Improving Engineering Education Using Augmented Reality Environment

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Abstract. The purpose of the research is to compare the impact of students' learning performance between an augmented reality (AR) environment and in-class environment. To create an efficient AR environment, we used Microsoft HoloLens, which is the next generation of a see-through holographic computer. We developed the AR learning module: ergonomic guidelines for manual material handling (MMH). We hypothesize that AR changes the way students understand the concepts of MMH. Our analysis includes a careful evaluation of student experimental skills during the learning activities. This new AR environment could allow students to engage hands-on training of MMH and strengthen their understanding. Student test score was used as metrics for performance assessment. We found a significant improvement on student understanding of MMH lecture after they used the AR module. The findings of this study indicated the potential benefits of using AR environment interfaces in engineering education and training.

Keywords: Augmented reality · Engineering education
Learning performance

1 Introduction

Students often get bored in a classroom and take a long time to understand the engineering concepts they learned in a classroom. Although there are needs to improve engineering education, many traditional learning methods, such as power point slides, lecture notes, or videos, have shown limitations to meet the goals of future engineering education. Augmented reality (AR) is one of the advanced technologies that might meet this need and increase the student learning performances in engineering education.

AR combines virtual and real objects coexist in a common space seamlessly to reinforce human interaction. It provides the ability to develop more effective learning environment for novice workers and students. AR has many potential benefits. First, engaging and motivating students to explore class materials from different angles to help students create the spatial feeling (e.g., astronomy and geography). Second, enhancing collaboration between students and instructors. Third, fostering student creativity and imagination. Fourth, helping students control their own learning pace and path [1].

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Previous research related to AR has demonstrated the effect on student motivation during the learning process. According to Kim et al. [2], the materials that were designed in an AR environment could provide a positive learning effect in a computer-based training simulation. Yen and Tsai also found that AR environment could improve student interaction in class [3]. AR has applied to many educational concepts, such as earth-sun relationship [4], electromagnetism [5], and education of anatomy [6]. Their findings show that AR could provide instant feedback and improve student's academic achievement. AR also has been implemented in the various fields of medical and engineering training [7–10].

Teaching staff can take part in this new endeavor by being aware of applications in AR that can benefit students and educators [11]. AR in education is an emerging field, which exhibited the benefits in engineering education. An AR-based system designed explicitly for engineering graphics education can improve student's spatial awareness and interest in learning [12]. AR application consisting of 3D models, animations and sound help students understand the specific objects in electrical engineering. [13]. AR also enhance mechanical engineering students to learn how to sketch, design and normalize mechanical elements [14]. The study explored the impact of AR technology as used for engineering students, which influence academic performance and encourage student motivation. Besides, AR allows users to work on their own pace.

In many higher educations, AR modules have been already implemented, but have not generated any educational material for enduring use. In this study, we used Microsoft HoloLens, which is the next generation of a see-through holographic computer, to create relatively efficient and advanced AR environment.

2 Methods

2.1 Apparatus

HoloLens (see Fig. 1) is used as a head-mount teaching device with Windows 10 operating system for students which can project holograms in front of participants' eyes to combine the real and virtual worlds [15]. Participants can touch, gaze and rotate to control the holograms. HoloLens Clicker is the input device which allows students to control and interact with the holograms in the AR environment. In our experiment, we used two HoloLens interaction model Gaze and Gesture. The Gaze relates to what you are looking at (e.g. head tracking), the Gesture is an "air-tap" movement that the HoloLens will recognize and allow for selection of items. The HoloLens Clicker can be used instead of the "air-tap" gesture.

2.2 Participants

A total of thirty-two students of industrial engineering were recruited from the University of Missouri. Twenty-nine participants were male, and three participants were female. The average game level was 3.17/5 (StDev = 1.03) and the average AR level was 1.4/5 (StDev = 0.85). The game level is rating participants' previous experience level playing computer graphic video game. AR level is students' previous

Fig. 1. Microsoft HoloLens

experience level participating in an augmented reality task before. Twenty-four participants' AR level was 1, and they never knew or touched AR device before. Most students were regarded as novices for the AR experiment. Participants had an age range from 20 to 31 (Mean = 21.5, StDev = 1.50).

2.3 Engineering Education Contents

In this study, we developed the AR modules for manual material handling (MMH). It is one of the core contents of an ergonomics class. Traditionally, many students commonly make a mistake in the aspect of the meaning of asymmetric multiplier and do not know how to measure the multiplier. As a result, instructors are challenged to find new ways of presenting MMH lecture that is more beneficial for student learning.

In the MMH lecture, the revised NIOSH lifting equation is used to quantify the lifting task risk or acceptability. It contains six variables or multipliers, which are the Horizontal Multiplier (HM), the Vertical Multiplier (VM), the Distance Multiplier (DM), the Asymmetry Multiplier (AM), the Coupling Multiplier (CM) and the Frequency Multiplier (FM).

Specifically, HM is the horizontal distance of the load from the body. VM is the vertical distance of the load from the floor. DM is the vertical distance the load is lifted. AM is the angles from the sagittal line to origin or destination position. FM is the frequency and duration of the task. CM is coupling with the load about handles or handholds. All of these factors is to determine the weight of a load that can be safely handled by most people.

The revised NIOSH lifting equation shows RWL = LC * HM * VM * DM * AM * FM * CM, where RWL is the Recommended Weight Limit; LC is the Load Constant and is always equal to 51 lb (23 kg). The LC is the weight a person should be able to lift once under ideal conditions at minimal risk; The other six multipliers (HM, VM, DM, AM, FM, and CM) reduce this weight based on the actual conditions of the lift being examined. Lift Index (LI) = actual weight of the load divided by the RWL. The higher of LI, the higher the risk to the persons performing the task. The goal should be for all lifting tasks to have a Lift Index less than 1.0. The revised NIOSH equation can assist in the elimination of specific task variables of concern. The individual multipliers can identify specific aspects of the lift that are problematic and require addressing to make the lift more acceptable.

2.4 Design of Experiment

We developed the AR learning module: ergonomic guidelines for manual material handling (MMH). We hypothesize that AR changes the way students come to understand specific concepts.

In the AR MMH lecture (see Fig. 2), participants learned MMH concepts and were educated how to measure all MMH variables and assess working safety condition. In the training part, the participants was taught how to use HoloLens interaction and learn MMH lecture in AR environment. After learning the lecture, the test score was used to evaluate participant's learning performance. We can compare the test performance difference between AR group and in-class group and know more benefits with AR system.

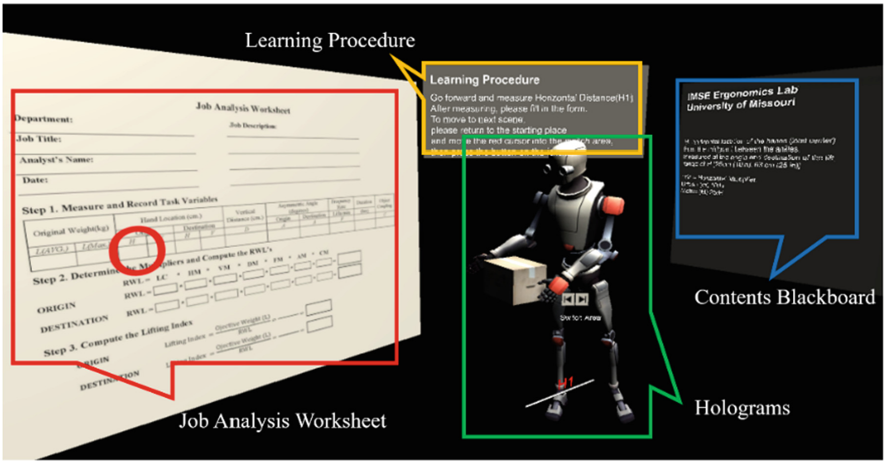

Fig. 2. Screenshot of the MMH Module

Figure 2 shows a screenshot of the MMH module. On the left side in the figure shows the job analysis worksheet that is commonly used for the observation form of MMH. The module also displays learning procedures of how to complete each module. The middle of the figure shows the primary hologram for MMH animation. Also, two arrows help students to navigate the module. The left arrow corresponds to the previous module, and right arrow corresponds to the next module. The right side of the figure displays the MMH contents that students must learn from each module, which including the definition of MMH, how to measure all multipliers (a horizontal multiplier, vertical multiplier, and asymmetric multiplier), and calculate them.

Figure 3 shows the learning module in AR environment. This scene presents all the multipliers which let participants understand clearly about MMH in a 3D space. Participants can move close to measure and observe distances in each angle.

Figure 4 presents the practice module for students and let them practice the MMH measurement and calculation to verify if they understand the MMH contents or not, meanwhile deepening their understanding of MMH content and cultivate their experimental skills.

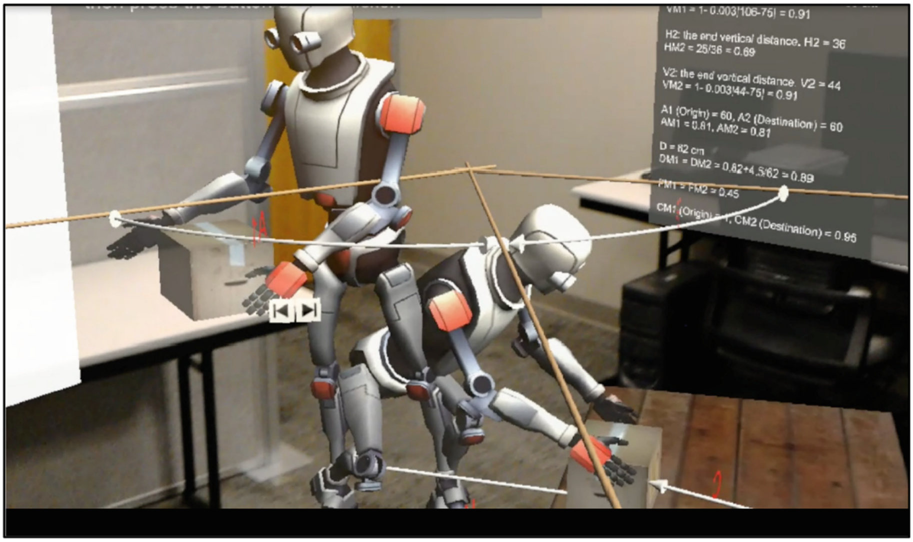

Fig. 3. Learning module of AR MMH lecture

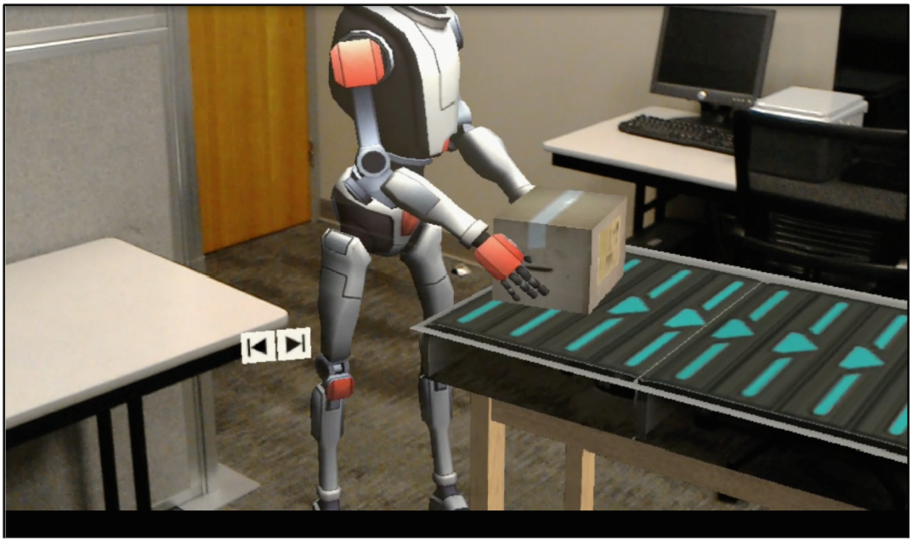

Fig. 4. Practice module of AR MMH lecture

3 Procedure

For AR group: Before the experiment, participants were asked to answer demographic questionnaires if they had computer experience level and the similar experience on AR task in the past. During the training session, participants experienced how to fit the HoloLens to get the best view, conduct gestures and modules in HoloLens, as well as how to fill in job analysis worksheet. Participants must understand how to use gestures or clicker to switch to the previous or next scene to learn MMH contents. After being trained, participants underwent the experimental test session in HoloLens. The experiment test took 40 min for learning materials. After learning materials about manual material handling, the participants needed to take a test to verify their learning performance. So the total time was expected to last one and a half hours.

For another in-class control group, the teacher explained the MMH material as in previous years. Students participated in normal activities in the classroom. The only difference was that a group of the experimental students had the AR notes available to study in the lab and the control group students used their traditional class notes to study.

To compare the learning performance in AR and in-class group, a test about MMH was taken which evaluated up to a 100 points maximum. Each multiplier (the Horizontal Multiplier (HM), the Vertical Multiplier (VM), the Distance Multiplier (DM), the Asymmetry Multiplier (AM), the Coupling Multiplier (CM) and the Frequency Multiplier (FM)) would be tested to prove if they understand. The only difference was that a group of the experimental students studied in the AR environment and the control group students learned in the classroom.

4 Results

For learning performance, a statistical analysis was carried out to identify the significant differences between the results obtained by both groups. Student test was used to compare average test score values obtained in each group. We considered hypotheses there is a significant difference between test results obtained by two groups. All the participants regarded AR use to be very interesting when educational purposes are considered. The overall opinion of the students was that studying and using AR was an excellent experience. The AR group was more motivated than the in-class control group who just studied and whose only interest was to pass the test. The two groups (Group A: augmented reality, Group B: in class) test scores were compared. It showed that there was a significant difference between two groups ($F(1, 91) = 4.39$, p-value = 0.039). The mean score of group A was 76.25/100 (SD: 30.61). The mean score of group B is 62.00/100 (SD: 31.32) (Fig. 5).

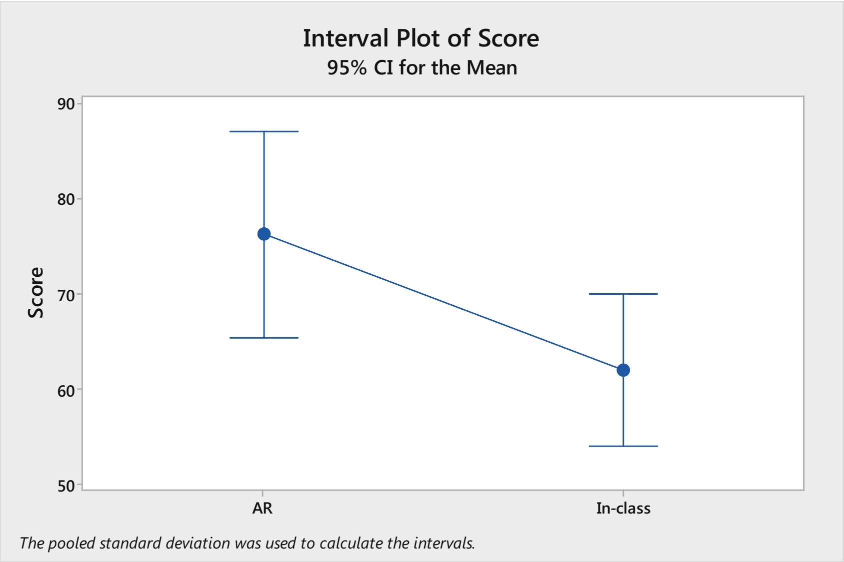

Fig. 5. Test scores (AR vs. In-class)

5 Discussion and Conclusion

According to our results, students who used the AR-based MMH lecture showed better academic performance than those using traditional class notes. 53.1% of students in the AR group marked a perfect score while only 23.3% of the students received a full credit when they used traditional learning method.

Manual material handling is a good teaching material in engineering education which can be displayed in AR environment. Successful learning MMH contents contain two aspects concepts knowledge and practical exercise. As a practical hands-on exploration, suitable design visualization and presentation are crucial for participants to understand and gain adequate knowledge. MMH AR lecture allows students to learn through three-dimensional experiences that merge the physical with the virtual and allow students to interact with the content. Through the AR environment, students can see a real human movement and objects in 3D animation. Students can measure the distance with ruler and angles with goniometer by themselves without an instructor's help. Thus, students can incorporate hands-on training for deepening the understanding of contents.

MMH is also related to safety training materials; it is definite that MMH AR lecture is much more productive and fruitful than traditional methods or medias, such as booklets, posters, videos, and other content ever before. Students might get hurt or injured in the real manual material handling environment, while AR has benefits in skills training regarding dangerous and hazardous work environments.

Furthermore, our MMH AR lecture exists many contextual elements possibly embedded in MMH AR lecture to enhance engineering education quality by creating and delivering productive, constructive, and gainful content.

Also, the AR can be extremely useful in providing information to a user dealing with multiple tasks at the same time. In our study, material handling holograms models, worksheet, and MMH concepts showed simultaneously to participants.

Moreover, AR systems can provide motivating, entertaining, and engaging environments conducive for learning. AR applications in educational settings are attractive, stimulating, and exciting for students and provide effective and efficient support for the users.

At last, the AR modules allows students to follow their own learning pace to understand how to solve MMH problems. Therefore, the findings of this research suggest that the AR is favorable in the aspect of engineering education and training.

6 Limitations and Future Work

Although the AR setting could support the enhancement of spatial ability according to the studies reviewed in this paper, learners' original ability to understand 3D objects or concepts might interfere with their learning process, learning experiences, or even learning outcomes. Moreover, students' perceived presence, which is a mental state when students participate in a virtual world, in AR-related environments may be an important learner characteristic variable to consider [16].

By detecting learning process through videotaping analysis, how students structure the scientific thinking and knowledge in AR learning activities could be better understood. Although these qualitative methods have been commonly utilized in AR-related studies, there is a need to apply mixed method analysis to attain an in-depth understanding of the learning process. For example, content analysis and a sequential analysis might be adopted to analyze students' behavioral patterns when involved in science learning with AR technology. With the aid of eye-tracking technology, researchers could collect data about eye movement sequences to represent learners' attention to AR information and further compare the quantitative data with the results of learning process analysis generated by qualitative methods.

The rise of students studying engineering degrees makes the practice's laboratories overcrowded worsening the teaching quality and reducing teacher's dedication to every student. Besides, learning and teaching procedures need to evolve for taking into account the high technological profile that most students show. In some cases, outdated teaching creates barriers for some students that are used to interact with modern technological gadgets and computers. The AR technology can accelerate the learners' acquisition of new training procedures and improve the adjustment of the training process. AR applications allow that in certain teaching/learning contexts performed by the student on his own saving the teacher's time for repeating explanations. A well-planned AR application will allow them to perform learning processes and motivate their learning desire. Students want to be empowered by technology and to apply their knowledge and experience to communicate designs that lead to improved results and higher personal satisfaction. The system can thus build a future in which students will experience competence, clarity, control, comfort, and feelings of mastery and accomplishment. We believe that AR is a cost-effective technology for providing students with more attractive contents than class paper notes.

Also, we will investigate the cognitive process flow of MMH lecture in the AR environment. The outcome of this study will improve engineering education and help students achieve their goals better. More research is required to study learning experience such as motivation and learner characteristics such as spatial ability or perceived metal state, involved in AR. Mixed methods of inspecting learning processes such as a content analysis or a sequential analysis, as well as in-depth examination of user experience beyond usabilities such as affective variables of esthetic pleasure or emotional fulfillment, should be considered. Theories including mental models, spatial cognition, situated cognition, and social constructivist learning are suggested for the profitable uses of future AR research in science education [16].

AR has compelling features for engineering educational purposes if the device is affordable for students [17]. For the future work, we will develop the advanced AR modules, which reinforce a positive learning effect of AR contents in engineering education. Besides, we hope to encourage teachers who want to motivate their students and improve student learning performance to start to take advantage of AR technologies in the classroom in their work.

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