Examining the Influence of Metacognitive Monitoring Feedback in an AR Learning Environment

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Abstract. In the context of student learning, investigating effective feedback mechanisms within augmented reality (AR) learning systems is crucial for better understanding and optimizing study behaviors. This study examines the influence of metacognitive monitoring feedback within an AR setting. Our hypothesis suggests that regularly providing students with feedback on their metacognitive monitoring within an AR learning environment has a beneficial effect on their metacognitive state. The results of the study confirm that frequent exposure to such feedback significantly improves scores on the Metacognitive Awareness Inventory. Essentially, there was a marked increase in the inventory scores of participants who received ongoing feedback, in contrast to those who were only given metacognitive monitoring feedback once after the lecture, particularly in the areas of planning, monitoring comprehension, and debugging strategies. This enhancement is achieved by influencing student calibration by directly impacting their metacognitive state.

Keywords: Augmented Reality · Metacognition · Engineering Learning

1 Introduction

According to Flavell [1], metacognition involves managing and controlling one's own thinking processes using strategies like planning, monitoring, and adjusting Norman and Furnes [2]. Metacognition helps individuals understand how they learn, reflect on

S. Jin et al. (Eds.): IEA 2024, SSDI 56, pp. 473–479, 2025.
https://doi.org/10.1007/978-981-95-0289-9_70

their thinking patterns, and guide their personal and professional development [3–5]. It includes organizing approaches for learning, problem-solving techniques, and self-evaluation to correct mistakes and track progress [6, 7]. Metacognitive awareness, defined as regulating one's own thinking, is linked to better learning outcomes [8]. However, in augmented reality (AR) learning environments, the opportunity to cultivate these evaluative skills may be hindered by reduced interaction and feedback. Addressing this issue necessitates an investigation into effective feedback strategies within AR learning platforms to comprehend better and assess students' study practices. Consequently, this research aims to investigate the impact of feedback on metacognitive monitoring in an AR context.

2 Methodology

For this study, we developed a total of fifteen 3D scenes using the Unity Game Engine, with seven modules in lecture 1 and eight modules in lecture 2 [9]. Lecture 1 covers the introduction to biomechanics and shows students how to draw force and moment on different body segments (comprised of an introduction to basic biomechanics knowledge including definitions, concepts of force and moment, static equilibrium, multiple link examples, and center of mass); and lecture 2 which is more challenging than lecture 1 (comprised of a review of lecture 1, free body diagrams on hand, upper arm, lower arm, and trunk segments). Each scene includes a large semicircular blackboard comprising five interconnected panels (as depicted in Fig. 1 Right). This design offers users a convenient and immersive experience in the virtual lecture space when they stand at the center of the scene and face forward. These five panels display various elements, including figures, human avatars, formula calculations, problem statements, and tables of figures (refer to Fig. 1 Left). In the first experiment (experiment #1), participants were required to respond to a question concerning the material they had studied, as well as to rate their confidence in their answers. However, no immediate feedback was provided; they only received a single, comprehensive feedback session after the lecture concluded [9]. In contrast, the second experiment (experiment #2) provided participants with immediate metacognitive monitoring feedback, detailing both their performance and confidence levels, but did not offer the summary feedback at the lecture's end. To evaluate changes in their Metacognitive Awareness Inventory (MAI) scores, participants in both experiments completed the MAI questionnaire following the lecture. For the duration of the experiment, participants were equipped with two devices: A HoloLens for accessing AR learning content and an NFER tag to track their physical location within the setup, which comprised seven distinct learning spots for each lecture [10]. Each spot is a signed place on the ground which has been determined for each module. It means when a student is moving on the marked sign with the table which has an NFER tag, the AR scene will be shown based on the programming connected to the tag on the table (see Fig. 2). The entire experimental process, including material review and the final biomechanics practice on the computer, was designed to last approximately 35–40 min.

The only difference between experiments #1 and #2 is how the question is presented to students. In experiment #2, student confidence level and performance are evaluated on a monitor screen instead of paper. In the metacognitive monitoring feedback, students can see their performance and confidence level results after each module;

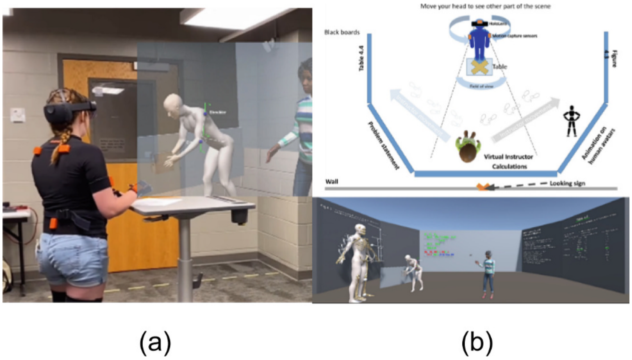

Fig. 1. Description of AR learning system (a): student is watching a scene in the AR environment, (b): arrangement of 3D objects in an AR scene showing the system setup.

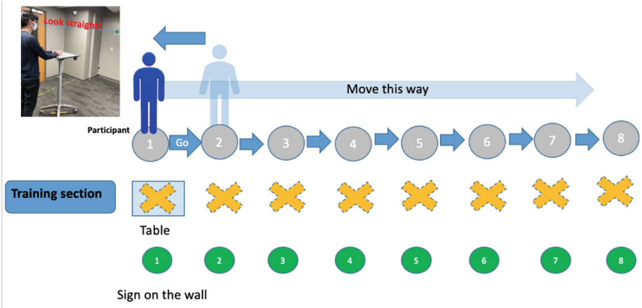

Fig. 2. The learning process during each lecture

however, in the paper-based, students can access their results at the end of each lecture. The metacognitive monitoring feedback is associated with the student's capacity to accurately assess their current metacognitive state, discerning between over-confidence and under-confidence. This feedback mechanism enhances student learning by fostering self-awareness and regulation. The metacognitive monitoring feedback comprises two distinct components (as illustrated in Fig. 3).

1) Student's response and the answer to the exercise problem (Left).
2) Visual graphs of the confidence and the performance level of the exercise problem (Right).

The first component of the metacognitive monitoring feedback encompasses students' responses to various quizzes and the retrieval of the correct answers for them. The second component involves visual representations, such as graphs, displaying the retrospective confidence judgments (RCJ) scores alongside the scores for the quiz outcome. The RCJ is one of the metacognitive prompting techniques to self-evaluate the learner's confidence levels before knowing actual test scores. For the retrospective confidence judgment, students were supposed to answer: "How well do you think have you performed question 1? (1%—low confidence level, 100%—high confidence level)" [11]. These graphical representations highlight disparities between students' RCJ and their actual competency in the assigned lab activities. When a student is over-confident (RCJ > competency), the RCJ graph appears larger than the outcome graph. In contrast, an under-confident student (RCJ < competency) exhibits an RCJ graph smaller than the outcome graph. To help students rectify their confidence levels in line with their competency, an asymmetrical triangular shape is employed as a visual aid in both graphs.

Fig. 3. Example of Metacognitive Monitoring Feedback showing the performance and confidence level

3 Result

The paired sample t-test was done between lecture #1 and lecture #2 between MAI subcategory factors for both experiments #1 and #2 separately to see how metacognitive monitoring has changed between two lectures in both experiments. The findings (see Tables 1 and 2) showed that in experiment #1, there was a noticeable MAI difference in Evaluation between lectures #1 and #2. In experiment #2, significant variations were observed in the MAI scores related to Conditional Knowledge, Planning, Information Management Strategies, and Comprehension Monitoring.

Table 1. MAI Comparisons between lectures #1 and 2 in Experiment #1

MAI CATEGORY	LECTURE	N	MEAN	SD ERROR	T-RATIO	P-VALUE
Declarative knowledge	1 2	31 31	0.772339 0.792500	0.02883	0.657439	0.5188
Procedural Knowledge	1 2	31 31	0.905 0.9125	0.02672	0.280652	0.7820
Conditional Knowledge	1 2	31 31	0.790323 0.872581	0.05871	0.9815	0.3258
Planning	1 2	31 31	0.689658 0.670552	0.04720	0.0819	0.7757

(*continued*)

Table 1. (*continued*)

MAI CATEGORY	LECTURE	N	MEAN	SD ERROR	T-RATIO	P-VALUE
Information Management Strategies	1 2	31 31	0.804839 0.760000	0.03500	0.8205	0.3687
Comprehension Monitoring	1 2	31 31	0.721339 0.701184	0.04135	0.1188	0.7315
Debugging Strategies	1 2	31 31	0.806452 0.801806	0.02898	0.0128	0.9101
Evaluation	**1** **2**	**31** **31**	**0.650294** **0.779665**	**0.04566**	**4.01138**	**0.0497**

Table 2. MAI Comparisons between lectures #1 and 2 in Experiment #2

MAI CATEGORY	LECTURE	N	MEAN	SD ERROR	T-RATIO	P-VALUE
Declarative knowledge	1 2	20 20	0.8205 0.8395	0.0289	0.6574	0.5188
Procedural Knowledge	1 2	20 20	0.905 0.9125	0.02672	0.28065	0.7820
Conditional Knowledge	**1** **2**	**20** **20**	**0.8685** **0.93**	**0.02602**	**2.36366**	**0.0289**
Planning	**1** **2**	**20** **20**	**0.6282** **0.8358**	**0.06088**	**3.41003**	**0.0029**
Information Management Strategies	**1** **2**	**20** **20**	**0.67315** **0.85725**	**0.07077**	**2.601427**	**0.0175**
Comprehension Monitoring	**1** **2**	**20** **20**	**0.755** **0.849**	**0.02563**	**3.667142**	**0.0016**
Debugging Strategies	1 2	20 20	0.9035 0.92	0.04951	0.33326	0.7426
Evaluation	1 2	20 20	0.6195 0.7066	0.04576	1.9034	0.0722

4 Discussion

This research investigated how metacognitive monitoring feedback impacts students' metacognitive state within the AR learning environment. The comparison between lectures #1 and #2 for experiment #1 showed that no significant MAI score improvement between the two lectures (except the evaluation). In experiment #1, students were informed of their confidence level and overall performance across all modules in the lecture only once at the end of each lecture. Providing feedback only at the end of the lecture series allowed students to evaluate their learning strategies over an extended period. This broad perspective could enhance their ability to assess their learning behaviors thoroughly. Since students are required to monitor their understanding and performance individually, this setting may promote deeper self-assessment practices and strengthen their evaluative skills.

On the other hand, for the results from experiment #2, the comparison between lectures 1 and 2 showed improvements in areas such as Conditional Knowledge, Planning, Information Management Strategies, and Comprehension Monitoring, which are all parts of the regulation of cognition in the MAI. Regulation of cognition involves employing techniques for efficient information management throughout the learning process as well as proactive planning and monitoring activities before engaging in educational activities [12]. With regular access to metacognitive monitoring feedback, students could adjust their learning strategies for each module in real time. This means they might change their approach based on the effectiveness of their current methods, potentially enhancing skills such as information management and planning. In this study, metacognitive monitoring feedback in AR learning environments significantly enhances students' ability to effectively plan, monitor, and adjust their learning strategies, leading to improved comprehension and metacognitive awareness. This research highlights the importance of feedback timing and method, suggesting that continuous, contextually relevant feedback is essential for maximizing learning potential and metacognitive development within immersive educational settings.

Acknowledgements. This research is supported by NSF IIS-2202108.

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