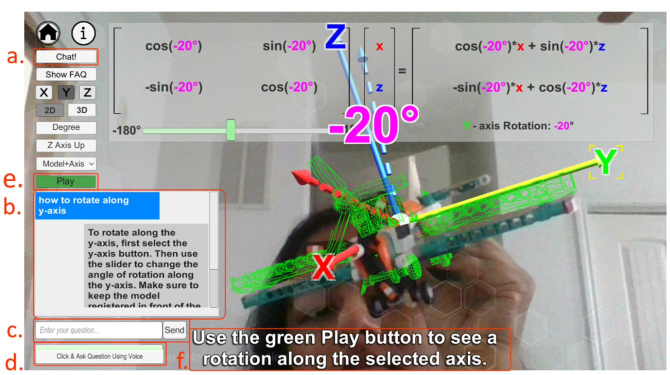



Fig. 4. Conversational AI User Interface. (a) Button for AI interaction. (b) Conversational panel. (c) Text input section. (d) Voice input section. (e) Play button for rotation animation along X-, Y-, and Z-axis. (f) Step-by-step instruction with voice-over.

We also added some additional features: (1) Play Button to visualize an animation of rotation along the X-, Y-, and Z-axis to guide the students (Figure 4e), (2) Step-by-step vocal and text instruction for guiding students through the application (Figure 4f). Both additional features are developed using the text-to-speech of Amazon Polly. For the Play Button in Workshop 1, we created the animation using the existing green wireframe model (Figure 5a). However, Workshop 2 requires the student to rotate the physical model by hand, which is challenging to visualize. In this case, we utilized

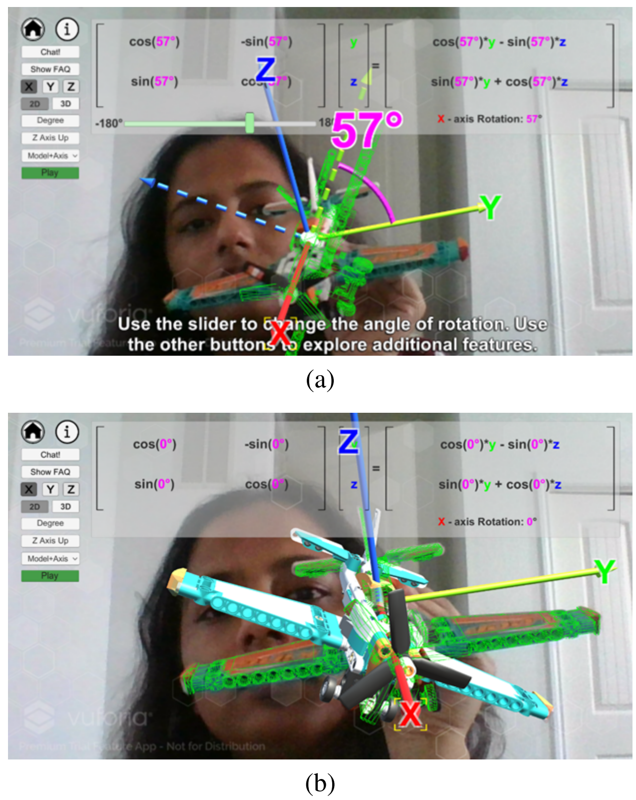



Fig. 5. (a) Play Button rotation animation in Workshop 1. (b) Play Button rotation animation in Workshop 2.

a rendered virtual model rotation animation to replicate the rotation of the real model (Figure 5b).

### E. *Exploratory Test and Discussion*

While developing the conversational AI, we tested the accuracy of our implementation by asking several questions based on the limitations that were found during the test of the previous version of AR-Classroom. The AI component utilized the information that was provided on the features and functionality of the AR-Classroom application successfully and gave answers effectively in most cases. We have added some selected examples to discuss how AI performed in different cases (Figure 6) which addresses the first limitation mentioned in Subsection III-B. It could answer basic questions about rotation matrices concisely (Figure 6a) and then answer a follow-up question (Figure 6b).

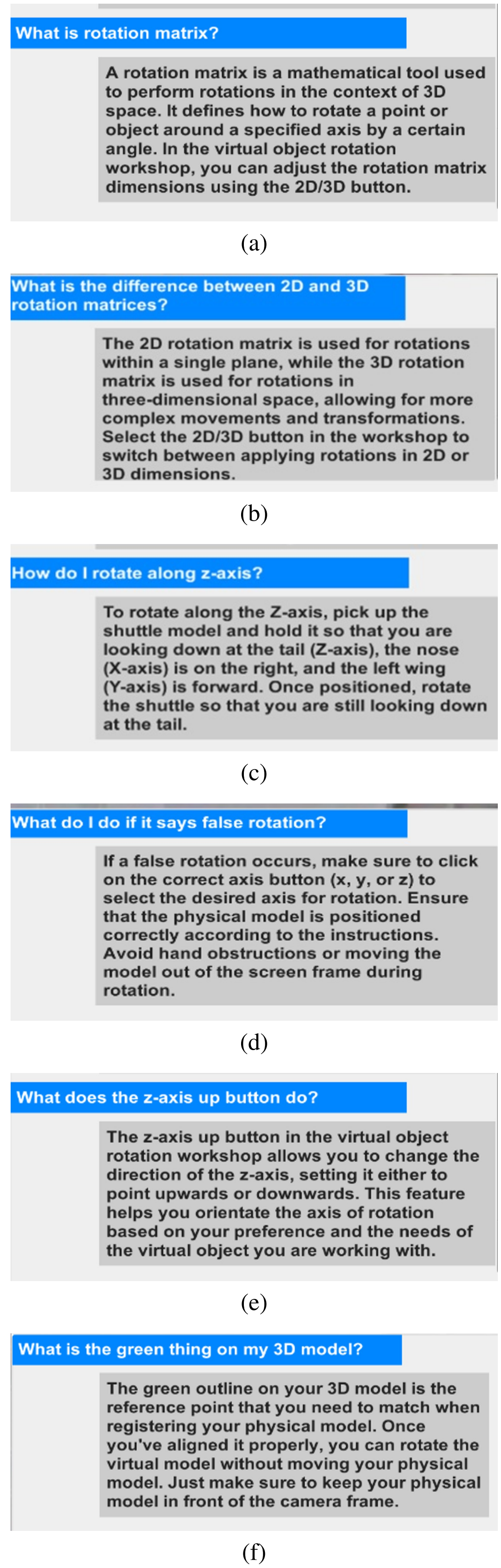
It could also connect the mathematical concepts with related features of the application and guide the user to explore those features (Figure 6a, Figure 6b). In addition, it could answer the process of rotating the model along a certain axis referencing different parts (connected tail with Z-axis, nose with X-axis, and left-wing with Y-axis) of the physical LEGO model (Figure 6c). This addresses the second limitation mentioned in Subsection III-B. One major issue the students faced was dealing with false rotation which is mentioned in the third limitation of Subsection III-B. In the exploratory test of Workshop 2, after choosing a certain axis and getting the "False Rotation" flag, the AI was asked what to do in case of false rotation (Figure 6d). It replied, "*If a false rotation occurs, make sure to click on the correct axis button (x, y, or z) to select the desired axis of rotation. Ensure the physical model is positioned correctly according to the instructions. Avoid hand obstructions or moving the model out of the screen frame during rotation*." Although the answer is not wrong, it did not provide an axis-specific answer when a certain axis was selected. This leaves room for the future development of the AI functionality of the application with higher accuracy. When asked about the UI elements, for example, the functionality of each button or dropdown, it gave the correct answer in all cases (Figure 6e). It could also answer correctly when asked about different elements of the AR environment (e.g., green wireframe model and its purpose, how to maintain registration, etc.) (Figure 6f). This addresses the second limitation mentioned in Subsection III-B. Based on these positive findings, we organized a user study focusing on the efficiency of AI for further exploration.

## IV. User Study of AR-Classroom Focused on Conversational AI

To understand how users perceive the usability of the AR-Classroom's AI features and identify initial areas for improvement, a qualitative exploratory usability test of the AI features within the AR-Classroom was conducted.

### A. Exploratory Usability Test

Participants were recruited via flyers and email from a large R1 university in Texas. The experiment took 1 hour. Participants were six undergraduate students enrolled in a STEM major or discipline, randomly assigned to either the virtual rotation - Workshop 1 (n = 3) or physical rotation - Workshop 2 (n = 3) conditions. 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




(a) (b) (c) (d) (e) (f)

Fig. 6. Exploratory Communication between Researcher and AI.

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 first spent five minutes of free play to interact with the app and discover what functionalities the app possessed. After five minutes, participants completed four information search tasks using the app's AI text or voice option (Figure 4c, 4d): (1) use the voice function to ask the AI a question about matrix algebra, (2) use the text function to ask the AI a question about matrix algebra, (3) use the voice function to ask the AI a question about the AR-Classrooms functions, and (4) use the text function to ask the AI about the AR-Classrooms functions. While completing each task, participants were instructed to think aloud, explaining their impression of using the AI, the AI's answers, and any thoughts related to their experience using the app. While participants were thinking aloud, notes were taken on participants' reported experience using the AR-Classroom's AI functions.

### *B. Thematic Analysis and Discussion*

The qualitative data collected during the user-app-interaction section was analyzed using thematic analysis methodology to identify patterns and themes in user-reported experiences while interacting with the AR Classroom's AI features. After conducting a thematic analysis of each section of the experiment, we found four main themes related to users' perceptions of AR-Classroom AI features usability: (1) AI chatbot ease-of-use, (2) Need for answer elaboration from AI, (3) Desire for visual information, and (4) Increased understanding of the content area.

After completing each task, participants reported a single ease-of-use (i.e., SEQ) score of 1 (very difficult) to 7 (very easy). Ease-of-use describes how easily users can navigate and interact with a product, complete tasks, and achieve their goals. After interacting with the AR-Classroom, participants completed a post-test with the same math abilities and a confidence measure. All participants (n = 6) could easily ask the AI questions, both with the voice chat feature and the text feature, and immediately received an answer that provided excellent information about matrix algebra or the app's functionality. Almost all study participants (n = 5) rated each task with the AI chatbot as a six or a seven on the SEQ score. Participants also noted that the AI could pick up questions with the voice well and answer the questions accurately and correctly. However, one participant found that using their voice to ask the AI how to perform a specific function on the app was difficult, with a SEQ score of 4 for the task, and further explained that the answer was not as adequate as they needed and discovered that they had to ask the question in a different, more specific way to get the desired answer.

Another recurring finding was that participants wanted visual representation as part of the AI's answer (n = 4). One participant mentioned that "*diagrams and arrows pointing to the functions or matrices...*" would be better for visual learners. While another participant noted that if the AI "*ran [them] through an example...*" it would be more helpful. Finally, at the end of each experiment, participants overwhelmingly agreed that the voice chat feature was more valuable than the text feature, as "*when you're playing with [the model], it's easier to ask the question rather than type it.*"

### *C. Limitations and Future Direction*

Findings from the exploratory study of the AR-Classroom's usability provided researchers and developers insight into how users naturally interact with novel conversational AI in an educational context and what they expect to learn from the information AI provides. Users are equipped to effectively use AI for learning, as demonstrated by their ease of interacting with AI and asking AI questions. Such findings suggest that future usability studies can investigate more complex tasks using AI features with less concern for the cognitive load that may occur when using new technology since most college-aged users have some familiarity and ability to navigate AI chatbots. Moreover, users expressed they expect detailed answers to their questions. However, they may not know how to ask questions in ways that would elicit such responses but can provide follow-up questions to retrieve the information they desire. Finally, though participants could easily interact with the AI, they preferred that answers were presented visually, which may mean that future versions of the app may need to incorporate visual cues or examples of solutions provided by AI that can generate images or videos of learning materials in real-time for specific questions. Future usability testing of the AR-Classrooms AI functions and improvements made to the app will be driven by the results of this exploratory usability test prior to a more rigorous study.

## V. Conclusion and Future Work

To improve the learning experience and address challenges faced in the previous user studies of AR-Classroom of spatial transformations and their mathematical representations, we integrated conversational AI with AR-Classroom's existing features. Spatial transformations and their mathematical representations are crucial in STEM fields. By combining physical manipulatives, like a LEGO model, with virtual manipulations through an app interface, students can observe and understand the dynamics of rotations and rotation matrices in real-time. Additionally, they can interact with AI to gain a further understanding of spatial transformations and interaction methods of the application.

This paper discusses the process of incorporating conversational AI in an AR environment to teach complex mathematical concepts (i.e. transformation matrices) to undergraduate students and to reduce the limitations of the previous version of AR-Classroom. This AI-driven, multi-sensory interactive assistance is supported by OpenAI's ChatGPT, which learns from AR-Classroom's documentation, to provide real-time, personalized help. The AI utilizes OpenAI's Whisper and

Amazon Polly for voice-to-text and text-to-voice functionalities, respectively. This allows for flexible communication modes, which are essential when handling physical models. After testing the system with pre-existing questions, we conducted a qualitative exploratory usability test of the AI features within the AR-Classroom.

This paper also discusses the process and outcomes of exploratory usability test to evaluate the effectiveness of conversational AI to answer complex mathematical questions and successfully guide the students using the AR environment. The user study among 6 undergraduate students in the STEM field showed promising results with the potential for future developments. The thematic analysis of each section of the user experiment of AR-Classroom AI features displayed four main themes: (1) AI chatbot ease of use, (2) Need for answer elaboration from AI, (3) Desire for visual information, and (4) Increased understanding of content area. The ease-of-use scores reflect AI's ability to assist with complex tasks in an AR environment by utilizing AI features that can minimize cognitive load.

After the user study, we found some limitations of the conversational AI and AR integration in AR-Classroom and the directions of future improvements the application. The overall findings suggest the necessity for further exploration into integrating AI-guided visual cues to help navigate the AR environment. Based on the findings of this research, we will improve the information provided to conversational AI, adopt a technique to make the interaction more seamless and conduct more elaborate user studies. We will also focus on providing visual cues with the replies from the AI in future developments. In addition, we will investigate the integration of AI with vision (e.g., GPT-4 Vision) and AR-Classroom's detection of user's actions (e.g., false rotation) to enhance learning analytics and user guidance.

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