THE EFFECT OF VIRTUAL INSTRUCTOR AND METACOGNITION ON WORKLOAD IN A LOCATION-BASED AUGMENTED REALITY LEARNING ENVIRONMENT

Jung Hyup Kim[1], Ching-Yun Yu[2], Kangwon Seo[1], Fang Wang[2], and Danielle Oprean[3]

[1]Industrial & System Engineering Department, University of Missouri, Columbia, MO
[2]Information Technology Department, University of Missouri, Columbia, MO
[3]Info Science & Learning Technology Department, University of Missouri, Columbia, MO

Augmented Reality (AR) technology offers the possibility of experiencing virtual images with physical objects and provides high-quality hands-on experiences in an engineering lab environment. However, students still need help navigating the educational content in AR environments due to a mismatch problem between computer-generated 3D images and actual physical objects. This limitation could significantly influence their learning processes and workload in AR learning. In addition, a lack of student awareness of their learning process in AR environments could negatively impact their performance improvement. To overcome those challenges, we introduced a virtual instructor in each AR module and asked a metacognitive question to improve students' metacognitive skills. The results showed that student workload was significantly reduced when a virtual instructor guided students during AR learning. Also, there is a significant correlation between student learning performance and workload when they are overconfident. The outcome of this study will provide knowledge to improve the AR learning environment in higher education settings.

INTRODUCTION

Many studies have discussed the benefits of augmented reality (AR) technology in education and training environments (Bacca, Baldiris, Fabregat, & Graf, 2014; Chen, Perera, Fang, & Chen Fitts, 2022; Nesterov, Kholodilin, Shishkov, & Vanin, 2017; Saidin, Halim, & Yahaya, 2015). However, Jeffri and Rambli (2021) recognized that the relationship between mental workload and performance is not well identified in the previous AR studies. Also, students could be easily overloaded when they learn complex materials in AR learning environments. Furthermore, due to a lack of interaction and feedback, students experience difficulties improving their monitoring skills to be aware of how much they understand the AR learning content. To overcome those challenges, we implemented a 3D human avatar, which acted as a virtual instructor during AR learning and investigated the workload impact on a virtual instructor. Also, we investigated the participants' metacognitive skills and their correlation with performance and workload in the AR environment by employing the Retrospective Confident Judgments (RCJ) probe.

Metacognition is thinking about one's own thinking (Dunlosky & Metcalfe, 2008). It involves the ability to monitor, evaluate, and regulate learners' cognitive processes and knowledge, and includes awareness and understanding of their strengths and weaknesses in learning. In other words, metacognition is the higher-order thinking that enables individuals to plan, monitor, and reflect on their learning activities. It includes knowledge about when and how to use various problem-solving strategies and the ability to self-evaluate their understanding and performance. Improving metacognitive skills can help individuals become more effective learners and better decision-makers (Dunlosky & Metcalfe, 2008).

Several studies have investigated the effects of metacognition in AR environments (Agusta, 2022; Guo & Kim, 2020; Nidhom et al., 2019; Tugtekin & Odabasi, 2022). However, few studies have been conducted on the relationship between student workload and metacognition in AR learning environments. Metacognition can affect workload in AR learning environments. It can reduce mental workload by leading students to manage their attention better and focus on the most relevant information. On the other hand, they may struggle to prioritize information and allocate their cognitive resources, leading to an increase in their workload (Wang et al., 2022). Hence, it is necessary to investigate how students' metacognitive status (i.e., overconfidence vs. underconfidence) influences their workload in the design of AR environments to ensure they are optimized for efficient information processing and reduced mental workload. In metacognition, if students' learning performance is higher than their confidence levels, it is called underconfidence (UC). In contrast, their performance scores are lower than their confidence levels; it is called overconfidence (OC). Both are related to their beliefs about their own abilities and the accuracy of their judgments (Kim, 2018). Overconfidence could lead students to terminate their learning process without fully considering all information. On the other hand, underconfidence could lead students to limit their effort to overcome the challenges they were facing while in the learning process. Therefore, both metacognitive statuses might be deeply related to student workload, and a virtual instructor in AR learning environments could positively impact the workload due to its step-by-step guidance. To determine the effect of a virtual instructor and metacognition on workload in the AR environment, we developed an advanced location-based AR learning platform by integrating Near-Field Electromagnetic Ranging (NFER) real-time location system. More details of this AR system and the experimental setup are described in the method section.

The following hypotheses were made to answer the research question**:** the existence of a virtual instructor could significantly influence student workload and the relationship between performance and workload in the AR learning environment. As a result, the contributions of the current study are summarized below:

- The virtual instructor could significantly reduce the student workload in the AR learning environment. However, there was no performance difference between the conditions.
- There was a strong correlation between performance and workload when the students were overconfident and experienced the virtual instructor during AR learning.

METHOD

In this study, we developed two biomechanic AR lectures. A total of fifteen 3D scenes using Unity Game Engine were created. Lecture 1 contains seven modules, and lecture 2 has eight modules. To test the effect of a virtual instructor, two different sets of AR lectures were made. With a virtual instructor version, we placed a large semicircular blackboard in each scene, consisting of five smaller connected panels (see Fig. 1). This design provides the users with the ease and comfort to view and interact with the virtual space used for the lecture when they stand in the center of the scent and face forward. These five panels display figures, human avatar, formula calculations, problem statements, and tables of figures (see Fig. 2). Another version, on the other hand, does not have a virtual instructor. However, every visual and auditory information is the same.

Figure 1: Location-Based AR Learning with Virtual Instructor

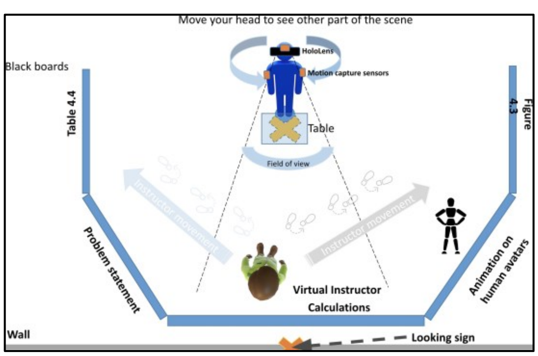
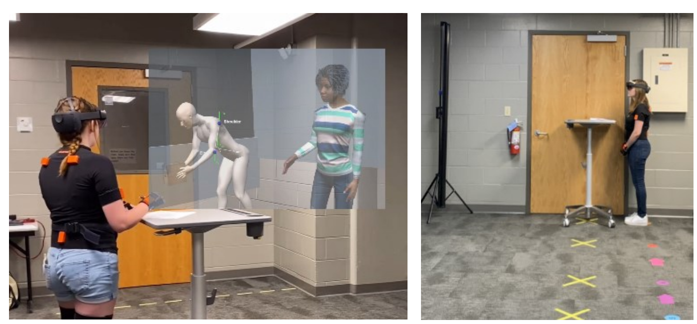


Figure 2: Bird's-eye View of the AR Learning Platform

Location-Based AR Learning System

A Microsoft HoloLens 2 device was used to project all 3D computer-generated images and a virtual instructor for the AR learning environment (see Fig. 3 (a)). Microsoft Mixed Reality Toolkit 3 (MRTK3) was also used for the input system and building blocks for spatial interactions and user interfaces. For each of the Unity scenes built, we exported them separately as a Visual Studio solution for the Universal Windows Platform. After pairing Visual Studio with HoloLens over Wi-Fi, we deployed these solutions to HoloLens, creating fifteen AR applications. To allow users to easily navigate through these AR applications based on their positions, an accurate and fast indoor tracking technology that could be integrated with the AR systems was needed. The Q-Track NFER system met these needs. It consists of four components, the router, locator receiver, real-time positioning sensor, and real-time positioning software. The system uses a Transmission Control Protocol (TCP) socket-based protocol. After receiving the location signal sent by the real-time positioning sensor using NFER technology, the locator receiver transmits the information through the router using Wi-Fi to the real-time tracking software running on TCP port 15752 on a laptop. We developed a client program in C# based on the Application Programming Interface (API) of the Q-Track NFER system to determine which AR scene should be triggered based on the received location coordinates. Since we divided the experiment site into seven areas for lecture one and eight areas for lecture two, the client program could easily determine which area the current location belongs to based on the pre-defined boundaries and open Microsoft Windows Device Portal for HoloLens through the browser automation tool Selenium to run the corresponding AR application and project the scene onto HoloLens.



(a) Participant with AR Learning (b) Location Setup

Figure 3: Location-Based AR Learning System

The collected tag data can be replayed and exported using Q-Track's real-time positioning software for analyzing the participants' learning patterns. Sensors for 11 body parts, including the head, sternum, pelvis, and various limbs, were attached to the participants to accurately collect upper body movement data for gesture recognition. Participants were asked to stand and move according to Xsens MVN software instructions to calibrate the sensors. The recorded motion data can be saved as a 3D avatar video or exported as an Excel file containing sensor measurements. Xsens SDK was used to develop gesture recognition programs for integration into the AR system. Once equipped, participants could begin the AR lessons. An X at a specific point was marked in each area to help the participants navigate in the physical space (see Fig. 3(b)). The table equipped with a Q-Track sensor was prepared to capture the current location of the participants and served as a navigator for switching AR scenes. The client program received the position information through the locator receiver as soon as the participants moved the table to the X mark in a certain area illustrated in Fig. 3 (b). After determining the area, the Windows Device Portal was used to run the AR application and project the scene onto the HoloLens. The table with the Q-Track sensor served as the positioning basis and must be placed on the designated X mark until the participants chose to switch scenes. To avoid projecting the AR scene to a difficult-to-view position, each area was marked with a number on the wall and participants were instructed to look at the number until they saw the AR scene before looking away. After each AR scene, participants filled out a quiz sheet to assess their learning outcomes before moving to the next area.

Participants

A total of 42 undergraduate students (M = 22 years old, SD = 4.5) were recruited from the University of Missouri. Sixteen participants were in the group with a virtual instructor. Twenty-six other students were assigned to the group without a virtual instructor.

Design Procedures

The experiment was conducted in two groups (with a virtual instructor vs. without a virtual instructor). Both groups had retrospective confidence judgments (RCJ) probes to measure their confidence levels after answering each question about the scene content. Their learning performance was measured by calculating the average quiz scores. Both groups underwent two learning sessions within 48 hours. Before the participants started the experiment, they answered a demographic questionnaire and were trained on the learning process, answering questions, and interacting with the systems before the experiment. After that, they were equipped with HoloLens and motion-capture sensors. During the experiment, they were required to move the table with a Q-Track sensor to the designated X mark, look at the wall number, and freely move while watching each AR content module. After the participants finished studying all AR modules, the NASA-TLX questionnaire was given to them to measure their workload.

RESULTS

Learning Performance

The participants who experienced a virtual instructor had a higher performance average (M = 83.04, SD = 13.0) than those who did not experience a virtual instructor (M = 79.35, SD = 14.0). However, no statistical performance difference was found between the two groups. Also, there was no significant performance difference between underconfident (UC) students and overconfident (OC) students. On the other hand, a significant difference was found in the interaction effect (see Table 2). The students' performance, who were underconfident, significantly improved when they learned the material with a virtual instructor (see Fig. 4).

Table 1: Descriptive Statistics for Learning Performance

Term	Condition	N	Mean	SD	SE Mean
Virtual Instructor	YES	16	83.04	13.0	3.25
	NO	26	79.35	14.0	2.75
Meta Status	OC	28	80.50	12.4	2.34
	UC	14	81.24	16.2	4.33

Table 2: Learning Performance Fit Mixed Model

Term	SS	df	F	P-value
Virtual Instructor (VI)	557.68	1	3.456	0.071
Meta Status (MS)	145.45	1	0.901	0.348
VI * MS	1306.77	1	8.098	**0.007**

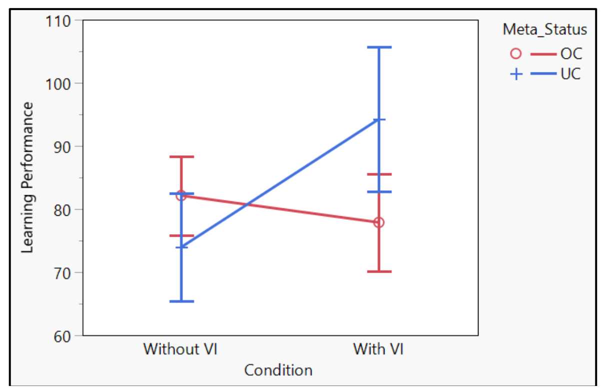


Figure 4: Performance Interaction Plot for VI * MS

Workload

Table 3 shows that the participants who experienced a virtual instructor had a lower workload (M = 57.27, SD = 8.93) than those who did not experience a virtual instructor (M = 67.08, SD = 9.16) during the experiment.

Table 3: Descriptive Statistics for Workload

Term	Condition	N	Mean	SD	SE Mean
Virtual Instructor	YES	16	57.27	8.93	2.23
	NO	26	67.08	9.16	1.79
Meta Status	OC	28	63.27	11.28	2.13
	UC	14	63.47	7.90	2.11

Table 4: Workload Fit Mixed Model

Term	SS	df	F	P-value
Virtual Instructor (VI)	705.967	1	8.2541	**0.0066**
Meta Status (MS)	1.73	1	0.02	0.8878
VI * MS	44.45	1	0.52	0.4754

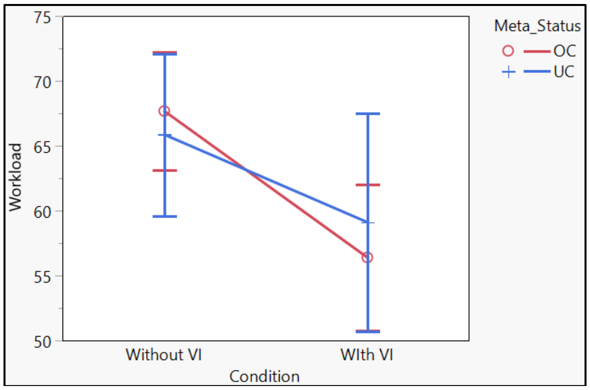


Figure 5: Workload Interaction Plot for VI * MS

Correlation between Workload and Learning Performance

Table 5 showed a strong negative correlation between workload and learning performance when the overconfident students learned the AR material with a virtual instructor ($r = -0.6891$, $p = 0.019$). It indicates that overconfident students who performed well had a significantly low workload during AR learning.

Table 5: Correlation Matrix between Workload and Performance

Meta Status	Virtual Instructor	Correlation	P-value
OC	YES	**-0.6891**	**0.019**
	NO	0.2696	0.2954
UC	YES	-0.5404	0.3471
	NO	0.0285	0.942

DISCUSSION

This study investigates the effects of a virtual instructor and metacognition on workload in a location-based AR learning environment. Students easily navigate various AR scenes by using an interactive AR system incorporating Near-Field Electromagnetic Ranging (NFER) real-time location system. The results show that using a virtual instructor in an AR learning environment could significantly reduce the student workload. The overall impact of a virtual instructor on learning performance was not significant (see Table 2). However, when students lacked confidence, the virtual instructor had a notable positive effect, leading to significant improvements in their performance. Also, we found a strong correlation between performance and workload when students were overconfident and received instruction from a virtual instructor during AR learning.

We could observe the positive effects of a virtual instructor on workload in the AR learning environment. Compared to AR learning without a virtual instructor, the system could provide step-by-step guidance to students and helps remind them what they are learning in each AR module. Also, the virtual instructor offers support to students based on the context in which they are learning. With the virtual instructor, students can assemble a complex piece of information better to calculate the forces and moments acting on each body segment during AR learning. It can help students decrease their workload by improving the efficiency of their learning behaviors.

Although the virtual instructor provides several positive effects on student workload, it does not significantly improve student learning performance. To understand this phenomenon, further analysis is needed. One of the possible explanations could be a lack of interaction design between a virtual instructor and students. Some students might refuse to accept guidance from a virtual instructor because they are used to studying a certain way or unfamiliar with new technologies. Secondly, a virtual instructor may not be able to create the same level of engagement as a human instructor. This can lead to a lack of motivation and difficulty retaining information. Lastly, technical limitations, such as system latency or poor graphic quality, could negatively affect the student learning experience. During the test, we experienced several hardware malfunctions that disrupted the learning experience, such as the loss of sound from the HoloLens and a disconnection between the motion capture sensors and the computer. Those technical issues might make participants uncomfortable using the AR instructional system and could limit the benefits of a virtual instructor and prevent them from improving performance. One interesting finding is that underconfident students' performance was significantly improved when they had a virtual instructor during AR learning (see Fig. 4). It means that a virtual instructor might help reduce the fear of failure for underconfident students and create a more supportive and less intimidating AR learning environment. Underconfident students are usually afraid of making mistakes and tend to doubt their abilities and decisions. However, step-by-step directions from a virtual instructor might make them feel more engaged and motivated to learn the material. As a result, their performance could be significantly improved.

This study also found a strong correlation between performance and workload when the student's metacognitive status is overconfident and experienced the virtual instructor during AR learning. The workload can influence an individual's performance. How many cognitive resources (i.e., attention, memory, and problem-solving abilities) a student uses to learn the material will affect the workload level and the learning performance. For example, when students learn difficult material, they should put more effort into being familiar with the contents. However, the relationship between mental workload and performance is not well identified in previous AR studies (Jeffri & Rambli, 2021). One of the possible explanations could be related to the positive effects of a virtual instructor, as we described earlier. The learning performance of overconfident students commonly falls short of their expectations and is negatively impacted by their lack of preparation and effort. However, the virtual instructor could help them better understand their abilities and the amount of work required to perform well. This could lead to a stronger correlation between their workload and their performance, as they are more likely to see a direct relationship between the effort they put in and the results they achieve. Due to the step-by-step guidance from the virtual instructor, overconfident students may better understand how to manage their cognitive resources when using AR environments as their learning platform. In addition, the virtual instructor might reduce the potential consequences of overloading or underloading to overconfident students during AR learning. Hence, a virtual instructor could be crucial in AR learning environments to identify the right balance between confidence level and student workload to optimize performance and achieve desired outcomes.

There are several limitations of this study. First, the participants were given learning assessment questions in paper form. Due to the multiple pages of questions being stapled together, participants encountered confusion when turning the pages after viewing each AR scene. To remove the limitation, we plan to create a touch-based question-answering and scoring system using a tablet computer. The touch screen of the tablet on the desk will allow participants to answer questions easily, and they will be able to see their test scores, problem-solving steps, and learning assessment results in real time. This feature will provide a more engaging learning experience for students. These can help them to actively participate in the learning process. Secondly, participants were limited to accessing each AR module by physically moving their desk location. Based on the feedback received from participants, they expressed a preference for a more engaging learning environment. As a solution, we intend to utilize the gesture data to develop a gesture recognition system, enabling participants to interact using gestures in the future. Lastly, all subjects who participated in this experiment were college students (same age group). In future research, it would be better to experiment with different age groups to explore the effects of a virtual instructor and metacognition on workload in a location-based AR learning environment. Overall, a virtual instructor in AR learning environments can help to reduce student workload by avoiding confusion and distractions, allowing students to focus on the key information and concepts.

ACKNOWLEDGMENTS

This research is supported by NSF IIS-2202108.

REFERENCES

Agusta, I. P. G. L. (2022). Augmented Reality Media to Improve Science Literacy and Metacognitive Ability for Fifth Grade Elementary School. *Journal for Lesson and Learning Studies, 5*(2), 300-308.

Bacca, J., Baldiris, S., Fabregat, R., & Graf, S. (2014). Augmented reality trends in education: a systematic review of research and applications. *Journal of Educational Technology & Society, 17*(4), 133.

Chen, K., Perera, G., Fang, E., & Chen Fitts, K. B. (2022). *Augmented reality (AR) posture training for manual material handling: iterative design, evaluation, and recommendation for AR interface.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Dunlosky, J., & Metcalfe, J. (2008). *Metacognition*: Sage Publications.

Guo, W., & Kim, J. H. (2020). *Using metacognitive monitoring feedback to improve student learning performance in a real-time location-based augmented reality environment.* Paper presented at the IIE Annual Conference. Proceedings.

Jeffri, N. F. S., & Rambli, D. R. A. (2021). A review of augmented reality systems and their effects on mental workload and task performance. *Heliyon, 7*(3), e06277.

Kim, J. H. (2018). The effect of metacognitive monitoring feedback on performance in a computer-based training simulation. *Applied ergonomics, 67*, 193-202.

Nesterov, A., Kholodilin, I., Shishkov, A., & Vanin, P. (2017). Augmented reality in engineering education: Opportunities and advantages. *Communications-Scientific letters of the University of Zilina, 19*(4), 117-120.

Nidhom, A. M., Smaragdina, A. A., Dyah, K. G., Andika, B. N. R., Setiadi, C. P., & Yunos, J. M. (2019). *Markerless Augmented Reality (MAR) through Learning Comics to Improve Student Metacognitive Ability.* Paper presented at the 2019 International Conference on Electrical, Electronics and Information Engineering (ICEEIE).

Saidin, N. F., Halim, N., & Yahaya, N. (2015). A review of research on augmented reality in education: Advantages and applications. *International education studies, 8*(13), 1-8.

Tugtekin, U., & Odabasi, H. F. (2022). Do interactive learning environments have an effect on learning outcomes, cognitive load and metacognitive judgments? *Education and Information Technologies, 27*(5), 7019-7058.

Wang, Y., Wu, Y., Chen, C., Wu, B., Ma, S., Wang, D., . . . Yang, Z. (2022). Inattentional blindness in augmented reality head-up display-assisted driving. *International Journal of Human–Computer Interaction, 38*(9), 837-850.