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WIP: Promote Inquiry-Based Linear Algebra Conceptual Learning Using Mobile Devices with Collaborative Augmented Reality (CAR)

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Abstract—**This WIP paper introduces a concept of designing and developing a Collaborative Augmented Reality (CAR) application for educational purposes, especially in linear algebra. The paper presents the on-going project, potential problems, and motivations. The CAR for classroom education not only presents the knowledge using the augmented reality technology, but it also enables interactions through the CAR between the instructor and the students. We believe it will promote greater understanding of the knowledge the students are learning in the classroom.**

Index Terms—**Augmented Reality, Collaborative, Education, STEM, Application**

I. Introduction

In the past few years, Virtual Reality (VR) and Augmented Reality (AR) applications for education, rehabilitation, exercise, training, etc. have proliferated dramatically. Educators love to use VR or AR technologies to assist students. However, almost all of the existing VR/AR educational applications focus more on presenting the learning contents. This means the applications are supplanting the instructor's role in delivering knowledge to the students and answering questions from the students. Since educators still believe the classroom is necessary, the new technology should be used as a tool to assist the instructor. This preserves a vital component of classroom time, the classroom interaction between the students and the instructor.

The students learn by listening to the instructor, but they learn more by active interaction with the instructor, such as asking questions. Therefore, we propose that VR/AR technologies should be a tool which enhances education from different aspects, including delivering knowledge, promoting classroom interaction, etc. In this paper, we present a prototype of Collaborative Augmented Reality (CAR) learning tool for Inquiry-Based Math Conceptual learning: Linear Algebra.

Inquiry-Based Learning (also enquiry-based learning in British English [1]) is similar as the development and practice of thinking skills [2]. The learners usually identify questions, issues or problems rather than trying to obtain the knowledge from a lecture or presentation [3].

The inquiry relies on the student's attitude. The student is expected to ask questions about new resolutions while gaining new information.

The definition of inquiry is seeking knowledge, information, or truth through questioning. All people carry on with this process throughout their life. For example, infants use inquiry to build their sense of the world. Babies turn toward voices, put things in their mouths, grasp things, and observe faces that come near. The inquiry process is mainly the gathering of data and applying that information to senses like smelling, tasting, touching, hearing, and seeing.

Sadly, our traditional ways of teaching discourage the process of inquiry. Sometimes, asking a question is difficult, especially a question with a very abstract concept. All of the potential problems cause the student to ask fewer questions as they move throughout their grade levels. They are expected to listen and recite the expected answers. This is due to a lack of understanding of inquiry-based learning. Inquiry-based learning is not just asking questions, but it is also a way of converting data and information into useful knowledge. A useful application of inquiry-based learning involves many different factors, including a different level of questions, a focus for questions, a framework for questions, and a context for questions.

Much information is readily available. Students need an understanding of how to turn that information into useful knowledge. Teachers must not only accumulate information, but also must to synthesize it into useful knowledge. This process may be accomplished by inquiry-based learning. The USA's success depending upon natural resources is the past; the future of our country's success now depends upon the education of the workforce.

The CAR application allows each student have a personalized view of the application which is the easiest viewing angle for that particular student. It also allows the students to ask questions through the CAR, which means the CAR could visualize both the teaching concepts from the instructor and the questions from the students as well. We also believe that the CAR will motivate students to ask more questions in the classroom.

Aside from enabling classroom interaction, the CAR

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prototype could also demonstrate how to apply the concepts of linear algebra to 3D object translation based on 3D vector addition or matrix multiplication.

The ultimate goals of this project are 1) to allow the students with the CAR application to explore the knowledge from their perspective; 2) to present the potential applications of fundamental linear algebra knowledge to the students.

II. RELATED WORK

VR and AR applications have been developed for numerous diverse fields, including physical rehabilitation and healthcare. Beneficiaries of VR technology include children, the elderly, and persons with physical and mobility impairments [4-7].

Recently, researchers have found many advantages of AR technologies in educational applications. The main motivations for educators to use AR may be summarized as: 1) AR offers a combination of traditional classroom aids, physical objects and virtual information, drawing on the strengths of each [8], 2) VR and AR can be used to increase the students' motivation [9-11], and 3) its ability to present to a group of learners' multiple incomplete, yet complementary perspectives on a problem situated within a physical space [12].

Combining the virtual and physical space makes the users visualize both real and virtual objects in the same context. This helps the users associate actual objects and related information in a simple, direct way. For example, Quarles et al. [8] developed the Augmented Anesthesia Machine (AAM) which uses a magic-lens approach to combine a real anesthesia machine and a virtual anesthesia machine. The AAM allows students to interact with the real anesthesia machine while visualizing how these interactions affect the internal components such as the invisible gas flows in the anesthesia machine. NLVM by Utah State University [13] allows students to investigate differences in shapes of cross-sectional slices taken from 3D geometric shapes, which is difficult to explore in the real world.

It has been reported that AR games can result in a substantial increase in the users' motivation. AR has gained large success in commercial games. Pokemon Go by Niantic [14] is an AR game which uses the mobile devices' GPS location and camera to combine the real world with a virtual game world. It quickly went viral and became the biggest mobile game in U.S. history (regarding daily active users) within two weeks. Educational AR applications inherit the same feature of increasing users' motivation. For instance, Radford Outdoor Augmented Reality (ROAR) Project [15] by Radford University uses AR to create mobile games requiring critical thinking, communication, and collaborative problem-solving skills for the K-12 environment. It allows the students to actively learn while playing the AR educational games. Trail of Integrity and Ethics (TIE) by Hong Kong Baptist University [16] is an AR learning trail in which students visit various locations, make use of the mobile devices to retrieve details of different ethical dilemmas, and produce responses to these scenarios. The user survey revealed a positive overall user experience and a high level of interest in the AR learning trail.

Group collaboration is an important feature of AR applications. Collaborative problem-solving skills are one of the important training targets of AR educational applications such as ROAR [15]. However, almost all of the existing VR or AR educational applications are only used for one-way education. This means they can only deliver the information, but they cannot allow users to ask questions or provide feedback.

In this current research, we will enable these collaborations in the classroom.

III. SYSTEM DESCRIPTION

We will use Unity to develop all of the VEs. Regular Android smartphones will be used as testing clients. The instructor's screen will be projected to a big projector screen. All of the devices will be connected by the local network for now. Most of the interactions are designed based on touchscreen devices, except the instructor's interface.

IV. FINISHED DESIGN AND DEVELOPMENT

A. Transformation Synchronization on Local Network

Since the CAR application will create a shared Virtual Environment (VE) for all of the users, one of the key problems is how to synchronize the transformations of all of the objects. Currently, the network component of Unity is used for synchronization.

B. Collaborative Permission Management on Local Network

To enable the **Inquiry-Based Learning**, we designed collaborative features for CAR application between the instructors and the students. The students could use the CAR application to present their questions, problems, or even scenarios.

By default, the instructor is the administrator to determine who can manipulate the objects in the shared VE. For the best and safest experience, one CAR should only allow one "Driver," which means there is only one user can manipulate the User-Interface (UI) to modify the object attributes. Therefore, we designed a permission requesting procedure to avoid multi-user reader-writer problems. We developed a touch button on students' devices to request permission. Specifically, if the student presses the button to request permission, the instructor's screen will notify the instructor of the request. If the instructor wants to authorize permission to the student, the instructor needs to click the "Allow" button. Then, the student will be able to manipulate the UI or the object. The objects are shared on each client, which means all of the manipulations will be synchronized to all of the users. When the student receives permission, CAR will memorize the current status of all of the objects in the shared VE. Once the student finishes asking questions, he or she presses the "Finish" button. Then, the shared VE will be reverted to the saved state before the student received permission.

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C. *Implementation*

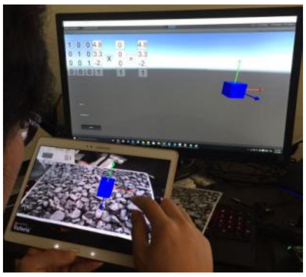

Fig 1. Using mobile device to interact with instructor's screen

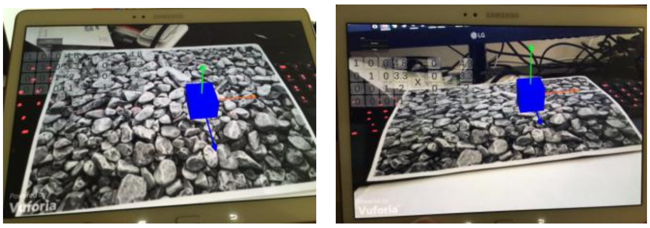

Fig 2. Two different viewing angles from the mobile device.

We already implemented a CAR prototype. The prototype is designed for teaching matrix multiplication and 3D vector addition. The CAR will be used to explain how to do matrix multiplication. Fig 1 and Fig 2 show a matrix multiplication on the screen and a blue cube. The red, green, and blue arrows on the blue cube represent its x, y and z-axes. If the student changes the value of the matrix, the CAR will show you the result of the multiplication. The cube will be transformed according to the matrix multiplication result. The student can also manipulate the cube. The matrix will be updated based on the position of the cube. Fig 1 shows an instructor's screen (the monitor) and a student's screen (the mobile device). The values of the matrix and the position of the blue cube are synchronized. The left and right images of Fig 2 display two different viewing angles for the student. The left image is from higher top view. The right image is from the front of the cube. The student just needs to move the mobile device while keeping the camera pointed at the marker.

V. On-Going Design and Development

A. *AR Collaborative Permission Management Between Students*

We have designed an AR UI to manage the permissions of students. We will use a special AR marker. For example, if the instructor wants to authorize permission to one student, the instructor needs to pass the AR marker to that student. The only thing that student needs to do is point his or her smartphone camera toward the AR marker to receive the authorization. Of course, all of the manipulations will be synchronized to every user. However, when the student receives permission, CAR will save the current status of all of the objects in the shared VE. Once the student finishes asking questions, he or she will pass the AR marker back to the instructor. The instructor can choose when to restore the shared VE back to the saved state.

B. *3D Objects Streaming on Network*

The current CAR prototype pre-loads all of the 3D objects needed. So, the only information that CAR needs to synchronize will be the objects' transformation information. However, the mobile devices' capacity creates a potential problem in pre-loading all of the 3D objects. Usually, those 3D objects are large, which will make the mobile app huge. Also, if CAR needs more 3D objects, the users need to update the mobile app, which is not user-friendly. To allow better user experiences, we propose investigating if and how to stream 3D objects directly from the server. The users just need to download the mobile app as a platform. Most of the content will be streamed from the server. There will be minimal contents maintenance needed.

Currently, the design and development are all based on local network, which means the instructor and the students need to be in the same local network. The 3D objects streaming will also help distance learning in the future. We will attempt to allow the users to "drive" the CAR on the Internet (iCAR). The iCAR should be well-suited to online education programs as well.

C. *3D User Interaction Design*

To use the CAR application, UI is another challenge. The main problem will be how to design a touchscreen-based 3D UI for manipulating the objects in the shared VE. Usually, manipulating an object in a 3D VE is difficult, because most of our display devices are 2D. A touchscreen-based 3D UI used for a relatively stationary mobile device does not allow the 3D coordinate system to change. However, the CAR application allows users to move the mobile device around, and the coordinate system will be moved along with the device as well. Designing and developing an appropriate 3D UI for CAR application is necessary. We will still use dragging as the gesture to manipulate the objects, but only lock it on a 2D surface. To manipulate the 2D surface, users can use their cameras, select either one or two axes, and use a dragging gesture to rotate the surface about the selected axis.

VI. Future Work

The CAR project will include three phases. The first phase will address the question of how to design the collaborative interaction methods and user interface. In this phase, the major problem that needs to be solved is the sharing space problem. This AR application will allow multiple users to interact with the same virtual environment. So, we will face two traditional Computer Science problems here, Networking and Human-Computer Interaction (HCI). We need to address the following: how to make sure the virtual environment of each user is correctly synchronized; how to permit a student to ask questions through the CAR; what is the most convenient way of making the virtual environment interactive for both students and instructors. The presented prototype has partially finished this phase.

The second phase is using the collaborative interaction methods and UI designed in the first phase to design and develop an application for teaching linear algebra. We have targeted teaching linear algebra because there are many linear algebra concepts related to Computer Graphics, such as matrix multiplication and 3D transformation. For many students, 3D-related concepts are too abstract to understand. We are planning on finishing a prototype with 5 areas in linear algebra education:

A. *Geometric interpretation of linear equations*

Solving a system of linear equations by matrix reduction is a fundamental part of linear algebra. For a system involving two variables, the solution set is the intersection of the lines. For a system involving three variables, the solution set is the intersection of the planes.

B. *Geometric interpretation of the determinant*

The absolute value of the determinant of a 2×2 matrix is the area of the parallelogram determined by the rows/columns of the matrix. For a 3×3 or larger matrix, it is the volume of the parallelepiped. This also demonstrates the idea of linear independence or dependence. For example, if 3 vectors are linearly dependent, they must lie within the same plane.

C. *Linear transformations*

Many common transformations are used to simplify problems in areas such as differential equations. For example, rotations and expansions/contractions are often used. As an example, any parabola could be transformed into $y = x^2$ using linear transformations and translations. Projections are another common transformation, and they could be used to demonstrate ideas such as the Gram-Schmidt process.

D. *Eigenvalues, eigenvectors, and applications*

There is much visualization that can enhance understanding of eigenvalues and eigenvectors. For example, given any diagonalizable matrix A, any vector x can be written as a linear combination of the eigenvectors. Then, it can be visually shown how Ax can be calculated using only eigenvalues and eigenvectors. There are many fields where similar applications can be represented, such as linear systems of differential equations and stochastic processes.

E. *Least squares method and applications*

The least squares method is one of the most commonly applied approximation techniques. There are many ways to visualize the methods. Given the linear system Ax = b and the least squares solution, the simplest method is to graph Ax, b, and b - Ax. Applications of least squares would also be useful, such as line fits, quadratic fits, etc.

The third phase is conducting a within-subject usability study using the prototype developed in the second phase. The participants will be given two different versions of prototypes: 1) With collaborative functions (CAR) 2) Without collaborative functions (Non-CAR). The hypotheses are 1) Participants prefer learning using the CAR, and 2) Participants will be motivated by the CAR to ask more questions. We will also use subjective questionnaires and objective data collected from the prototypes to evaluate this usability study.

We will also attempt to "drive" the CAR on the Internet (iCAR) in the future.

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