USING METACOGNITIVE MONITORING FEEDBACK TO IMPROVE STUDENT LEARNING IN AUGMENTED REALITY ENVIRONMENTS

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WENBIN GUO

Dr. Jung Hyup Kim, Dissertation Supervisor

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The undersigned, appointed by the dean of the Graduate School,

have examined the dissertation entitled

USING METACOGNITIVE MONITORING FEEDBACK TO IMPROVE STUDENT LEARNING IN AUGMENTED REALITY ENVIRONMENTS

Presented by Wenbin Guo

A candidate for the degree of

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And hereby certify that, in their opinion, it is worthy of acceptance.

Dr. Jung Hyup Kim

Dr. Luis G. Occena

Dr. James Noble

Dr. Bimal Balakrishnan

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ABSTRACT

This research aims to use metacognitive monitoring feedback to improve student learning performance in an augmented reality environment. In this study, Microsoft HoloLens, a prominent augmented reality device and independent mobile computer, provided a more realistic augmented reality environment to engineering students. The near field electromagnetic ranging system collected students' real-time location data when they experienced the augmented reality learning modules. In Phase 1, the study utilized one of the topics in the Ergonomic class, called manual material handling. The Phase 1 experiment results showed that retrospective confidence judgments in augmented reality modules could significantly influence the way students learn when the contents require a high level of spatial awareness during content learning. Therefore, Phase 2 research considered specific engineering education related to spatial recognition. For Phase 2, the location-based augmented reality system was developed to improve user interaction. The augmented reality learning module was biomechanics: one of the Ergonomic class problematic concepts to engineering students. This new location-based augmented reality system allowed students to immerse themselves in the studying process and improved student engagement of hands-on training in an augmented reality environment. Metacognitive monitoring feedback was another tool applied to improve students' learning performance. Student test scores, confidence level, answering time, and reviewing time were collected as metrics for performance assessment during the experiment. Overall, Phases 1 and 2 study outcomes advanced our understanding of students' interactions and the learning content in an augmented reality learning environment. This study also provided a guideline for how engineers need to develop valuable learning content in augmented reality environments. Furthermore, using a metacognitive monitoring feedback tool in an augmented reality learning environment is an effective strategy to improve students' academic performance and calibration.

CHAPTER 1. INTRODUCTION

1.1. Problem Statement

Augmented reality shows potential development and implementation in education and training (Garzon & Acevedo, 2019; Garzón, Baldiris, Gutiérrez, & Pavón, 2020; Prodromou, 2019; Sirakaya & Kilic Cakmak, 2018). Due to the augmented reality learning environment for learners are typically more knowledge retention (Radu, 2012), motivation (Martin Gutierrez & Meneses Fernandez, 2014), and learning gains (Akçayır & Akçayır, 2017) with self-learning (Martin-Gutierrez, Guinters, & Perez-Lopez, 2012).

Most papers discussed the advantages and applications of augmented reality in education and training (Bacca, Baldiris, Fabregat, & Graf, 2014; Nesterov, Kholodilin, Shishkov, & Vanin, 2017; Saidin, Halim, & Yahaya, 2015). However, H.-K. Wu, Lee, Chang, and Liang (2013) recognized that students were cognitively overloaded by multiple information in the augmented reality environment. Furthermore, students might lack the essential skills to conduct the devices in augmented reality learning environments (Akçayır & Akçayır, 2017). Consequently, usability influenced the effectiveness of student learning, and students underwent numerous user interactions with virtual objects in the augmented reality environment. The usability obstacle required a longer duration of training for participants compared with the control group. Kinateder et al. (2018) discovered that participants existed at the risk of overconfidence. They were more confident in the challenging assignments in the augmented reality environment than in the non-augmented reality group. Nevertheless, the authors did not provide practical approaches to overcome this issue. Although overconfidence happened in learning and training with the augmented reality system, rare studies focused on providing effective instructional strategies and guidance to support learners in augmented reality environments.

Metacognition refers to the human ability to use metacognitive knowledge to monitor and control a person's cognitive processes (Flavell, 1979; Nelson, 1990), which includes three components: knowledge related to cognition, metacognitive monitoring, and control (Dunlosky & Metcalfe, 2008; Livingston, 2003). Most metacognition researches focused on monitoring and control (Fiorella & Vogel-Walcutt, 2011). Monitoring involves the awareness of the learner's cognitive processes—a flow of cognitive information from cognition to metacognition. Metacognition is applied to influence cognitive activities. Researchers used metacognition to improve student learning in different disciplines (Rhem, 2013). Therefore, in this study, metacognition was tested in the augmented reality learning environment. According to Kim's papers (Kim, 2018a, 2018c), metacognitive monitoring feedback is an effective tool in a computer-based simulation. However, suppose this tool is helpful and thriving in the augmented reality learning environment, then we need to test how metacognitive monitoring feedback influences students' learning, answering time, and reviewing time to improve their study performance.

1.2. Research Motivation and Scope

According to the overview of metacognition's influence on learning processes, metacognitive prompting (Fiorella & Vogel-Walcutt, 2011) is provided to collect students' metacognitive judgment, and metacognitive monitoring feedback was developed as a tool to monitor and calibrate students' metacognitive judgments. Currently, the metacognitive monitoring approach and its calibration are not widely applied in augmented reality learning environments. The augmented reality environment was developed to investigate the impacts of metacognitive monitoring feedback. Metacognitive monitoring feedback may results in student learning performance improvement. This study helped understand the impacts and benefits of metacognitive monitoring feedback on student learning in an augmented reality environment. The following are specific goals and hypotheses motivated by this research.

1. Investigating how augmented reality influences student learning performance: Many papers describe the advantages or benefits of the augmented reality technology to improve spatial thinking or skills and depth perception(Carlos Carbonell Carrera & Luis Alberto Bermejo Asensio, 2017; Carlos Carbonell Carrera & Luis A Bermejo Asensio, 2017; Cidota, Clifford, Lukosch, & Billinghurst, 2016). However, humans have different visualization abilities. This study explored different visualizational abilities that influence students' performance in the augmented reality environment.
2. Exploring how metacognitive prompting influences student learning performance in the augmented reality environment: Many researchers have applied metacognitive prompting in the computer-based learning environment (Hoffman & Spatariu, 2008; Moser, Zumbach, & Deibl, 2017; Winters, Greene, & Costich, 2008), and showed the benefits to the users. This study used metacognitive prompting to collect students' metacognitive judgment and revealed how students learn in the augmented reality environment compared with the no prompting group.
3. Investigating workload in the augmented reality environment: Some researchers reported that learners were cognitively overloaded in the augmented reality (H.-K. Wu et al., 2013; P.-H. Wu, Hwang, Yang, & Chen, 2018). Some researchers

stated that the cognitive workload was reduced during the learning activity in the augmented reality environment (Lai, Chen, & Lee, 2019; Wei, Weng, Liu, & Wang, 2015). Hence, this study tested the students' workload in six dimensions, including mental, physical and effort directions, and so forth. Compared with the traditional class environment's workload, how is the workload level in the augmented reality environment?

4. Investigating how metacognitive monitoring feedback influences students' learning performance in an augmented reality environment: Researchers have rarely tested the metacognitive monitoring feedback in the augmented reality learning environment; how this tool's performance needs to be explored in this study. Participants with metacognitive monitoring feedback might have better calibration and more accurate responses to the learning content.
5. Investigating how metacognitive monitoring feedback influences student answering time, reviewing time, and workload: Metacognitive monitoring feedback as a tool might influence the way of students' learning, such as answering time and reviewing time. Students' learning time was recorded with the real-time location system to help us analyze their learning process. NASA-TLX tool (Cao, Chintamani, Pandya, & Ellis, 2009; Hart, 2006) was used to validate the workload with metacognitive monitoring feedback in the augmented reality environment. In sum, this study expected to implement the metacognition method to support student self-regulated learning (Stolp & Zabrucky, 2017; Zimmerman, 2000, 2008). Metacognition is a critical component of self-learning. Self-regulated learners are aware of their knowing and unknowing information to identify how

to use and when to operate effective strategies to improve their learning performance.

1.3. Structure of Research

In this study, the experiments were designed as a multi-phase study. The rest of this research is organized in this manner. Chapter 2 is a literature review related to augmented reality and metacognition. Chapter 3 describes the theoretical framework of the study design. Chapter 4 describes the details of the Phase 1 study, including the apparatus, participants, experiment design and setup, experimental procedures, data analysis as well as the discussion. Chapter 5 states Phase 2 study design, results, and discussion. Chapter 6 draws a general conclusion, future work, and limitations.

CHAPTER 2. LITERATURE REVIEW

2.1. Augmented Reality in Engineering Education

Researchers (Borrero & Márquez, 2012) said lab practices and experiments are critical in engineering education or training. Authors posed the augmented reality-based lab system making students and instructors work remotely. Besides, Covid-19 has massive impacts on higher education globally (Brammer & Clark, 2020). Remote education reduces the damage to students' learning, and augmented reality is a decent instrument to assist instructors in teaching students. Students experienced sensations and explored practical training in an augmented reality learning environment with less physical configuration limitations (Andujar, Mejías, & Márquez, 2010). Students have a greater sense of realism to improve students' learning by augmented reality technology. In recent years, researchers have started to build powerful platforms for education or training using augmented reality (Dalim, Kolivand, Kadhim, Sunar, & Billinghurst, 2017; Guo, 2018; Mourtzis, Zogopoulos, & Vlachou, 2018; Tang, Au, Lau, Ho, & Wu, 2020).

Unlike virtual reality, augmented reality does not cover the physical world but mixes the virtual objects into the physical world to expand a person's view (Hondori, Khademi, Dodakian, Cramer, & Lopes, 2013). Students can explore learning experiences and spatial sensations in the augmented reality. Researchers also brought the idea that users had an immersive feeling in the augmented reality environment and tangible connection because of hand gestures, such as grabbing, selecting, and moving, assist users' ongoing cognitive process and make users aware they are inside the environment (Seichter & Schnabel, 2005).

Augmented reality technology has many potential advantages in education and training (Radu, 2014).

First, augmented reality is more effective in spatial memory than books, slides, and traditional learning content. Instructors can set up the spatial configuration to enable students to acquire the structure of machines, human skeleton, and geometrical shapes. Students usually exhibited better spatial short-term memory in the augmented reality environment (Munoz-Montoya, Juan, Mendez-Lopez, & Fidalgo, 2018). Researchers found that participants outperformed in remembering objects and their locations compared with the non-augmented reality group. They believed that the brain developed and increased visuospatial short-term memory skills.

Second, augmented reality increases content understanding. Coimbra, Cardoso, and Mateus (2015) indicated that students could build an accurate understanding of learning, and augmented reality applications increased the access to knowledge for students. Augmented reality is a value-added tool for instructors if demanding high practical and experimental interaction in engineering education or training. This interaction contributes to high performance in student self-learning. Augmented reality applications consist of dynamic models, vivid animations, and learning audio to help students understand the complex objects in electrical engineering lab practice (Martin-Gutierrez et al., 2012). Augmented reality also enhances mechanical engineering students to observe, learn, and design mechanical elements in their study (Martin Gutierrez & Meneses Fernandez, 2014). In a word, augmented reality caters for a better visual interaction for students to comprehend the learning materials in their focus areas.

Third, augmented reality also shows a positive effect on short- and long-term memory. Werrlich, Eichstetter, Nitsche, and Notni (2017) reported that long-term recall performance is high in the augmented reality environment. Participants forgot less when they used interactive augmented reality. Participants showed higher satisfaction with the augmented reality training platforms. Authors believed that augmented reality improved both users' short- and long- term memory. Users are encouraged to use an augmented reality device to promote their skill-transfer performance.

Fourth, augmented reality increased the students' learning motivation. (Khan, Johnston, & Ophoff, 2019) used the ARCS (attention, relevance, confidence, and satisfaction) prototype to understand the students' motivation in augmented reality learning. They revealed that attention, satisfaction, and confidence factors significantly increased. Motivation is necessary to assist students to focus on research and make more effort to learning content. Motivation also helps students sustain self-regulated learning. Therefore, augmented reality can improve students' motivation to improve their performance.

Fifth, augmented reality assists students in self-directed practice and learning. Wang (2017) indicated that students used augmented reality devices for self-learning to solve the problems, and augmented reality blended teaching would not interrupt students' learning. Students could control their learning speed and path. And students could manipulate the learning procedures step by step. However, the authors also mentioned the overloading of information in the augmented reality learning environment. Other strategies need to be developed to avoid the high cognitive workload.

In sum, augmented reality is a valuable and cutting-edge technology that might change the lab experiment, remote education and increase student learning performance in engineering education or training. Augmented reality mixes the virtual to the real world seamlessly in a shared space to improve users' interaction (Sommerauer & Müller, 2018). It delivers the opportunity to create a more effective learning platform for instructors' teaching, students' learning, and training. Augmented reality can remarkably educate and train learners without limiting geographic locations and timing (Lee, 2012). Moreover, augmented reality decreases the students' risk in the physical world and the repeated experimental cost due to the reliability of applications. Therefore, to explore and evaluate augmented reality performance and implications in engineering education, our research used the Microsoft HoloLens device to create a powerful and innovative augmented reality environment.

In augmented reality applications, some researchers considered location-based augmented reality to support collaborative inquiry-based activities. Position-free features provided more opportunities for users to make inquiries in learning topics (Cheng & Tsai, 2013). The location-based augmented reality setting motivates students learning experiences positively. Besides, location-based augmented reality enables learners to feel immersive in the learning procedures (Akçayır & Akçayır, 2017). However, the challenges are the low sensitivity to trigger recognition and missing information because of the global positioning system (GPS) error.

In our study, augmented reality is used for engineering education in the lab or remote teaching for students, so the indoor real-time location system is essential for designers. Near-field electromagnetic ranging (NFER) positioning system (Schantz, Weil, & Unden, 2011) is an advanced real-time location system and works well indoors. This system has a low average range error of 34.0 cm for receivers in positioning (Richards et al., 2010). Rare studies combined augmented reality and real-time location system in engineering education or training. Real-time location systems can be added to the augmented reality system to track users' location and movement when they experience learning, which helps researchers follow the users' learning procedures. Using a location-based augmented reality system in learning processes not only ensures such activity sequences can be firmly understood but can also generate significant benefits for learners to improve their learning efficiency.

While augmented reality provides a new learning environment, it can simultaneously increase the workload of learners. In an augmented reality environment, previous researchers used NASA-TLX to analyze workload (Hosseini & Lienkamp, 2016; Hou, Wang, Bernold, & Love, 2013; Shirazi & Behzadan, 2015). The prior studies found that learners memorized better content in augmented reality environments than in non-augmented reality experiences. However, conducting complex tasks with lots of information in augmented reality learning environments would cognitively overload learners. It was also reported that learners were unfamiliar with augmented reality simulation and felt overwhelmed or confused by multiple tasks. (Akçayır & Akçayır, 2017; Chen et al., 2011; Cheng & Tsai, 2013; Dunleavy, Dede, & Mitchell, 2009; H.-K. Wu et al., 2013).

Our research creates a relatively effective augmented reality environment using HoloLens to investigate its performance in engineering education. However, it still needs to be explored how the augmented reality environment influences student workload. Three multidimensional subjective workload assessment tools are valuable for testing users' workload: Subjective workload assessment technique (Reid & Nygren, 1988), Workload profile (Rubio, Díaz, Martín, & Puente, 2004), and NASA task load index (Hart, 2006). The NASA-TLX contains ratings and weights. Ratings have six dimensions of experience evaluation from subjects. Every dimension's numerical range is from 1 to 100 (low to high). When performing the tasks in a pair of options, weights represent the most significant contributor to a person's workload. Six dimensions constitute 15 pairs of weights, and the number of weights is from 1 (not relevant) to 5 (most relevant). The participant's overall workload depends on the weighted mean of ratings and weights (Cao et al., 2009). Hence, this study also applied the NASA-TLX tool in exploring a student's workload in an augmented reality learning environment.

NASA-TLX measures the overall human workload while immediately after completing a task (Hart, 2006). The tool applied in a variety of areas, including military simulation, personal driving, complex air traffic operation and control (Caldwell, 2005; Erzberger, 2005; Hwang et al., 2008; Lauer et al., 2007; Palinko, Kun, Shyrokov, & Heeman, 2010; Wiegmann & Shappell, 2001). Much research exhibited the NASA-TLX is a valuable tool to use for experiments during the past 30 years. Six dimensions (mental, physical, temporal, performance, effort, and frustration) represent independent clusters of variables to assess workload. Mental, physical, and temporal demands relate to the subject dimension, while effort, frustration, and performance interact with the task of the participants.

Many researchers reported augmented reality features in terms of advantages and effectiveness when they applied augmented reality in education or training (Bacca et al., 2014). However, the limitations of the previous augmented reality study in the field of education contain three categories: a) Attention tunneling, b) Usability difficulties, and c)

Learner differences (Radu, 2014). First, students were more likely to lose their attention due to the limited field of view. They would not fully participate in the augmented reality experience and interact with the augmented reality system actively (Biocca, Tang, Owen, & Xiao, 2006). So in the augmented reality environment, students are required greater attention to the objects, and they might ignore essential parts of the learning tasks. Second, usability is a common problem that students are not familiar with the augmented reality system. However, our study improves the user interaction between students and the augmented reality environment with a practical orientation and real-time location system. The augmented reality system is value-added in teaching and lab experiments. Third, students' learning and perceptual abilities varied from each other, and low spatial perceptual ability learners might show improvement from augmented reality experiences such as geospatial navigation, spatial orientation (Billinghurst & Duenser, 2012). However, high spatial ability students might feel limited scope or information through augmented reality experiences. Understanding students' learning cognitive processes and accurate judgments might benefit their augmented reality experiences in learning.

In our study, the advanced augmented reality modules provided suitable visual recognition and spatial feeling to students. Metacognitive prompting and metacognitive monitoring feedback, as effective instructional strategies, might positively influence engineering education or training in the augmented reality environment.

2.2. Metacognition and Self-Regulated Learning

Metacognition (Flavell, 1979) refers to the human ability to use metacognitive knowledge or beliefs to monitor and control one's ongoing cognitive processes.

Metacognition influences a person's cognition with knowledge, monitoring, and control (Dunlosky & Metcalfe, 2008; Livingston, 2003).

Metacognitive knowledge (Dunlosky & Metcalfe, 2008) is knowledge about a kind of cognition, such as how learning operates and how to improve learning. Cognitive processes consist of attention, learning, and problem-solving (Brosch, Scherer, Grandjean, & Sander, 2013; Dunlosky & Metcalfe, 2008). Learning is an essential piece of the cognitive process to incorporate new information into our prior knowledge. Metacognitive knowledge contains three parts person/self-knowledge (Castañeda, 1967), task knowledge (Johnson, Johnson, Waddington, & Shouls, 1988), and strategy knowledge (Jarzabkowski & Wilson, 2006; Zhang, 2010). Person knowledge is self-knowledge about students themselves as learners, and they can regard themselves as good or bad learners. Task knowledge is the purpose or significance of tasks, task demands, and knowledge required to complete the task. Strategy knowledge is an effective strategy for completing a specific task or evaluating the effectiveness of the strategy (Schraw, 1998). Therefore, metacognitive knowledge is critical for students to select appropriate learning strategies and managing ongoing cognitive processes.

Metacognitive monitoring and control relate to the framework between metacognition and cognition (Nelson, 1990) (Figure 1). The object-level is cognition, which is ongoing cognitive processes such as attention, learning, and problem-solving (Brosch et al., 2013). The meta-level is metacognition, which includes the model of understanding the ongoing cognitive processes that learners are involved in or the tasks they are performing. Metacognitive monitoring contains the flow of cognitive information from the object-level moving to the meta-level. The flow of cognitive information updates the understanding model based on the change in the object-level. Metacognitive control guides human ongoing cognitive processes at the object-level to repeat, change, or finish the cognitive processes to complete the goal in the meta-level. In this study, students' goal or model was to learn and understand the engineering content. Students with metacognitive prompting and metacognitive monitoring feedback observed and perceived in an augmented reality environment different from the traditional learning environment. This study provided metacognitive prompting to assist students in monitoring and controlling their learning processes. Students were expected to improve their performance and efficiency in an augmented reality learning environment.

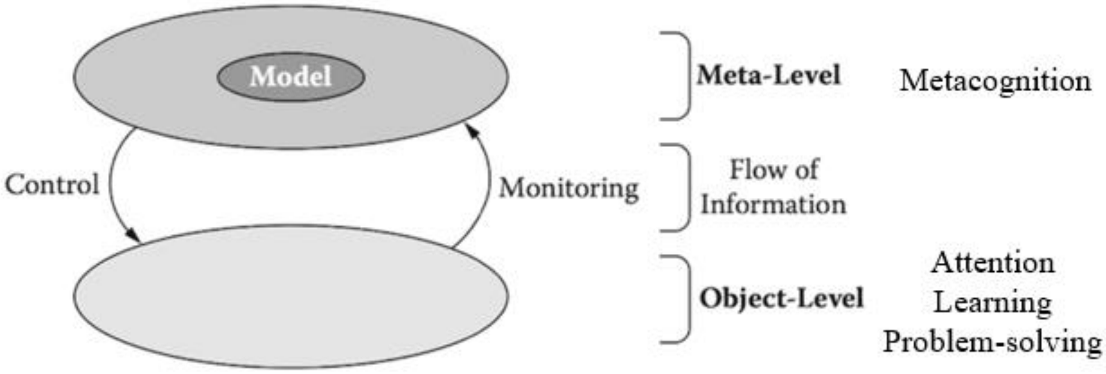


Figure 1: Metacognitive monitoring and control

Metacognitive prompting can simply be a specific question, action, or thought to learners that they are cognitively activated or reflected on their metacognition (Evans & Fisher, 2011). Alternatively, metacognitive prompting can be regarded as metacognitive cueing, reflective prompting, and self-questioning (Hoffman & Spatariu, 2008). The purpose of metacognitive prompting is to direct students to be aware of metacognitive knowledge, such as effective strategies to solve the problems. Metacognitive prompting guided students to monitor the flow of cognitive information from the cognition moving to metacognition. Based on understanding the tasks or goals, students could select learning strategies to identify the problems and figure them out effectively (Fiorella & Vogel-Walcutt, 2011).

Nietfeld, Cao, and Osborne (2005) found that metacognitive monitoring could help students reflect on their learning awareness and develop their metacognitive knowledge. Students' learning performance was related to metacognitive monitoring accuracy. According to Townsend and Heit (2011), metacognitive monitoring influenced students' allocation of study time, which finally impacted their performance. If students could correctly monitor their learning results, they could precisely judge whether they had an accurate solution to a particular problem and recognize their understanding level of materials. In this research, retrospective confidence judgments (RCJ) probes were used as a metacognitive monitoring component to assess the likelihood that students' responses on a test were correct. The likelihood was displayed in the form of a percentage scale. Metacognitive monitoring feedback was applied to help students evaluate themselves correctly and guide them to regulate processes with cognitive strategies (Dinsmore & Parkinson, 2013; Nietfeld et al., 2005). Effective goal settings involve students being aware of the current understanding of their current knowledge. Also, students can recognize the gaps in their knowledge and determine the pathway to acquiring new knowledge and skills successfully.

Metacognitive control regulates students' ongoing cognitive activities based on the updating model of understanding, such as deciding to use a new tactic to solve a difficult problem or question. According to previous research on metacognition (Boekaerts & Corno, 2005; Dunlosky & Bjork, 2013), students who had more metacognitive abilities were able to aware of their thinking and understanding of current learning contents and their own performance. Several studies have shown that good performers showed better insight into their advantages to judge learning performance accurately, but poor performers' accounted for misperception (Dunning, 2011; Schlösser, Dunning, Johnson, & Kruger, 2013). These results revealed that the calibration of metacognitive monitoring was important to improve students' learning performance. Metacognitive monitoring feedback could help students perceive their perfect calibration in the augmented reality environment. While researchers examined the effects of metacognitive monitoring calibration on participants' performance with simulation (Kim, 2018a, 2018c), there is still a gap in how metacognitive monitoring calibrates students' learning in augmented reality environments. Students' learning performance and response time were not the only results to be explored; students' awareness of how they knew the best way to learn and how they could control their learning were also to be considered in this study.

In Phase 1 of this research, retrospective confidence judgments were used to assess students' metacognitive accuracy and performance. This approach asked how much confidence level students felt and asked metacognitive prompting if students want to repeat the learning about the current task. In phase 2, metacognitive monitoring feedback was used in the location-based augmented reality system to advance our understanding of interactions between students and augmented reality learning experiences. Metacognition impacts on students' performance, answering time, and reviewing feedback time were explored in this study.

Because metacognition is the human ability to control and monitor a person's ongoing cognitive processes, human updates their activities based on different environments. Cox and Raja (2007) proposed three components ground-level, object-level, and meta-level, as shown in Figure 2. The meta-level goal is the same as the previous model in Figure 1 to monitor the cognition in the object-level and control the quality of its decisions. The cognitions in the object-level are based on the perception of the human organs at the ground level. Actions at the ground-level are selected based on the thinking of cognitions at the object-level. While meta-level control allowed students to adapt their object-level cognition, it could interfere with ground-level performance. Therefore, high-order cognitive skills in the meta-level were important to the performance of students operating in complex environments.

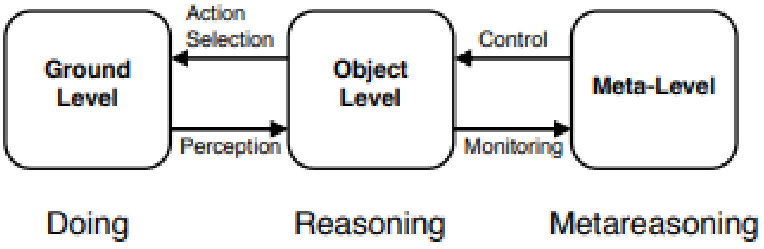


Figure 2: Introspective monitoring of reasoning structure (Cox & Raja, 2007)

In order to identify the cycles among these three levels, (Cohen & Thompson, 2005) provided a Recognition / Metacognition model to make learners understand their decision making in uncertain situations. The R/M model (Figure 3) consists of three cycles. On the left side is the basic cycle in the recognition system, which is like the ground-level and object-level, but this cycle discusses the details about perceptual encoding from external environmental stimuli and how the signals active a person’s long-term memory and cause the immediate action. The recognition system is monitored and controlled by the two nested cycles on the right-side meta-recognition system. The outer cycle is used to quickly respond to the recognition system problems based on monitoring the time, stake, and uncertainty. If learners have more time with a high stake and uncertain, they inhibit the immediate action and active critiquing and correcting. So the inner loop activates new information in mental models, and monitors the uncertainty status, accepted, gaps in evidence or knowledge, rejected or conflicting evidence or goals. Metacognitive correcting strategies shift attention to the mental models if the problems are found. New information or knowledge is integrated with the previous cycles in the recognition and meta-cognition system and fills the gaps and conflicts. This R/M model is applied to complicated situations and reinforces learners' monitoring and controlling the conflicts between predictions and their observations.

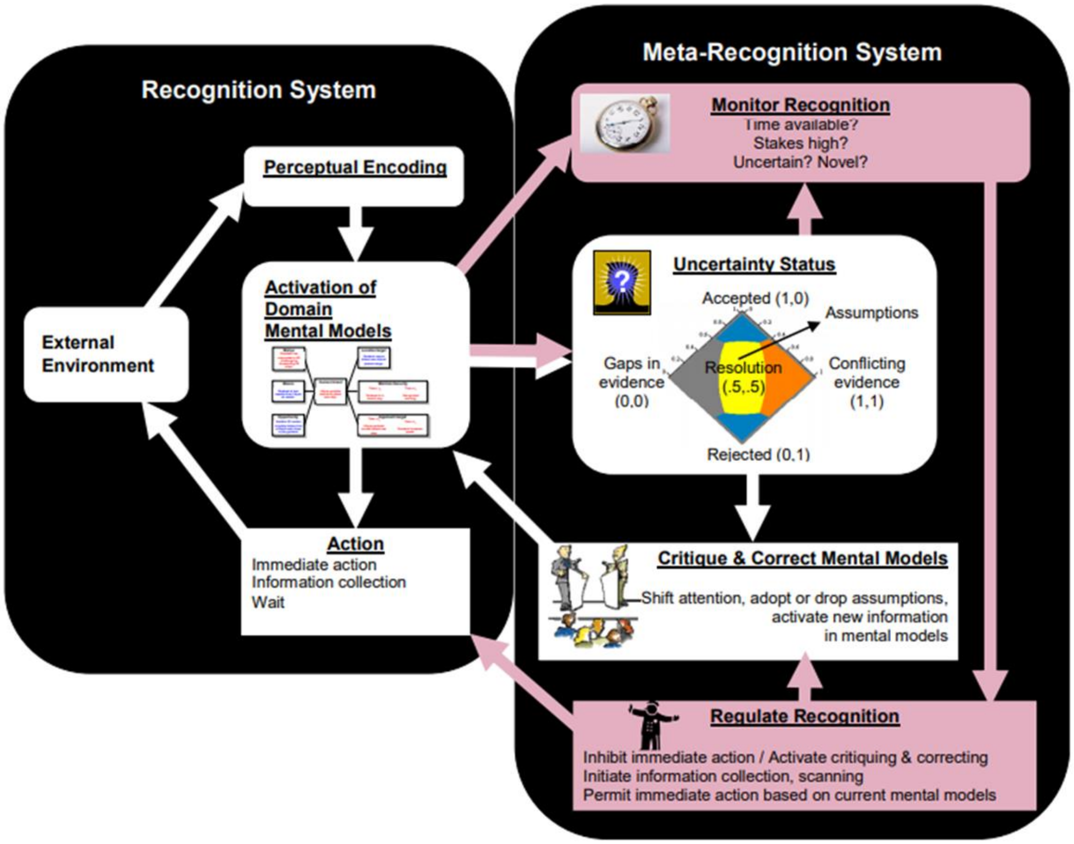


Figure 3: Overview of Recognition / Metacognition model

According to the theory of self-regulated learning (Zimmerman, 2002), improving monitoring skills can generate better performance (Dunlosky & Metcalfe, 2008). Pintrich, Wolters, and Baxter (2000) indicated that self-regulated learning is known as learners adapt or change their ongoing cognitive processes or activities. One of the important parts of self-regulated learning is to use effective strategies from simple memory to complex learning and problem-solving. Appropriate strategies improve learning and performance. Another critical part of self-regulated learning is allocating the resources such as time, personal effort, and learning pace. Different time spent on memorized the equations and understand the answer influence learners' performance. The amount of time also reflects the overall effort put into specific question. The pace of learning is related to the order to answer the questions, learners have their own strategies to solve the subtasks of the overall task.

Self-regulated learning consists of three phases (Figure 4). The forethought phase refers to the learners' goals and knowledge and the need to set their goals to achieve the tasks. And self-motivation is from the learners' beliefs, such as self-efficacy (Zimmerman, 2000). Learners expect to complete the given task and understand the learning goals. The performance phase is implementing behaviors to the processes, and it contains self-control and self-observation. Self-control is a way to use effective strategies based on the goals in the forethought phase. Self-observation is finding the causes of the tasks or events, for example, recording time to be aware of the time they spent on the task. The self-reflection phase refers to self-judgment and self-evaluation. And self-judgment compares the self-observation results with standard results. Learners judge the causes of their errors or successes of the tasks. The poor results influence their motivation and change the goals of the tasks. Self-reaction can be regarded as an adaptive/defensive response. If the self-satisfaction is high, learners continue to learn the tasks. Otherwise, learners try to protect themselves and avoid making mistakes in the tasks. In sum, self-regulated learning is a kind of cyclical mechanism to enable learners to manage their goals, motivation, and strategies. Students are responsible for their learning, and instructors also need to design appropriate learning platforms to guide students to self-regulated learning, improving their learning efficiency and performance.

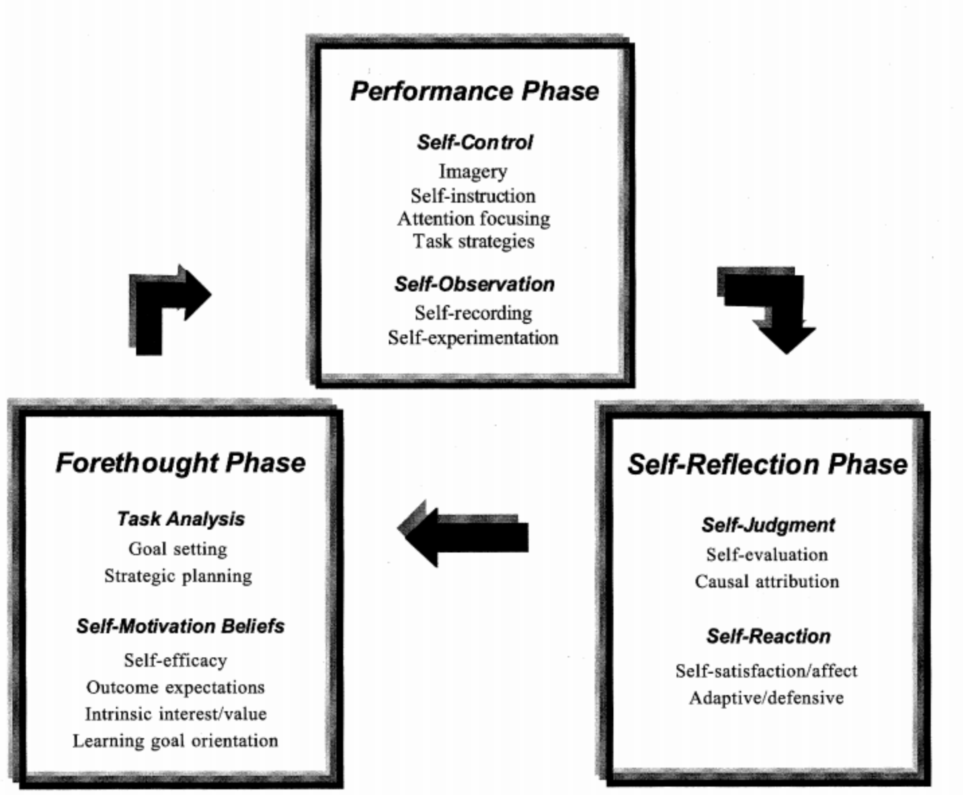


Figure 4: Self-regulated learning model (Zimmerman, 2002)

Self-regulated learners monitor, direct, and regulate actions or behaviors based on the goals and information. Metacognition can help learners to monitor and control their cognitive processes to impact their behaviors. And metacognitive prompting might not increase learners' workload and not distract learners. Metacognitive monitoring feedback is applied to calibrate the monitoring judgments, like rewards for efficacy, to increase students' self-efficacy perception.

CHAPTER 3. STUDY DESIGN

3.1. General Framework

In the Chapter 2 literature review, diverse frameworks and theories emerged out using metacognition and self-regulated learning to monitor and control learners' cognitive processes. According to a comprehensive overview of existing approaches, the introspective monitoring of reasoning structure (Cox & Raja, 2007) and the recognition/metacognition model (Cohen & Thompson, 2005) are combined to build a new theoretical framework using for metacognition and location-based augmented reality environments (see Figure 5).

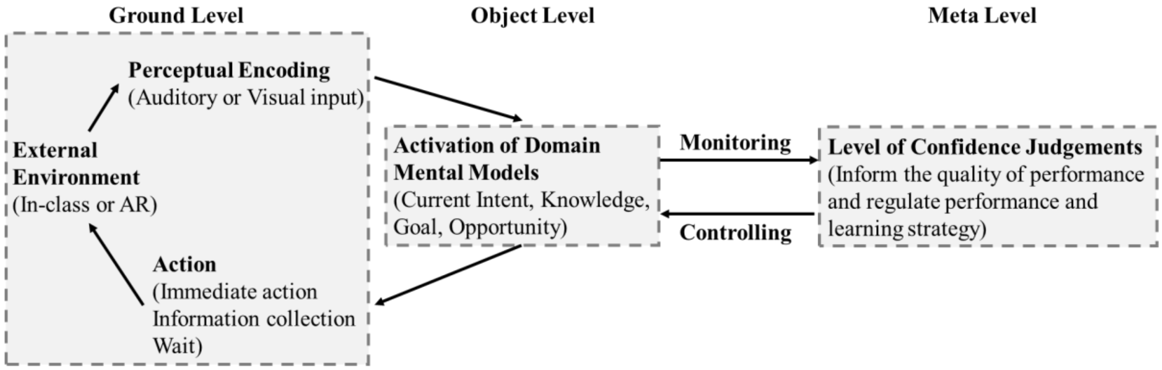


Figure 5: Theoretical framework

This framework consists of two cycles. The left cycle is between ground-level and object-level. The cognitions or the mental models in the object-level are based on the perception from the external environment at the ground level. Actions on the ground-level are selected based on the activation of domain or thinking of cognitions in the object-level. The right cycle is between object-level and meta-level. The goal of the meta-level is to monitor the cognition and mental models in the object-level and control the quality of its decisions. Furthermore, meta-level control allowed students to adapt to their object-level cognition. It could interfere with ground-level performance accordingly. Therefore, high-order cognitive skills in the meta-level were critical to students' performance in complex environments. The meta-level (metacognition) in this research is the level of confidence judgment, helping students judge whether they are approaching the correct solution to a problem or how well they understand what they are learning. The level of confidence judgments, also called retrospective confidence judgments, update based on the object-level goals and knowledge. Accordingly, the confidence judgment reflects students' learning cognition and provides feedback and insights to students.

This study consisted of two phases. Phase 1 explored how augmented reality impacts the students' spatial visualization and the effects of retrospective confidence judgments on learning performance in augmented reality environments. Phase 2 upgraded the augmented reality environment setting with real-time locations to improve user interaction in augmented reality environments. A metacognitive monitoring feedback tool was applied to improve student learning in a location-based augmented reality environment.

3.2. Phase 1: The Effects of Retrospective Confidence Judgments on Learning Performance in an Augmented Reality Environment

The Phase 1 study investigated students' learning success of tasks in an augmented reality environment compared with a traditional in-class environment in addition to exploring the impacts of retrospective confidence judgments on students' learning processes. Retrospective confidence judgments were tested in the computer-based training simulation successfully (Kim, 2018b), but they still need to be verified in the augmented reality environment. Augmented reality learning modules are designed in the augmented reality device, and students' retrospective confidence judgment scores and performance data were recorded for analyzing variations. Retrospective confidence judgment probes were asked to students while they were learning the knowledge in an augmented reality environment: repeated performance judgments to allow students to monitor their accuracy. During the experiment, students' test scores, confidence level, and workload were collected as metrics for their performance assessment. This study revealed the benefits of using retrospective confidence judgments in an augmented reality learning environment to prompt students' academic performance. From the study, we found that three-dimensional augmented reality contents could significantly influence learning if students needed to understand a high sensitivity of spatial situation awareness through the learning contents. This study's findings advanced our understanding of the interactions between students and the learning contents in an augmented reality environment. This study also delivered new guidelines on how to develop more valuable learning content in augmented reality environments. As such, Phase 1 found that understanding students' judgments can improve their achievement. However, how students' judgments influenced their performance in an augmented reality environment was not well studied in Phase 1.

3.3. Phase 2: Using Metacognitive Monitoring Feedback to Improve Student Learning in Location-Based Augmented Reality Environment

One of the limitations in Phase 1 was that the participants had difficulty in switching the next or previous learning module using hand gestures or a clicker device. Therefore, a real-time location system was developed to assist students in interacting with augmented reality modules in Phase 2. The real-time location system connected to the augmented reality device and located the participants' positions in the learning area. Each position matched each specific module in the augmented reality learning environment. Students could move forth or back to learn the next or previous module by walking to that spot or position with a specific number on it. Resultantly, real-time location-based interaction might help students reduce orientation time and frustration in interacting with augmented reality learning modules.

The Phase 1 study results showed retrospective confidence judgments could improve students' academic performance and augmented reality environments could significantly influence the way of learning if students need to understand a high level of spatial situation awareness through the learning contents. Therefore, Phase 2 applied engineering learning experiences related to spatial knowledge. Engineering learning materials were reorganized to show in the augmented reality environment and fit students' learning with augmented reality modules. In addition, metacognitive monitoring feedback allowed students to understand the way they were thinking of when learning engineering knowledge. However, we still need to investigate the effectiveness of metacognitive monitoring feedback in augmented reality environments and how to improve student learning performance in a real-time location-based augmented reality environment. During the experiment, participants' test scores, confidence level, answering time, reviewing feedback time, and workload were collected as metrics for their performance assessment. This study's findings advanced our understanding of how the metacognitive monitoring feedback tool affects student learning behavior in augmented reality environments.

CHAPTER 4. PHASE 1

4.1. Research Questions and Hypotheses

The purpose of phase 1 is to investigate the effect of retrospective confidence judgments (RCJs) on student learning performance in an augmented reality environment. Augmented reality (AR), a powerful technology, is projected to increase rapidly in engineering education, providing relevant real-time digital knowledge to support the learning of students (Schiffeler, Stehling, Haberstroh, & Isenhardt, 2019; Walker, McMahon, Rosenblatt, & Arner, 2017). A considerable amount of literature had reported AR features in the aspect of purposes, advantages, and effectiveness when they applied in various learning domains, especially in augmented reality training and educational settings (Bacca et al., 2014; Burke et al., 2017).

Because students in ergonomics classes often miscalculate the various multipliers especially asymmetric multipliers, instructors are challenged to create manual material handling (MMH) lectures to help students learn these concepts more effectively. In this study, manual material handling knowledge was used to develop augmented reality modules to address the challenge of improving students' learning performance. Much prior research proved augmented reality potential benefits. First, augmented reality was applied in astronomy and geography to help students engage and motivate their abilities to explore class materials from different angles (Kerawalla, Luckin, Seljeflot, & Woolard, 2006). Second, AR helped instructors to collaborate with students in the practical and experimental design (Billinghurst, 2002). Third, AR mixed the virtual and real objects to foster student creativity and imagination in the classroom (Klopfer & Yoon, 2004). Lastly, AR could be generated by the mobile device to help students control their learning steps and path (Hamilton & Olenewa, 2010; Yuen, Yaoyuneyong, & Johnson, 2011).

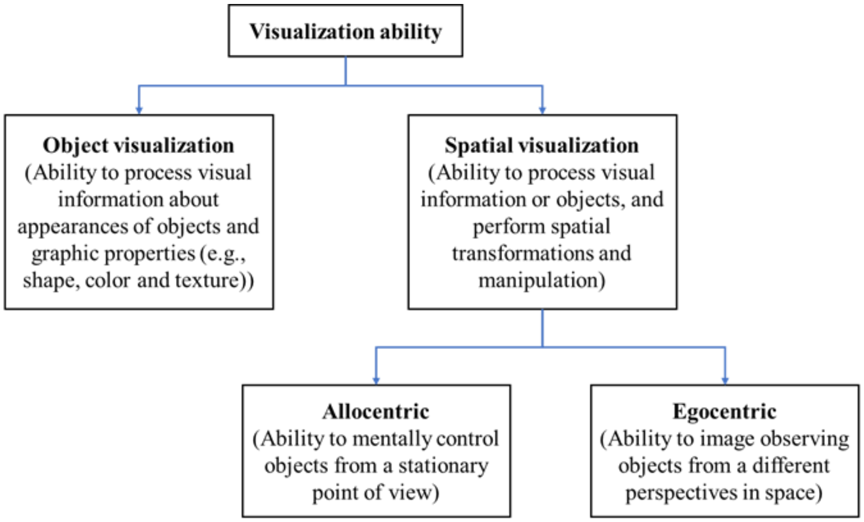


Figure 6: Human visualization ability navigation

In this study, the AR modules for manual material handling lectures were developed to investigate how the different visualization abilities were influenced by the AR environment and students' learning performance. The MMH lecture was selected as study material because each multiplier in MMH content has its unique visual features. According to Figure 6, spatial visualization is the ability to process visual information or objects, and perform spatial transformations and manipulations. Object visualization is the ability to handle object visual information about appearances and graphic properties (e.g., shape, color, and texture). Allocentric is the ability to control objects from a stationary point of view. Egocentric is the ability to observe objects from different perspectives in space. We would categorize each multiplier into different human visualization. Some multiplier features are concerned with egocentric visualization and AR performs well in egocentric depth perception (Swan, Jones, Kolstad, Livingston, & Smallman, 2007). Hence, the first hypothesis was proposed in phase 1.

Hypothesis 1-1: AR system is beneficial to egocentric depth perception to improve student learning performance.

Although the AR environment has many potential benefits to student learning, two main limitations are found in the AR environment for engineering education: 1) Attention tunneling and 2) Learner differences (Radu, 2014). First, students were easier to lose their attention when using AR modules than a paper-based module (Biocca et al., 2006). Second, everyone might have a different learning capability when he or she is exposed to an AR environment (Billinghurst & Duenser, 2012). In order to overcome those limitations, we would like to investigate the effects of metacognitive strategies for learning in the AR environment. Flavell's (1979) metacognition model has been used in various educational domains. It is an essential theoretical foundation for many researchers to study the metacognitive aspects of human thinking. Numerous studies investigated the effects of metacognitive strategies. However, not much study has been done in AR environments. In this study, the effects of retrospective confidence judgments (RCJs) on learning performance in an AR environment has been studied. RCJs refer to students' confidence judgments about the learning performance before knowing the outcomes (Kim, 2018a; Schraw, 2009a; Sperling, Howard, Staley, & DuBois, 2004). RCJ probes are used as one of the tools to measure metacognitive monitoring. They are expected to lead students' attention to the differentials between performance and confidence. This approach assists students to calibrate their RCJs with an understanding of learning materials (Huff & Nietfeld, 2009). In addition, RCJs might influence students' allocation of study time and their learning performance. If students are not able to correctly determine how well they studied the materials, they cannot develop an effective future study plan (Townsend & Heit, 2011). Therefore, we expect to observe the impacts of RCJs in the AR learning environment, and the second hypothesis is proposed in phase 1.

Hypothesis 1-2: Retrospective confidence judgments influence student learning performance in the AR environment.

Prior research (Hosseini & Lienkamp, 2016; Hou et al., 2013; Shirazi & Behzadan, 2015) used NASA-TLX to understand mental workload in an AR environment. The studies indicate that contents learned in AR environments were memorized better than non-AR experiences. However, complex tasks in AR learning environments with a large number of information leaded students to be cognitively overloaded by multitasks (Akçayır & Akçayır, 2017; Cheng & Tsai, 2013; H.-K. Wu et al., 2013). Dunleavy et al. (2009) reported that students were unfamiliar with the AR technologies making them feel overwhelmed and confused when dealing with complex tasks. Therefore, the third hypothesis was presented in phase 1.

Hypothesis 1-3: Augmented reality affects the workload of students.

During the experiment, students predicted their confidence level of how well they understood the learning materials by answering RCJ probes (scale: 1 – 100%) after they had learned MMH in the AR environment. They are free to move with the AR device to create a student-centered learning environment (Azevedo, 2005; Azevedo, Behnagh, Duffy, Harley, & Trevors, 2012). There are three groups (Group 1: AR w/ RCJs, Group 2: AR w/o RCJs, and Group 3: In-class). The results of this study could advance our understanding of human egocentric depth perception and the impact of RCJs on students' learning performance in the AR environment.

4.2. Methods

4.2.1. Apparatus

Microsoft HoloLens (Figure 7) is a prominent augmented reality device with Windows 10 operating system, which is used to create manual material handling content in the experiment. HoloLens is an independent mobile computer and students are completely free to move around to observe learning content in the experiment area. This device can mix real and virtual world objects and present them in front of the users. Students gaze at the targets they are observing. Several human gestures can be used to connect with virtual objects to understand the learning content better.

Figure 7: Microsoft HoloLens

4.2.2. Participants

There were 45 university students (40 males and 5 females) from the engineering school at the University of Missouri. The average age is 21.2 years (StDev = 1.50), and the range is from 20 to 31. The students answered the demographic questions containing video games and augmented reality experience before the experiment. The average level of video game experience was 3.28/5 (StDev = 1.07), and the average level of augmented reality was 1.5/5 (StDev = 0.87). The research was performed in three conditions, as shown in

Table 1. Group 1 students learned MMH content in an AR environment with RCJ probes; Group 2 was in the AR environment without RCJ questions; Group 3 learned MMH content in the class without the RCJs. Group 1, 2 and 3 respectively had 16, 16 and 13 participants.

Table 1: Group Description

Group	AR	RCJ
Group 1 (n=16)	Yes	Yes
Group 2 (n=16)	Yes	No
Group 3 (n=13)	No	No

4.2.3. Learning Content

Manual material handling knowledge was reorganized and generated in the augmented reality environment. The objective of learning MMH is knowing the revised NIOSH lifting equation to evaluate the lifting task risk. The equation consists of six multipliers (horizontal, vertical, distance, asymmetry, coupling, and frequency). These six variables determine the risk of lifting for workers. A horizontal multiplier (HM) refers to the horizontal distance from the body to the object. Vertical multiplier (VM) denotes the vertical distance from the floor to the object. Distance multiplier (DM) refers to the vertical distance the object is lifted or lowered. The asymmetry multiplier (AM) refers to the angle of the twisting body. Frequency multiplier (FM) refers to how many times to conduct the task in a particular duration. The coupling multiplier (CM) refers to how easy or hard of handling. All multipliers determine the object can be safely lifting or lowering by persons.

In this study, each multiplier matches one module in the augmented reality learning environment. Students can learn the horizontal, vertical distance concepts, they can also measure the distance with rulers in the augmented reality environment, which helps them practice and do hands-on exercises in order to remember and reinforce their memory. All the materials were displayed with three-dimensional objects and let students immerse themselves into the learning environment.

4.2.4. Human Visualization Ability Navigation

Figure 8 shows the steps of the categorization of each multiplier. Each multiplier represents a different visualization. HM, VM, DM, and AM are spatial visualizations that contain spatial recognition, FM and CM are object visualization, including basic concepts. VM and DM are allocentric visualizations, which are the vertical distance in the AR environment. However, HM and AM are egocentric visualizations that participants need to observe in different directions and recognize the depth or the angles in the AR environment. Different attributes of contents require different human visualization skill sets.

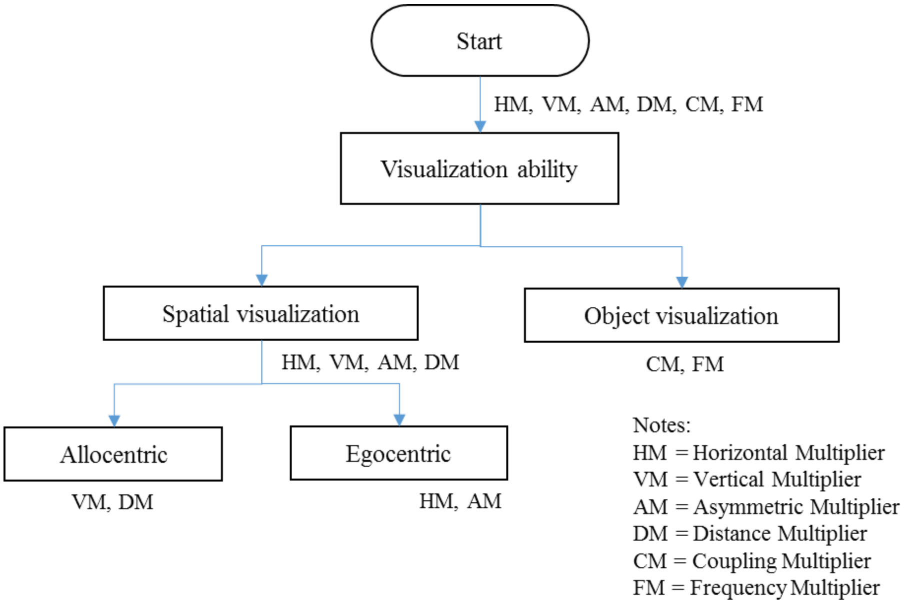


Figure 8: Flowchart of each multiplier visualization categorization

In general, students struggled with the variables AM and DM. The asymmetric multiplier is the twist degree of the human body turns in the lifting task, as shown in Figure 9. Six degrees of freedom refer to the human body's movement, which has broad freedom of action, and many variables need to be considered (Stewart, 1965). Specifically, the human body is free to change six positions, such as go forward and backward, up and down, left or right. Two multipliers (DM and AM) are so complicated and sophisticated that students would feel overwhelmed when they encounter these concepts. Students would miscalculate the angles of human twisting to the origin or destination position and found the vertical location (V) at the destination of the lift by mistake.

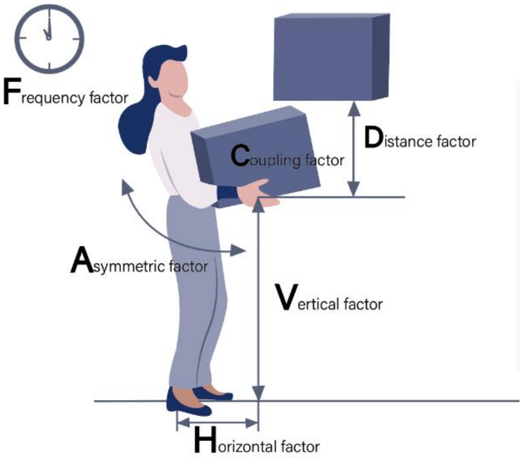
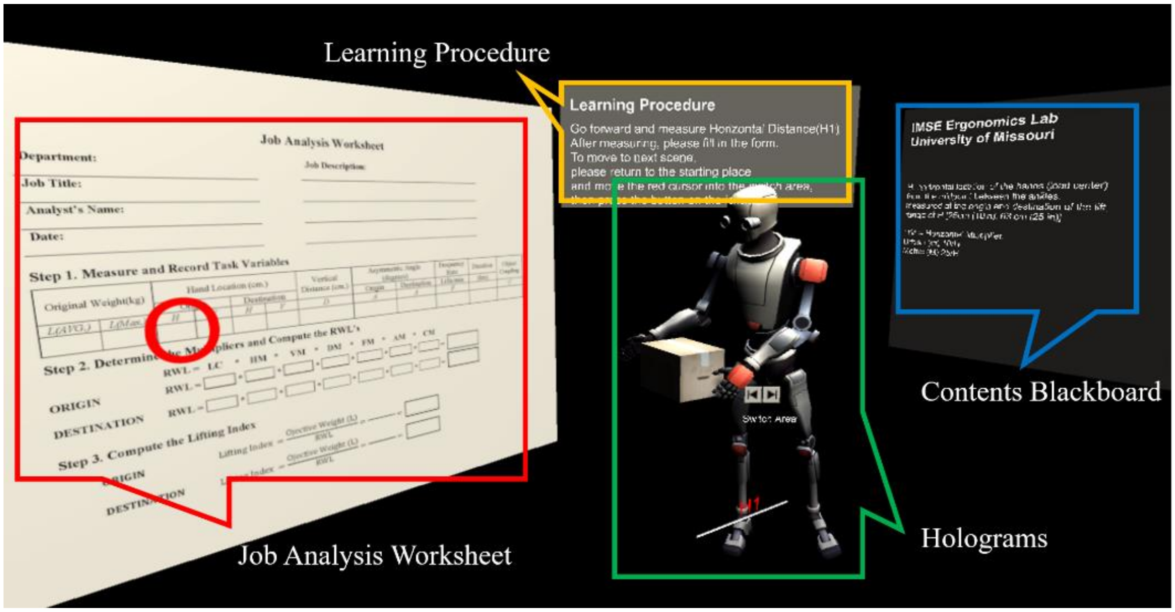


Figure 9: Variables in the lifting equation

4.2.5. Design of Experiment

Figure 10 displays an example of the MMH module, which contains (a) job analysis worksheet for recording, (b) learning procedure about calculating force and moment (c) Human animation for MMH, and (d) content blackboard (Guo, 2018). The job analysis worksheet helped students to observe and record data with MMH multiplier. The participants can check whether their answers are accurate according to the sheet on the learning module in the HoloLens. The learning procedure displays the steps of which multiplier needs to be calculated on each learning module. Human animation can enhance students' recognition of depth and angles in three-dimensional space. There are two arrows in front of human animation. The left arrow refers to the previous learning module and the right arrow moves to the next learning module. The content blackboard presents MMH's definition and formula, teaching students to measure and calculate each multiplier. When the students start learning the MMH content, the learning contents' audios help students navigate the MMH module and ensure they follow the steps to study the contents.



Learning Procedure

Go forward and measure Horizontal Distance(H1)
After measuring, please fill in the form.
To move to next scene,
please return to the starting place

Figure 10: Manual material handling education simulation

In order to compare the learning performance in an AR environment with an in-class environment, manual material handling tests evaluated students' performance from 0 to 100. Each multiplier performance demonstrated their understanding of the learning content and the influence of spatial visualization on students' cognitions. This research also compared the workload of students between augmented reality environments and in-class environments.

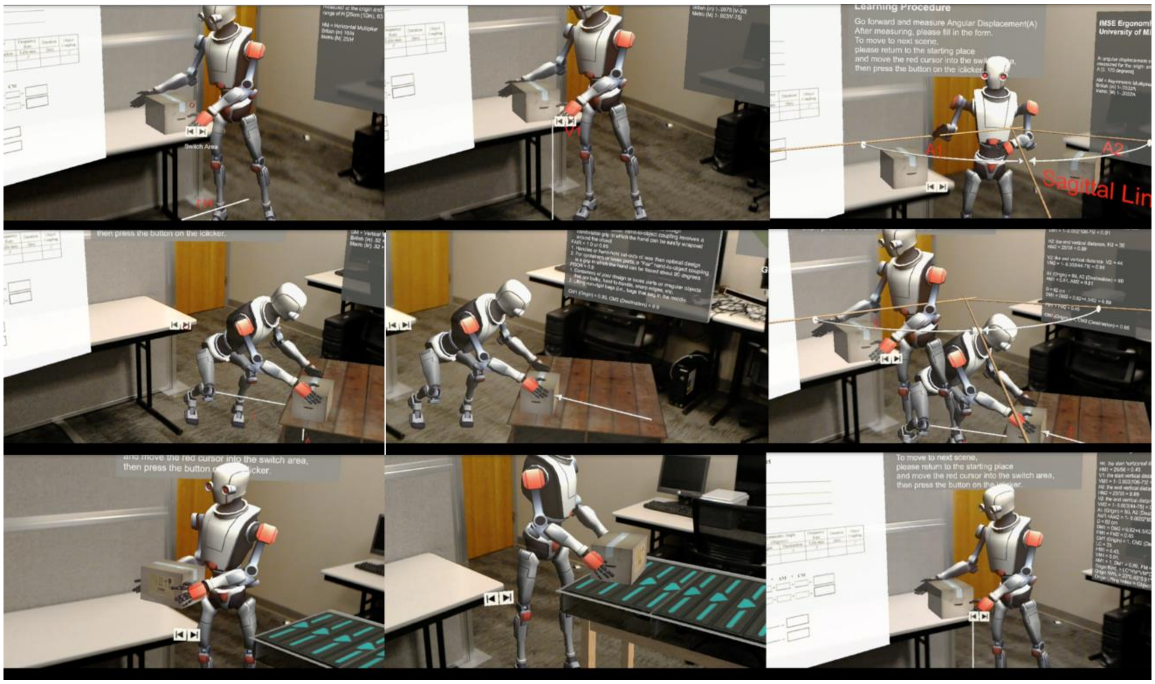


Figure 11: Screenshots for each module

Figure 11 displays each multiplier learning module in the first two rows, and the third row shows the practice module in the AR environment. Participants can observe and go forward using rulers to measure horizontal and vertical distances and using goniometers to measure angles. Also, participants can check and review each multiplier answers. The practice module lets students practice the MMH measurement with a practical example on the conveyor to verify their learning effectiveness and experimental skills.

Figure 12 shows the MMH flowchart with metacognitive questions. The difference between Group 1&2 and Group 3 is the learning environment difference. The difference between Group 1 and 2 is the metacognitive questions after the measurement of each multiplier.

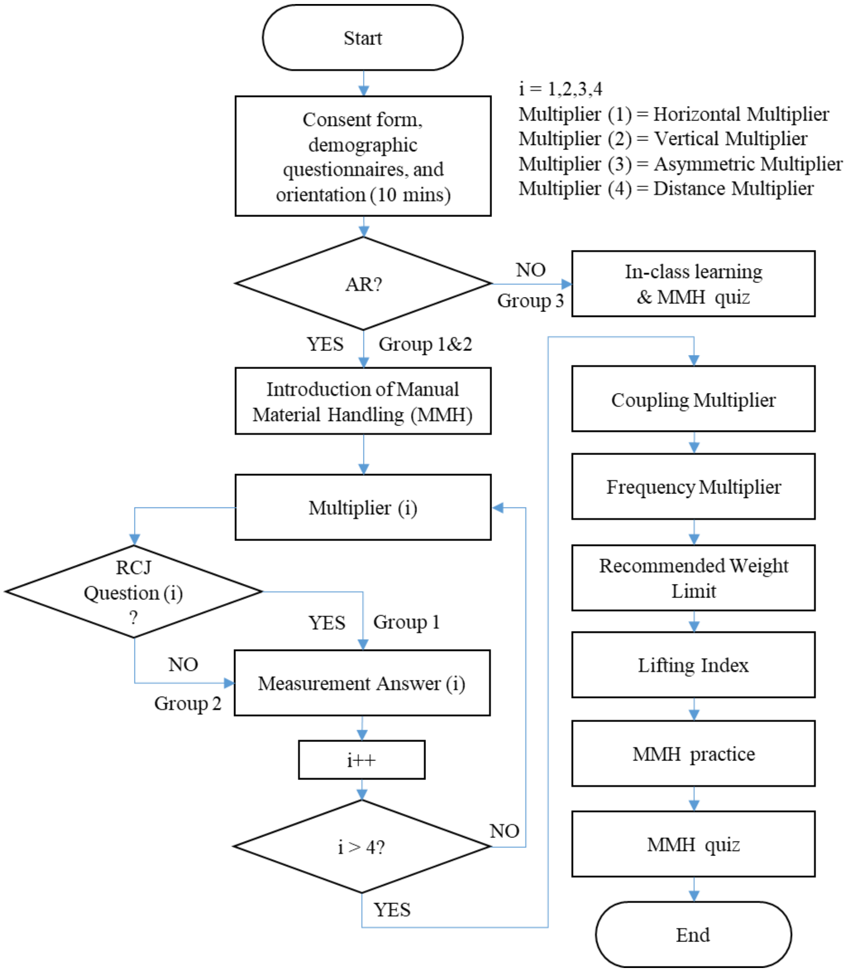


Figure 12: MMH education simulation flowchart with metacognitive question

First, every student filled up the consent form, demographic questionnaires. For in-class Group 3, students learned MMH in class with instructors. Students used the same notes with Group 1 and Group 2. They needed to understand each multiplier in the lifting equation. After learning all the materials, students took the in-class quiz to test their learning performance. The only difference is the learning environment.

For Group 1 and Group 2, participants had an orientation about the AR device and how to interact with virtual objects with gestures or a clicker. The questionnaire asked about students' computer game experience and AR experience before. Participants tried to wear the AR device to see the best view of learning modules. They also needed to fill in the job analysis worksheet when doing the measurement. The participants jumped to the next module after they completed and bounced back to the previous module if they forgot. After training, students started to learn MMH materials and conduct the hands-on exercise. After learning, the participants also took the same test with Group 1 to verify their learning performance. The difference between Group 1 and Group 2 is the retrospective confidence judgment questions. And the total experimental time was about 1.5 hours.

4.3. Results

4.3.1. Learning Performance

All the dependent variables were analyzed using ANOVA. The participant responses contained students' total test scores, performance for each multiplier (HM origin, VM origin, AM origin, DM, HM destination, VM destination, AM destination, CM, and FM) in different conditions. ANOVA analysis separated independent variables, withholding one factor fixed to account for within-subject and between-subject changes. To study the differences caused by different learning environments, we compared performance between the AR and in-class groups. For different learning environments (Group 2 vs. Group 3), Table 2 shows that there were significant differences in the performance of AM origin [$F(1, 28) = 17.38$, $p < 0.001$]. For the same AR learning environment (Group 1 vs. Group 2), Table 3 reveals that there was a significant difference on the performance of HM origin [$F(1, 31) = 5.00$, $p = 0.033$] and AM origin [$F(1, 31) = 5.00$, $p = 0.033$]. Group 1's average score was significantly greater than Group 2 on HM origin. However, Group 1's average score was significantly lower than Group 2 on AM origin.

Table 2: Descriptive statistics for test score in different learning environments (Group 2 vs. Group 3) (*p<0.05, **p<0.001)

Variable	Group2 (n = 16)		Group 3 (n = 13)		F	P
	Mean	StDev	Mean	StDev		
Overall test score	0.734	0.310	0.692	0.302	0.28	0.716
HM Origin	0.750	0.447	0.615	0.506	0.58	0.454
VM Origin	0.781	0.4047	0.692	0.480	0.11	0.741
AM Origin	**1.000****	0.000	**0.462****	0.519	**17.38**	**0.000**
DM	0.688	0.479	0.769	0.439	0.23	0.639
HM Destination	0.813	0.403	0.769	0.439	0.08	0.784
VM Destination	0.750	0.447	0.846	0.376	0.38	0.542
AM Destination	0.938	0.250	0.923	0.277	0.02	0.884
FM	0.813	0.403	0.923	0.277	0.70	0.409
CM	0.938	0.250	1.000	0.000	0.81	0.377

Table 3: Descriptive statistics for test score in the AR environment (Group 1 vs. Group 2) (*p<0.05, **p<0.001)

Variable	Group1 (n = 16)		Group 2 (n = 16)		F	P
	Mean	StDev	Mean	StDev		
Overall test score	0.791	0.295	0.734	0.310	0.28	0.603
HM Origin	**1.000***	0.000	**0.750***	0.447	**5.00**	**0.033**
VM Origin	0.781	0.407	0.750	0.447	0.04	0.838
AM Origin	**0.750***	0.447	**1.000***	0.000	**5.00**	**0.033**
DM	0.875	0.342	0.688	0.479	1.63	0.212
HM Destination	0.875	0.342	0.813	0.403	0.22	0.640
VM Destination	0.750	0.447	0.750	0.447	0.00	1.000
AM Destination	0.688	0.479	0.938	0.250	3.43	0.074
FM	0.875	0.342	0.813	0.403	0.22	0.640
CM	0.813	0.403	0.938	0.250	1.11	0.300

Table 4: Descriptive statistics for test score (Group 1 vs. Group 3) (*p<0.05, **p<0.001)

Variable	Group1 (n = 16)		Group 3 (n = 13)		F	P
	Mean	StDev	Mean	StDev		
Overall test score	0.791	0.295	0.692	0.302	0.78	0.385
HM Origin	**1.000***	0.000	**0.615***	0.506	**9.31**	**0.005**
VM Origin	0.781	0.407	0.692	0.480	0.29	0.594

AM Origin	0.750	0.447	0.462	0.519	2.59	0.119
DM	0.875	0.342	0.769	0.439	0.53	0.471
HM Destination	0.875	0.342	0.769	0.439	0.53	0.471
VM Destination	0.750	0.447	0.846	0.376	0.38	0.542
AM Destination	0.688	0.479	0.923	0.277	2.46	0.128
FM	0.875	0.342	0.923	0.277	0.17	0.686
CM	0.813	0.403	1.000	0.000	2.79	0.106

Next, HM Origin and AM Origin scores were compared between Group 1 and 3 in Table 4. It indicated that there were significant differences between Group 1 and 3 on HM Origin [F (1, 28) = 9.31, p-value = 0.005]. However, no significant difference shows on AM Origin. Figure 13 shows the HM Origin and AM Origin scores comparison among three distinct groups.

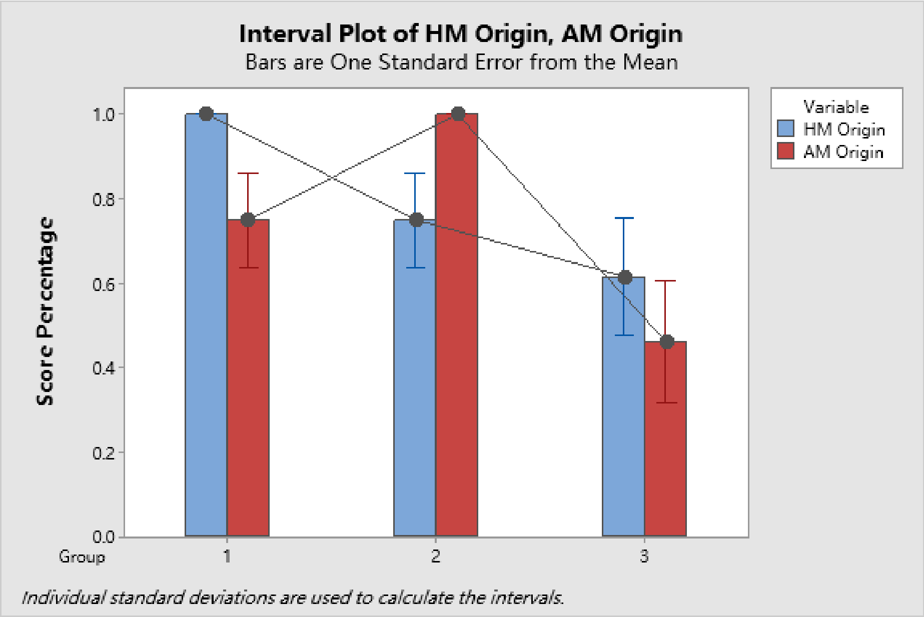


Figure 13: The horizontal multiplier (HM) and asymmetric multiplier (AM) score comparison

4.3.2. Workload

The three groups (Group 1: AR with RCJs, Group 2: AR without RCJs, Group 3: In-class) NASA-TLX scores were compared. It proved that there was no significant difference in the overall workload among the three groups.

Table 5: Descriptive statistics for workload comparison (p<0.05)

Variable	Group 1		Group 2		Group 3		F	P
	Mean	StDev	Mean	StDev	Mean	StDev		
NASA-TLX	60.98	8.43	61.10	10.67	54.95	8.84	1.95	0.156
Mental	**60.94**	16.85	**64.38**	11.81	**49.62**	15.34	3.81	**0.030**
Physical	33.81	25.57	32.25	20.63	25.23	22.46	0.55	0.581
Temporal	37.00	24.42	38.13	21.12	50.00	18.26	1.54	0.226
Performance	55.63	21.59	60.63	24.14	74.62	15.61	3.05	0.058
Effort	**67.81**	12.38	**63.44**	9.78	**52.31**	12.35	6.76	**0.003**
Frustration	**61.56**	24.68	**55.00**	26.89	**36.92**	22.13	3.70	**0.033**

Table 5 shows the details of the mean score and standard deviation in a different environment. Each dimension workload of NASA-TLX was compared in a different environment. The results indicate a significant difference in three dimensions (mental, effort, and frustration). Post hoc comparisons using the Fisher test showed that group 3's average score was significantly lower than group 1 and 2 for the mental and effort dimensions. Post hoc comparisons using the Fisher test showed that group 1's average score was significantly greater than group 3 for the frustration dimension.

The ANOVA approach shows workload differences caused by Group 1, Group 2 and Group 3. One-way ANOVA shows no significant difference in students' overall workload between AR environment and in-class environment.

Figure 14: Workload of dimensions (Group 1&2 vs. Group 3)

Figure 14 shows each dimension workload between AR environments and in-class environments. Three dimensions (mental, effort, frustration) significantly higher in the AR environments than in-class environments. Only one dimension (performance) significantly lower in the AR environments than in-class environments.

4.4. Discussion and Conclusion

In this study, students learned MMH and performed hands-on exercise in the AR environment. The MMH AR modules allowed them to experience mixed real and virtual objects with egocentric depth perception. Through the AR learning modules, students could observe vivid human animation and its continuous movement from different angles. After that, they measured the distance and angle using a ruler and a goniometer during the practice. Our findings showed that the AR environment improves students' egocentric depth perception and the RCJs could impact students' learning performance in an AR environment.

4.4.1. Performance (AR vs. in-class)

Although the overall test score (see Table 2) was not significantly influenced by different environments (AR vs. in-class), the AM Origin was significantly higher when the participants learned MMH in the AR environment. However, AM Destination has no significant difference between AR and in-class environment. Hence, we can conclude that hypothesis 1-1 (AR system is beneficial to egocentric depth perception to improve student learning performance) is partially accepted.

It means that the AR environment might be beneficial to learn the course contents, which include egocentric visual components. The relationship between AM and egocentric distance perception in the AR environment can be explained by angular declination (Messing & Durgin, 2005; Ooi, Wu, & He, 2001). According to human visualization ability navigation theory (see Figure 8), the students who learned MMH through the AR modules were able to improve their ability to understand the class contents that require a high level of spatial awareness. Spatial awareness is closely linked to the ability to recognize virtual 3D objects. The AR modules provided better spatial information and helped students improve spatial recognition. Therefore, the egocentric view in the AR environment is effective to assist student learning when they require a high level of spatial awareness

However, there is no significant difference on AM Destination between the AR and in-class environments. This phenomenon can be explained by the measurement difference between the Origin and Destination in the AR environment (see Figure 15). As shown in the figure, the origin measurement started from a physical table. Students could obviously measure the distances and angles. However, the destination measurement was done on the virtual conveyer. Due to the field of view and a resolution limitation of the Microsoft HoloLens device, virtual objects were sometimes disappeared when students had moved close to the conveyer, influencing their observation and measurement. For that reason, the AR environment could not provide the benefits to the students in the AM Destination. In order to address this problem, it is necessary to develop a virtual ruler and a goniometer when they need to measure the distances and angles of virtual objects.

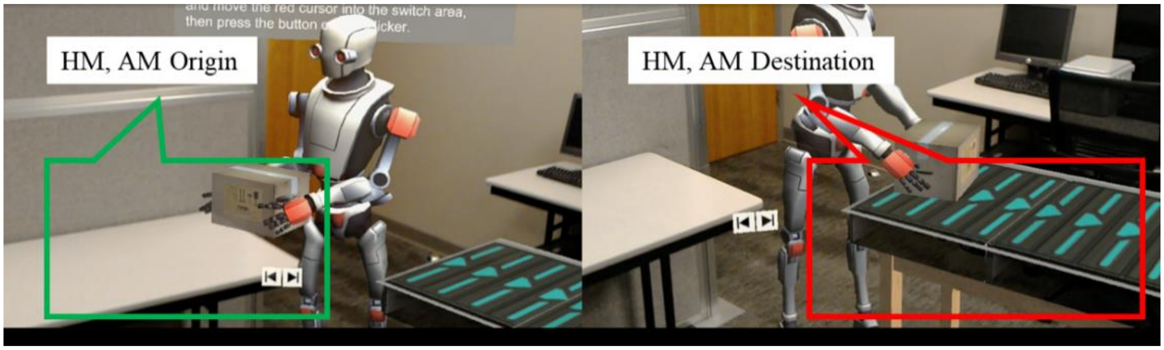


Figure 15: HM/AM Origin vs. HM/AM Destination

Based on the theoretical framework, the augmented reality environment allows students to improve their spatial recognition so that they change their knowledge in cognition at the object-level (Figure 16).

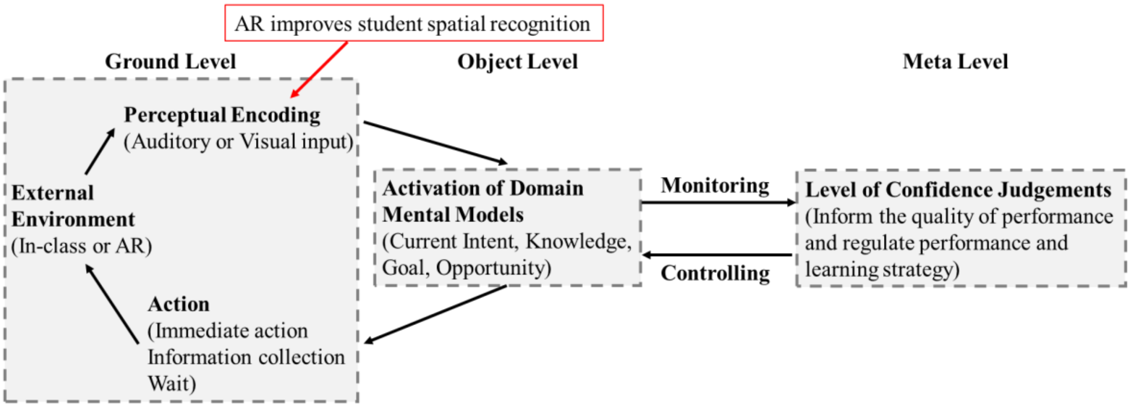


Figure 16: AR benefit in visualization

4.4.2. RCJs impact learning performance in the AR environment

Table 3 indicated that the students who experienced the RCJ probes showed a better HM Origin performance compared to the students without the RCJ probes. It means that the RCJ probes showed a positive impact on the HM Origin performance in the AR environment. However, the probes also showed a negative impact on AM Origin performance. Hence, we can conclude that hypothesis 1-2 is partially accepted. This outcome could be caused by the different aspects of HM and AM. The HM Origin is the original horizontal distance from the worker to the object. On the other hand, the AM Origin is the original angle from the sagittal line to the origin position, as shown in Figure 17. During the lesson, students needed to learn and gauge a horizontal distance for the HM from the object centroid to the human body centroid. They needed to measure the angles between the sagittal line, original grab position, and destination grab position for the AM. In the AR environment, the modules provide the virtual graphics and animation to measure the HM Origin and AM Origin by themselves.

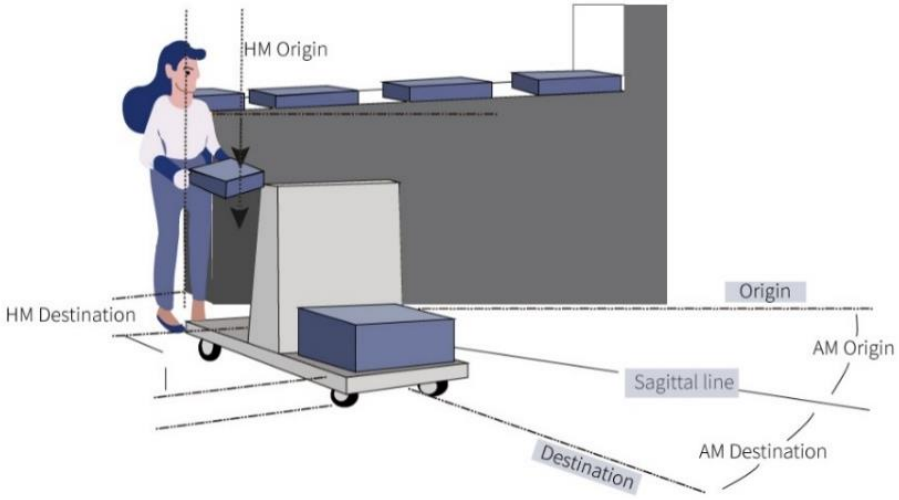


Figure 17: HM and AM in the manual material handling

During the hands-on exercise of Group 1, the students rechecked the HM Origin and AM Origin multiple times caused by the RCJ probes to make sure that there is no error in the values. From our observation, the HM Origin values were consistent most of the time. However, many students had experienced confusion after they collected multiple AM

Origin values due to inconsistency in the values. If the second measured AM Origin angle was different from the first measured angle, then they might doubt their skill to measure the AM Origin. This inconsistency would influence their confidence level of the AM, and the performance decrease could be explained by the effects of information inconsistency (Sengupta & Johar, 2002). According to Sengupta (2002), if students continuously expose to inconsistent values, it can lead to reconciliatory elaboration. The students who obtained different AM origin values for the same measuring task would create confusion corresponding to their AM knowledge. If the students cannot properly handle the confusion, then it would negatively influence their learning performance.

RCJs should support students to be aware of which learning contents need to be restudied and what problems they should practice more. The students who experienced the RCJ probes often selected to restudy some of the AR modules based on their confidence level. They were more likely to redo the modules when their retrospective confidence level was low, which helped them improve their performance. The HM origin performance is the case that showed this positive impact caused by RCJs (see Table 4). When the students only experienced the AR environment (Group 2), their HM origin performance was not improved compared to the students who learned MMH in a class environment (Group 3). However, when the RCJ probes were asked to the students, they could get the advantages using the AR modules. On the contrary, the RCJ probes had a negative effect on AM origin performance. Although the RCJ probes led the students to remeasure the AM values, they were confused by inconsistent AM outcomes and decreased performance. The outcomes of this study show that if the AR modules are designed to support egocentric spatial processing and all virtual objects are consistently displayed with minimum dynamic variability between real and virtual environments, then the RCJ probes are beneficial to improve student learning performance as we have seen in the HM outcomes. However, if the measurement values contain a large deviation, the RCJ probes might be hurtful to learners in AR environments. Therefore, selecting appropriate learning content to apply the RCJ probes is vital to successful learning in AR environments.

In conclusion, the AR environment is beneficial to the egocentric depth perception to improve students' learning performance. RCJs could have both a positive or negative influence on student outcomes in the AR environment. This study's findings advance our understanding of how AR and RCJs can affect student learning and show that mixed physical and virtual objects can improve learners' spatial awareness. Although there are technology limitations (i.e., need for virtual measurement tools and low image resolution of virtual objects), asking RCJ probes in the AR environment has a significant impact on the student learning performance. These results would help engineers, educators, and AR content developers optimize this new technology's merits.

4.4.3. The workload in the AR environment

Table 5 shows no workload difference between AR and in-class environments so that AR can be used in future studies, and it does not influence students' workload. Hypothesis 1-3 was rejected. However, these four dimensions, mental, performance, effort, and frustration, were significantly different between AR and in-class conditions.

The mental dimension was higher for students in the AR environment. Students spent more time observing, searching, and measuring the distances or angles of manual material handling in AR conditions than in-class conditions.

The performance dimension was lower in the AR environment. Students were underconfident about their performance in the AR environments compared with the in-class environments. In fact, the students performed better spatial visualization in the AR environments than in-class environments.

The effort dimension was higher in the AR environment. Students performed more effort with hands-on exercises. Students in the AR environment were supposed to be familiar with the new learning environment to achieve their goals.

The frustration dimension was higher in the AR environment. The students felt stressed or frustrated when they were not very familiar with the manipulation of new technology. Human gestures were still hard for them to interact with virtual objects.

The physical dimension and temporal dimension were not significantly different. Hands-on exercises did not increase the physical demand in the AR environment. Also, students followed their learning pace based on their understanding.

In conclusion, this research's findings evaluated the workload in six dimensions between the AR environments and in-class environments. The overall workload would not increase in AR environments. This Phase 1 study advanced our understanding of students' interactions and the learning contents in an AR environment. Also, this study reveals new guidelines on how to develop more valuable learning content to decrease learners' workload in an AR environment.

4.5. Limitations

One of the limitations in the phase 1 study is that we did not investigate how RCJs influenced the calibration process of students' confidence level and how it affected the student learning time in AR environments. It would be beneficial to collect response time data, such as study completion time or question review time, to answer those research questions. Also, we did not collect eye movement data and compare the attention differences between good performers and poor performers. By analyzing the learner's attention to virtual objects in the environment, we would discover some important gaze patterns correlated to learning performance. Besides, many students felt stressed when they learned manual material handling in the AR environment. Two-third of the participants had never experienced the AR learning environment before. Hence, it would be essential to study how the AR learning environment influences student workload between different AR experience levels. Finally, during the experiment, it took a long time to train the students to be familiar with how to touch, rotate, and control 3D virtual objects in order to navigate the AR learning modules. For that reason, more user-friendly interfaces must be developed to implement AR learning environments in other educational areas.

CHAPTER 5. PHASE 2

5.1 Research Questions and Hypotheses

Many researchers have studied metacognition impacts (Dunlosky & Tauber, 2016; Hacker, Dunlosky, & Graesser, 2009; Shaughnessy, Veenman, & Kennedy, 2008). As such, researchers have discovered that students who practice metacognitive monitoring strategies regularly could significantly improve their learning performance in a classroom environment (Coutinho, 2008; Huff & Nietfeld, 2009; Nietfeld, Cao, & Osborne, 2006). However, rare researchers have examined the impacts of those metacognitive strategies in an augmented reality (AR) environment. Although Kim (Kim, 2018a, 2018c) found that metacognitive monitoring feedback positively impacted student performance in a computer-based training simulation, the testing environment was not fully constructed in a 3D environment, and the tasks were deeply related to specific military domains. Recently, many researchers have found that teachers and trainers could create more effective educational and training content to improve students' spatial perception using AR technology (Deshpande & Kim, 2018; González, 2018; Radu, 2014). It may provide various advantages in engineering education and student learning (Schiffeler et al., 2019; Strzys et al., 2017; Xue, Sharma, & Wild, 2019). The current study is designed to explore the potential benefits of metacognitive monitoring feedback to improve student learning in the AR learning environment. Metacognitive monitoring feedback is one of the metacognitive monitoring tools, which is used to calibrate retrospective confidence judgments to enhance student learning performance. During the experiment, students were asked to answer retrospective confidence judgment questions after completing the given tasks. Subsequently, a group of students monitored the metacognitive monitoring feedback screen and was able to understand their discrepancies between their confidence levels and actual test performance.

The purpose of Phase 2 was to explore how metacognitive monitoring feedback improves students’ learning performance in a location-based augmented reality environment. Metacognitive monitoring feedback was the tool for reflecting and directing a person’s thinking in mastering difficult material and an essential skill in successful project learning environments to improve learning performance and enhance students’ awareness of the differentials between performance and confidence. Furthermore, metacognitive monitoring feedback could improve students' learning performance and develop life-long learning skills. According to previous studies, metacognitive monitoring feedback could improve learning performance in computer-based learning environments. However, we still need to verify whether metacognitive monitoring feedback is useful in the AR environment. Thus, the first hypothesis was pointed out in the Phase 2 study.

Hypothesis 2-1: Metacognitive monitoring feedback improves student learning performance in augmented reality environments.

In this research, retrospective confidence judgments can be regarded as one of the metacognitive monitoring metrics to measure students’ confidence levels about their actions before they know the performance results (Dunlosky & Metcalfe, 2008). Most retrospective confidence judgments often show over- or under-confidence. Therefore, monitoring accuracy is critical for learners to calibrate their confidence levels based on their performance. In order to calibrate the confidence level, two approaches (process-oriented approach and response-oriented approach) were proposed (Hacker, Bol, Horgan,

& Rakow, 2000; Keren, 1990). Huff and Nietfeld (2009) explained that these two approaches have different timings of the temporal sequence. The process-oriented approach allowed students to generate thoughts for their answers before making retrospective confidence judgments. However, the response-oriented approach provided feedback to inform students about their confidence level over-confidence or under-confidence. Metacognitive monitoring feedback is response-oriented to provide the visual discrepancy of confidence level and performance.

In order to calibrate the students' confidence level, two indicators can be used: calibration accuracy and calibration bias (Huff & Nietfeld, 2009; Schraw, 2009b). While the former indicates the absolute value of the discrepancy between confidence level and actual performance of learners, the latter reveals the degrees of over- or under-confident in human judgments, both of which indicate the calibration has a bias with the small or large deviation between confidence level and performance. Based on the perfect calibration presented by the solid diagonal line in Figure 18, over-confidence is described as a greater confidence level than the actual test performance. Under-confidence refers to a confidence level lower than the actual performance.

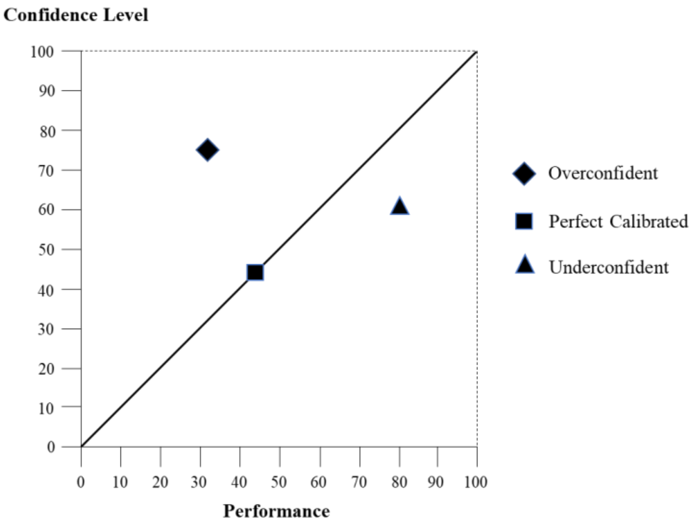


Figure 18: Calibration of performance and confidence level

Effective goal settings involve students being aware of the current understanding of their current knowledge. The metacognitive monitoring feedback was applied to repeatedly evaluate students' calibration and guide them to regulate learning processes with cognitive strategies. Students can recognize the gaps in their knowledge and determine the pathway to acquiring new knowledge and skills successfully.

The purpose of the Phase 2 study was to investigate the effects of the metacognitive monitoring feedback on student learning performance caused by debiasing students' retrospective confidence judgments in a location-based augmented reality learning environment. According to previous research on metacognition (Boekaerts & Corno, 2005; Dunlosky & Bjork, 2013), students were able to aware of their understanding of current learning contents and performance if they had great metacognitive abilities. Several studies have shown that good performers showed better insight into their advantages to accurately judge learning performance, but poor performers accounted for misperception (Dunning, 2011; Schlösser et al., 2013). These results revealed that the calibration of metacognitive monitoring was essential to improve students' learning performance. Metacognitive monitoring feedback could help students perceive their perfect calibration in the augmented reality environment.

In light of the above, how does metacognitive monitoring feedback influence the students in detail? This study repeated the monitoring feedback like a heuristic to monitor students' judgments. The confidence level was shown in the feedback on the screen. First, we presented Tversky and Kahneman (1974) anchoring-and-adjustment heuristic. Students evaluated themselves with an initial confidence level and adjusted their confidence level from the first anchor. Subsequently, they compared their confidence level with the actual scores after the test. There was a dispensary between the confidence level and performance. Students repeatedly adjusted their confidence level near the initial anchor and calibrated their under- and overconfidence in the judgments. Second, calibrating students' confidence judgments influenced their performance. Furthermore, students were continuously calibrating confidence levels compared with actual test performance, thereby showing improved test performance. Third, according to Arkes (1991), there are three types of judgment errors: strategy-based, which happens a person is making suboptimal cognitive strategies; association-based, which occurs in large associated items or systems existing; psychophysically-based, which result from incorrect attention from physical stimuli. Montibeller and Von Winterfeldt (2015) pointed out that overconfidence was a severe problem and belonged to AB errors. Learners can overcome these errors or biases through metacognitive monitoring feedback to improve their judgments and decisions. They were identifying the errors that could significantly influence students' answering time and review time in decision. As such, students with a high ability to calibrate showed how the use of debiasing techniques could reduce bias effects.

Metacognitive accuracy was an essential component of self-regulated learning (Huff & Nietfeld, 2009). Further, metacognitive monitoring feedback could improve both confidence judgment accuracy and students' learning performance since the students improved their self-efficacy with calibration, had rapid answering time related to identifying the biases, and improved learning performance with metacognitive monitoring feedback. The students used heuristic and self-efficacy to regulate their confidence level to improve their performance. Therefore, in this study, metacognitive monitoring feedback was a response-oriented approach and heuristic for students to calibrate confidence level and improve performance. Since the feedback tool directed students to the discrepancies between performance and confidence, it improved their judgment and decision towards judge and view feedback efficiency. In our experiment, augmented reality modules were used as learning contents and metacognitive monitoring feedback was developed to prompt students' reflection and improve their performance in a location-based AR environment. Metacognitive monitoring feedback can be applied to identify the gaps in human knowledge and skills and determine the pathway to acquiring new knowledge and skills successfully in the AR system. This study advanced our understanding of the interactions between students and the learning contents in an AR environment.

The Phase 1 experiment proved that retrospective confidence judgment probes were not suitable for all the knowledge or situations because they also had a negative influence on the students' performance. Therefore, selecting appropriate learning content to apply the retrospective confidence judgment probes was vital to successful learning in AR environments. As such, students were aware of spatial visualization and could learn methods and skills efficiently in an AR setting. Moreover, biomechanics knowledge showed the complexity of learning because of the internal and external forces and moments acting on the body segments. Accordingly, augmented reality might help students recognize spatial visualization and be beneficial for spatial awareness. The new framework provided appropriate metacognitive monitoring feedback in an augmented reality environment. Consequently, students might have a better learning curve and efficiency when using an augmented reality learning system with metacognitive monitoring feedback.

Three groups participated in the Phase 2 study. Group 1 had metacognitive monitoring feedback. Group 2 had retrospective confidence judgments without metacognitive monitoring feedback. Group 3 was the control group without metacognitive monitoring feedback and retrospective confidence judgments. Students tended to be overconfident at the initial stage during the learning process. They started to adjust the confidence level with slow performance improvement if they acknowledged the gap between their confidence level and actual performance. Moreover, the small gap would achieve performance improvement in learning.

Both over- and under-confidence indicated the calibration had a bias in terms of small or large deviation between confidence level and performance. The best performer group showed the smallest deviation between confidence and performance, while the poorest performer group showed the largest deviation. Accordingly, it is commonly observed that poor performers lacked the skills to respond to the correct answers or detect their judgment accuracy.

Therefore, in order to make sure students' calibration was perfect, students needed to monitor their judgment fluctuation during the learning tasks. Furthermore, understanding students' fluctuations could ensure that their calibration is consistent and improve their efficacy. The metacognitive monitoring feedback approach helped students calibrate their retrospective confidence judgments (RCJs) by understanding learning materials. Hence, the second hypothesis was presented in phase 2.

Hypothesis 2-2: Metacognitive monitoring feedback helps learners have better calibration and more accurate responses in augmented reality environments.

Hoffman and Spatariu (2008) found that monitoring prompting influences problem-solving time. The awareness of alternative strategies with monitoring might give learners additional scrutiny of the tasks or problems, resulting in longer problem-solving time and greater accuracy. The time devoted to the problems led to effective outcomes. Students allocated their study time according to the fluency of information in their minds. Monitoring the cognition helped to increase fluency. The authors also mentioned that learners with high self-efficacy discounted the effectiveness of the feedback. Learners relied on automatic strategies to solve the problems or tasks, not based on the feedback on learners' cognition.

Stolp and Zabrucky (2017) revealed that high self-monitoring students had effective strategies to adjust their time studying and confidence after receiving the first feedback. Moreover, they allocated more time and energy on subsequent tasks to achieve their task goals. The researchers suggested that self-monitoring students were more likely to set their goals dynamically with a smoothing confidence level over the study time. However, not every student had the ability to self-monitor and control themselves. Metacognitive monitoring feedback might encourage students to spend time on the problems that they are overconfident about. Rum and Ismail (2017) found that a metacognitive support system could help learners adapt to a particular learning situation, making them self-directed and independent and developing logical thinking and judgment. Montibeller and Von Winterfeldt (2015) pointed out that overconfidence is an association-based error that students could overcome these errors or biases through feedback to improve their judgments and decisions. They were identifying the errors that could significantly influence students' answering time in decision. Therefore, the third hypothesis was displayed in phase 2.

Hypothesis 2-3: Metacognitive monitoring feedback influences student problem-solving time in augmented reality environments.

Students' learning performance was related to metacognitive monitoring accuracy. Nietfeld et al. (2005) found that metacognitive monitoring could reflect their learning awareness and develop knowledge. According to Townsend and Heit (2011), metacognitive monitoring influenced students' allocation of study time, which finally impacted their performance. Consequently, if students could correctly monitor their learning results, they could precisely judge whether they had an accurate solution to a particular problem and recognized their understanding level of materials. In this research, retrospective confidence judgments (RCJ) probes were used as a metacognitive monitoring component to assess the likelihood that students' responses on a test were correct. The likelihood was displayed in the form of a percentage scale. Metacognitive monitoring feedback was applied to help students evaluate themselves correctly and guide them to regulate cognitive strategies. Moreover, effective goal settings involved students being aware of their current knowledge and identifying the gaps in their knowledge and determining the pathway to successfully acquiring new knowledge and skills (Dinsmore & Parkinson, 2013; Nietfeld et al., 2005). Further, increasing time was necessary to assimilate the feedback and respond to the problems. Hence, metacognitive monitoring feedback influences students' reviewing feedback time, and the fourth hypothesis was formulated in Phase 2.

Hypothesis 2-4: Metacognitive monitoring feedback influences students reviewing feedback time in augmented reality environments.

Metacognition could help learners to monitor and control their cognitive processes to impact their behaviors. Metacognitive monitoring feedback was applied to calibrate the monitoring judgments, like rewards for efficacy, to increase students' self-efficacy perception. Galy, Cariou, and Mélan (2012) revealed the mental workload was related to people applying learning strategies, a conscious search for patterns in the learning material. In addition, metacognitive prompting might not increase learners' workload or not distract learners (Fiorella & Vogel-Walcutt, 2011). Further strategies needed to be developed to avoid the high cognitive workload. NASA-TLX index was sensitive to alternations in mental workload. Students' mental workload with metacognitive monitoring feedback could be tested using the NASA-TLX. Thus, the fifth hypothesis was introduced in Phase 2.

Hypothesis 2-5: Metacognitive monitoring feedback does not influence the students' mental workload in augmented reality environments.

5.2 Methods

5.2.1 Apparatus

In Phase 2, a real-time location system was added to the Hololens to show students' engineering learning materials in an AR environment. Q-Track NFER system (Figure 19) was to record participants' real-time location data during the learning process, which was similar to GPS but more accurate and capable of working indoors. The system consisted of four components: (1) Two locators relatively opposite, (2) NFER sensors (tags carried by participants), (3) a laptop with the tracking software, (4) a router (to provide a data link), all of which could cover the whole learning area. Each Tag had its frequency, which could be used to identify different subjects. The data exported from the NFER database were combined to HoloLens to locate participants so that HoloLens could exhibit AR modules based on participants' locations. Figure 20 shows that a participant wore a HoloLens and an NFER tag in the experiment.

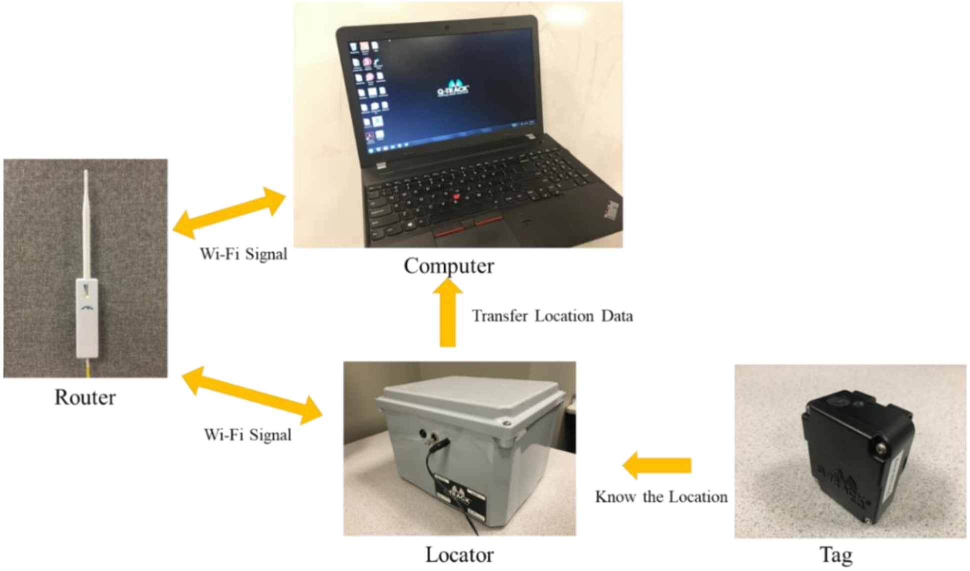


Figure 19: Q-Track NFER system for locating a position

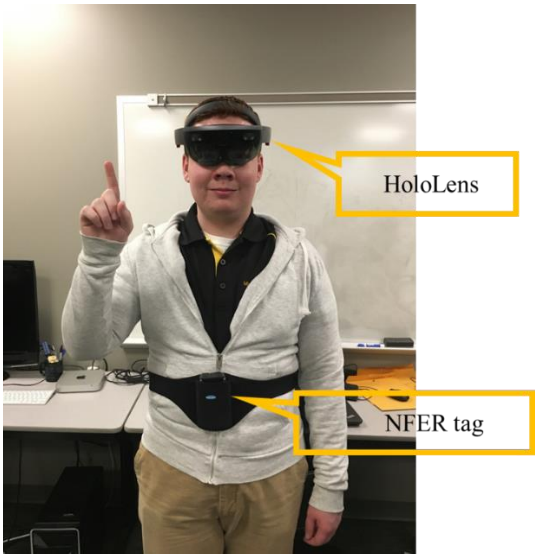


Figure 20: Experiment Devices Wearing

5.2.2 Participants

Subjects were fifty-six university students with an average age of 21.73 years (StDev = 3.94). The participants were all from engineering college at the University of Missouri, consisting of Thirty-seven male students and nineteen female students. The research was conducted in three conditions, as shown in Table 6. Group 1 students learned biomechanical content in an AR environment with MCMF and RCJ tools; Group 2 was in the AR environment only with RCJ; Group 3 learned biomechanics in the AR environment without other tools. Group 1, 2, and 3 respectively had 26, 16, and 14 participants. Before the experiment, the students filled out the demographic questions containing the AR experience level. The average AR level of students for three groups were listed based on a scale of 1 (novice) to 5 (expert). Group 1: M = 1.442, SD = 0.638; Group 2: M = 1.375, SD = 0.806; Group 3: M = 1.500, SD = 1.092 (p-value = 0.916). No significant difference in the AR level was found among subject groups.

Table 6: Group Description

Group	Metacognitive Monitoring Feedback (MCMF)	Retrospective Confidence Judgments (RCJs)
Group 1 (n=26)	Yes	Yes
Group 2 (n=16)	No	Yes
Group 3 (n=14)	No	No

5.2.3 Learning Content

Figure 21 shows an example of the biomechanics module. The left skeleton showed the center point of mass for each body segment. And the red callout presented a free body diagram showing all the forces and moments acting on the body segments. The yellow callout exhibited learning procedures to complete each module step by step. The green callout showed the main hologram for biomechanics animation. The right side blue callout presented the biomechanics contents, including the definition of biomechanics and formula.

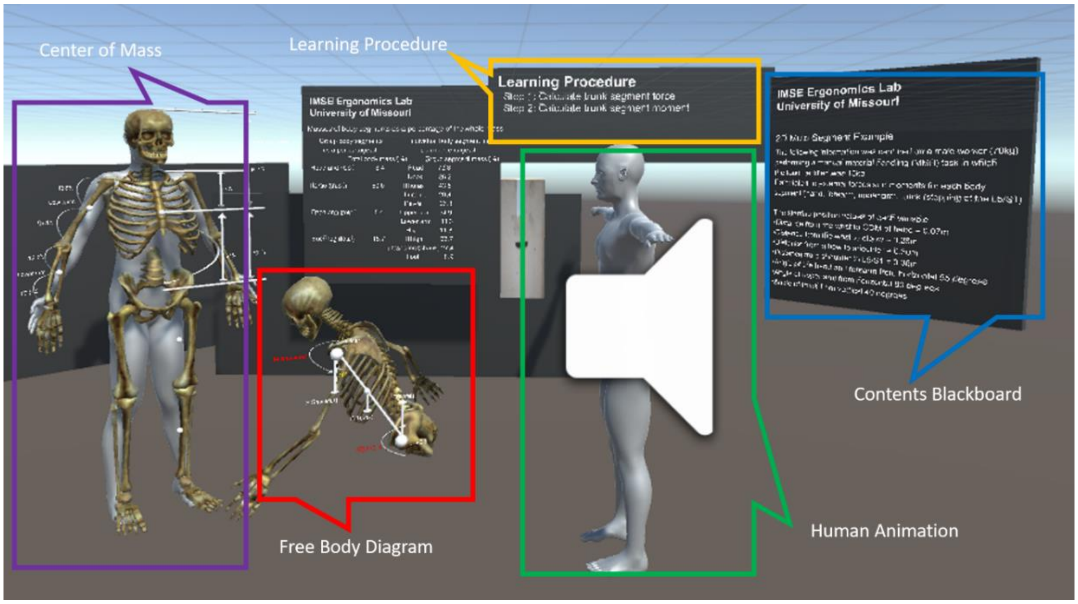
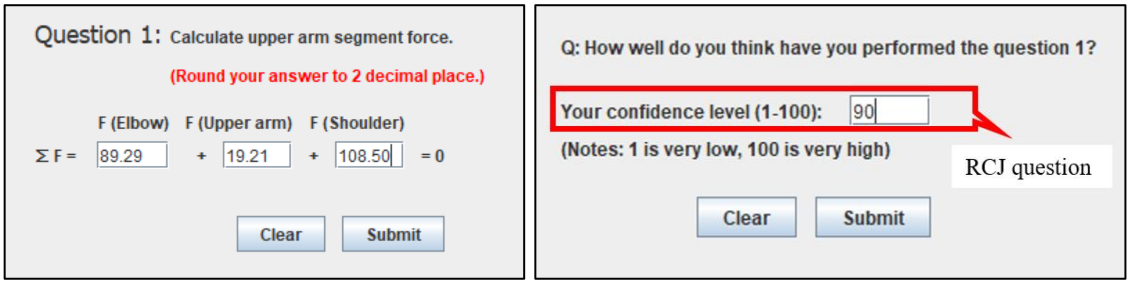


Figure 21: Screenshot of the biomechanics module

5.2.4 Metacognitive Monitoring Feedback

The retrospective confidence judgments (RCJs) were self-evaluating to measure the students' confidence level before knowing the actual task performance. Figure 22 shows that the learning module has been utilized to collect RCJ scores and students' performance data in an AR environment. RCJ might influence the student's confidence judgments so that they adjusted their learning pace and progress. Below is an example of the RCJ probes is "How well do you think have you performed the question 1? (1% - low confidence level, 100% - high confidence level)".



Question 1: Calculate upper arm segment force.

(Round your answer to 2 decimal place.)

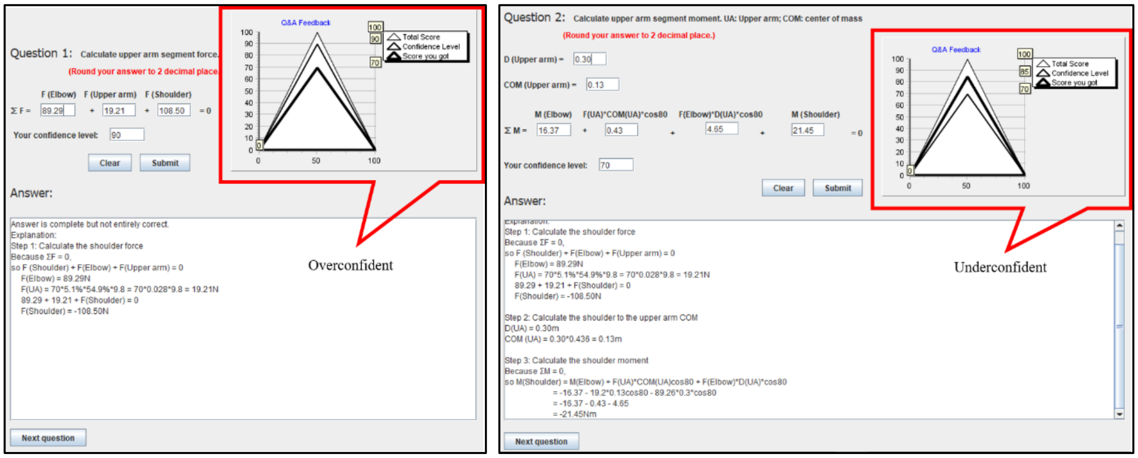
Σ F = F (Elbow) 89.29 + F (Upper arm) 19.21 + F (Shoulder) 108.50 = 0

Q: How well do you think have you performed the question 1?

Your confidence level (1-100): 90

(Notes: 1 is very low, 100 is very high)

Figure 22: Test question and RCJ question about participants' confidence level (Group 1&2)



Question 1: Calculate upper arm segment force.

(Round your answer to 2 decimal place.)

F (Elbow) F (Upper arm) F (Shoulder)

Σ F = 89.29 + 19.21 + 108.50 = 0

Your confidence level: 90

Answer:

```
Answer is complete but not entirely correct.
Explanation:
Step 1: Calculate the shoulder force
Because ΣF = 0,
so F (Shoulder) + F(Elbow) + F(Upper arm) = 0
   F(Elbow) = 89.29N
   F(UA) = 70*5.1%*54.9%*9.8 = 70*0.028*9.8 = 19.21N
   89.29 + 19.21 + F(Shoulder) = 0
   F(Shoulder) = -108.50N
```

Overconfident

Question 2: Calculate upper arm segment moment. UA: Upper arm; COM: center of mass

(Round your answer to 2 decimal place.)

D (Upper arm) = 0.30

COM (Upper arm) = 0.13

M (Elbow) F(UA)*COM(UA)*cos80 F(Elbow)*D(UA)*cos80 M (Shoulder)

Σ M = 16.37 + 0.43 + 4.65 + 21.45 = 0

Your confidence level: 70

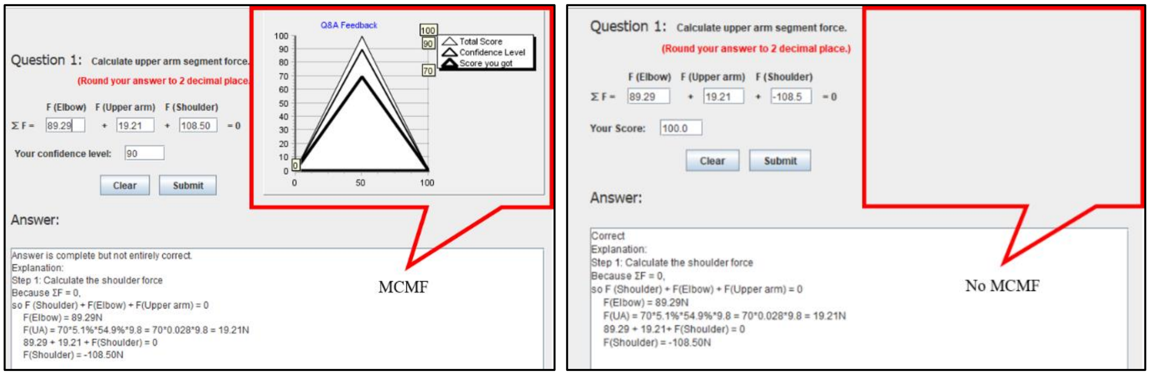
Answer:

```
Explanation:
Step 1: Calculate the shoulder force
Because ΣF = 0,
so F (Shoulder) + F(Elbow) + F(Upper arm) = 0
   F(Elbow) = 89.29N
   F(UA) = 70*5.1%*54.9%*9.8 = 70*0.028*9.8 = 19.21N
   89.29 + 19.21 + F(Shoulder) = 0
   F(Shoulder) = -108.50N

Step 2: Calculate the shoulder to the upper arm COM
D(UA) = 0.30m
COM (UA) = 0.30*0.436 = 0.13m

Step 3: Calculate the shoulder moment
Because ΣM = 0,
so M(Shoulder) = M(Elbow) + F(UA)*COM(UA)cos80 + F(Elbow)*D(UA)*cos80
                 = -16.37 - 19.2*0.13cos80 - 89.26*0.3*cos80
                 = -16.37 - 0.43 - 4.65
                 = -21.45Nm
```

Underconfident

Figure 23: Overconfident and underconfident feedback

Figure 23 presents the metacognitive monitoring feedback triangle graphs with the overconfidence and underconfidence results. The metacognitive monitoring feedback triangle graph displayed three values: (a) the total score of the question; (b) the actual score the student got; (c) the student confidence level. The participants could check their actual test scores and confidence level in the right top figure as well as compare their test scores and confidence levels to determine over- or under-confidence. Figure 24 shows Question 1 with metacognitive monitoring feedback (Group 1) and without metacognitive monitoring feedback (Group 2 and 3). Figure 25 displays the easy question vs. the hard question (Force vs. Moment).



Question 1: Calculate upper arm segment force.

(Round your answer to 2 decimal place.)

F (Elbow) F (Upper arm) F (Shoulder)

Σ F = 89.29 + 19.21 + 108.50 = 0

Your confidence level: 90

Answer:

```
Answer is complete but not entirely correct.
Explanation:
Step 1: Calculate the shoulder force
Because ΣF = 0,
so F (Shoulder) + F(Elbow) + F(Upper arm) = 0
   F(Elbow) = 89.29N
   F(UA) = 70*5.1%*54.9%*9.8 = 70*0.028*9.8 = 19.21N
   89.29 + 19.21 + F(Shoulder) = 0
   F(Shoulder) = -108.50N
```

MCMF

Question 1: Calculate upper arm segment force.

(Round your answer to 2 decimal place.)

F (Elbow) F (Upper arm) F (Shoulder)

Σ F = 89.29 + 19.21 + -108.5 = 0

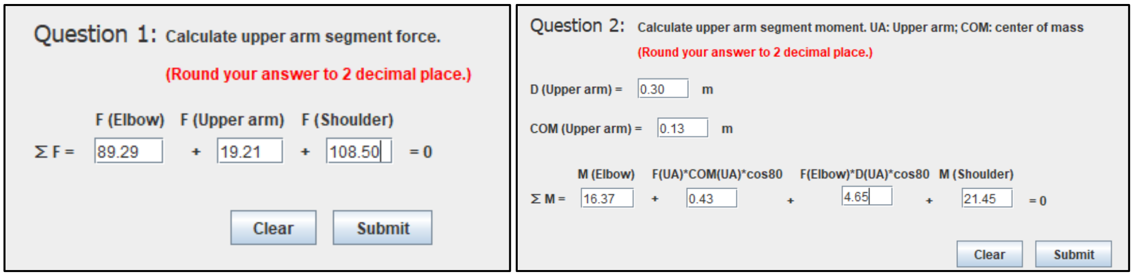
Your Score: 100.0

Answer:

```
Correct
Explanation:
Step 1: Calculate the shoulder force
Because ΣF = 0,
so F (Shoulder) + F(Elbow) + F(Upper arm) = 0
   F(Elbow) = 89.29N
   F(UA) = 70*5.1%*54.9%*9.8 = 70*0.028*9.8 = 19.21N
   89.29 + 19.21+ F(Shoulder) = 0
   F(Shoulder) = -108.50N
```

No MCMF

Figure 24: Results with/without metacognitive monitoring feedback (Group 1 vs. Group 2&3)



Question 1: Calculate upper arm segment force.

(Round your answer to 2 decimal place.)

F (Elbow) F (Upper arm) F (Shoulder)

Σ F = 89.29 + 19.21 + 108.50 = 0

Question 2: Calculate upper arm segment moment. UA: Upper arm; COM: center of mass

(Round your answer to 2 decimal place.)

D (Upper arm) = 0.30 m

COM (Upper arm) = 0.13 m

M (Elbow) F(UA)*COM(UA)*cos80 F(Elbow)*D(UA)*cos80 M (Shoulder)

Σ M = 16.37 + 0.43 + 4.65 + 21.45 = 0

Figure 25: Easy Question vs. Hard Question

5.2.5 Experiment Design

There were three groups in this study. For the participants who assigned in Group 1, they were asked RCJ probes and biomechanics test questions, and they viewed the feedback screen with the correct answers of the biomechanics questions with the MCMF. Group 2 also received RCJs and biomechanics test questions, but the feedback screen only included the biomechanics questions and correct answers (No MCMF). As a control group, the participants who were in Group 3 had the biomechanics test questions (No RCJ probes) and correct answers (No MCMF). Figure 26 shows the experiment flowchart. Group 1 students experienced the biomechanics module in AR environments with metacognitive monitoring feedback and retrospective confidence judgments. Group 2 students learned in the AR environment without metacognitive monitoring feedback. Group 3 students engaged in biomechanics learning without metacognitive monitoring feedback and retrospective confidence judgments. The difference between groups 1 and 2 was the metacognitive monitoring feedback in the feedback screen. The difference between groups 2 and 3 was the retrospective confidence judgment questions after answering questions.

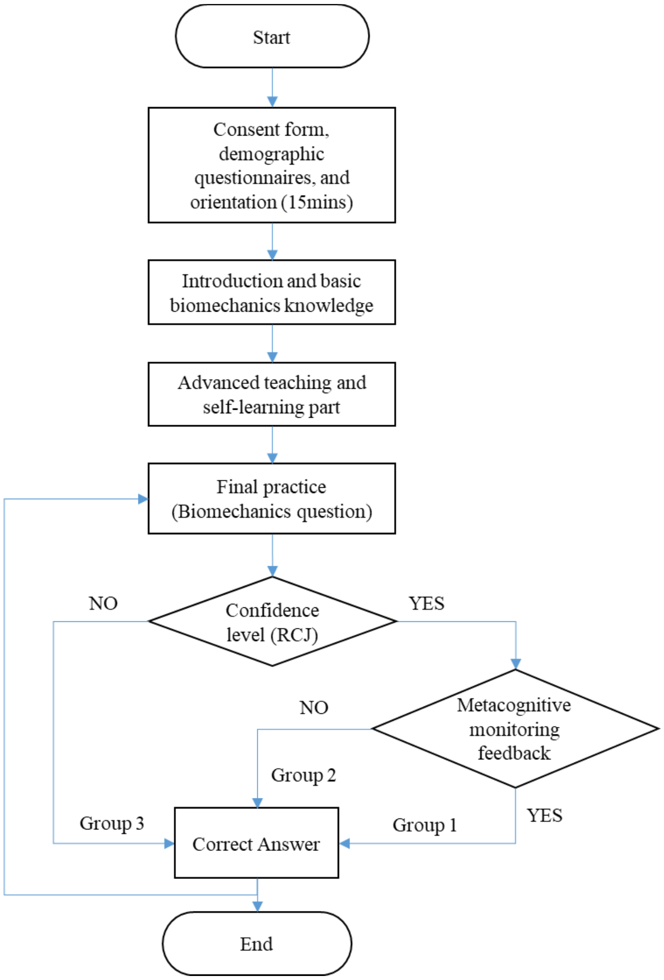


Figure 26: The procedure of Phase 2 experiment

First, every student filled the consent form and demographic questionnaires, including their computer experience level and AR experiences before. A general orientation briefing would be provided at the beginning of the experiment, which covered the information, including introducing the simulation, user interface, the function of the equipment, and participants' role in the tasks. It was expected to last 15 minutes. During the training session, participants would experience training through PowerPoint slides, which contained how to use the AR device to get the best view of the example module seen through the HoloLens. Further, the training session included the contents for blackboard (biomechanics concepts and formula), learning procedure (calculating steps), human animation, free body diagram (showing all the forces and moments acting on the body segments), and the center of mass (telling the mass percentage of the body segments in the whole body). The side view of the experiment is shown in Figure 27. Participants followed the numbers from 1-14 (see Figure 28) to finish the whole experiment. They could just walk to that number and stand there and the HoloLens device showed a specific module to them.

Figure 27: Side view of experiment

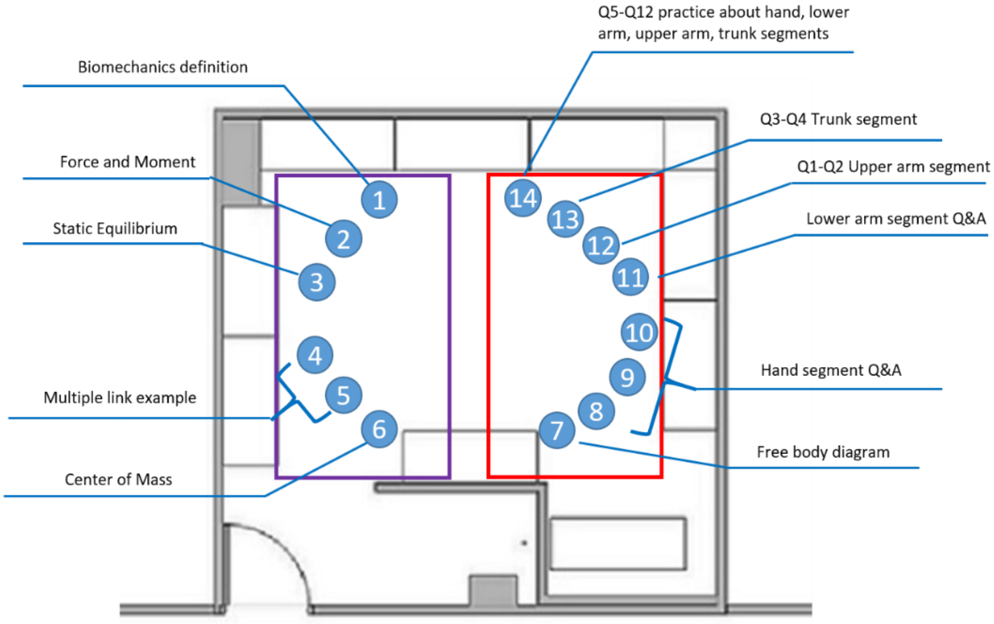


Figure 28: The lab floorplan with spot markers

The experiment set contained three parts: (1) introduction and basic biomechanics knowledge (biomechanics definition, force and moment, static equilibrium, multiple link example, the center of mass); (2) advanced teaching and self-learning part; (3) final practice and exercises including metacognitive questions. Participants could move on to the next number when they understood and comprehended biomechanics knowledge. In order to make the study more user-friendly, participants could freely move back to the previous number to see the modules or take essential notes, if any. The experiment test involved every participant taking 70 minutes to learn materials and the final practice about biomechanics on the computer. Subsequently, participants filled in a NASA-TLX form, including a comparison of a more significant contributor to the workload for this task. So the total experimental time was about 1.5 hours.

5.3 Results

Table 7 showed that there was a significant difference between the average test score of groups with metacognitive monitoring feedback (Group 1) and without metacognitive monitoring feedback (Group 2) [F (1,41) = 40.04, $p < 0.001$]. The results showed a significant difference between the average answering question time of groups with metacognitive monitoring feedback (Group 1) and without metacognitive monitoring feedback (Group 2) [F (1,41) = 7.59, $p = 0.006$]. For the average reviewing feedback time, results revealed a significant difference between groups with (Group 1) and without metacognitive monitoring feedback (Group 2) [F (1,41) = 16.05, $p < 0.001$]. It also suggested that a significant difference between the average reviewing question time of groups with (Group 2) and without retrospective confidence judgments (Group 3) [F (1,29) = 12.50, $p < 0.001$].

Table 7: Descriptive statistics for the test score, answering question time, reviewing feedback time ($p<0.05$)

Activity	Factor	Level	Group	N	Mean	StDev	F-Value	P-Value
Test score	Metacognitive monitoring feedback	Yes	Group1	26	81.55/100	25.88	40.04	**<0.001**
		No	Group2	16	64.60/100	33.91		
	Retrospective confidence judgments	Yes	Group2	16	64.60/100	33.91	1.67	0.197
		No	Group3	14	69.23/100	33.80		
Answering question time	Metacognitive monitoring feedback	Yes	Group1	26	196.94 sec	121.67	7.59	**0.006**
		No	Group2	16	230.80 sec	151.60		
	Retrospective confidence judgments	Yes	Group2	16	230.80 sec	151.60	0.73	0.394
		No	Group3	14	245.20 sec	168.70		
Reviewing answer time	Metacognitive monitoring feedback	Yes	Group1	26	49.38 sec	40.87	16.05	**<0.001**
		No	Group2	16	71.79 sec	83.99		
	Retrospective confidence judgments	Yes	Group2	16	71.79 sec	83.99	12.50	**<0.001**
		No	Group3	14	45.52 sec	50.34		
			Group1	26	49.38 sec	40.87	0.82	0.365
			Group3	14	45.52 sec	50.34		

5.3.1 Learning Performance

In order to investigate if there was a relationship between the calibration (X) and test score performance (Y), linear regression was applied to compare groups 1 and 2. Figure 29 shows the Group 1 coefficient of determination $R^2 = 22.6\%$, and Group 2 coefficient of determination $R^2 = 2.5\%$. The calibration (X) and test score performance (Y) had a weak correlation for Group 1 but no correlation for Group 2.

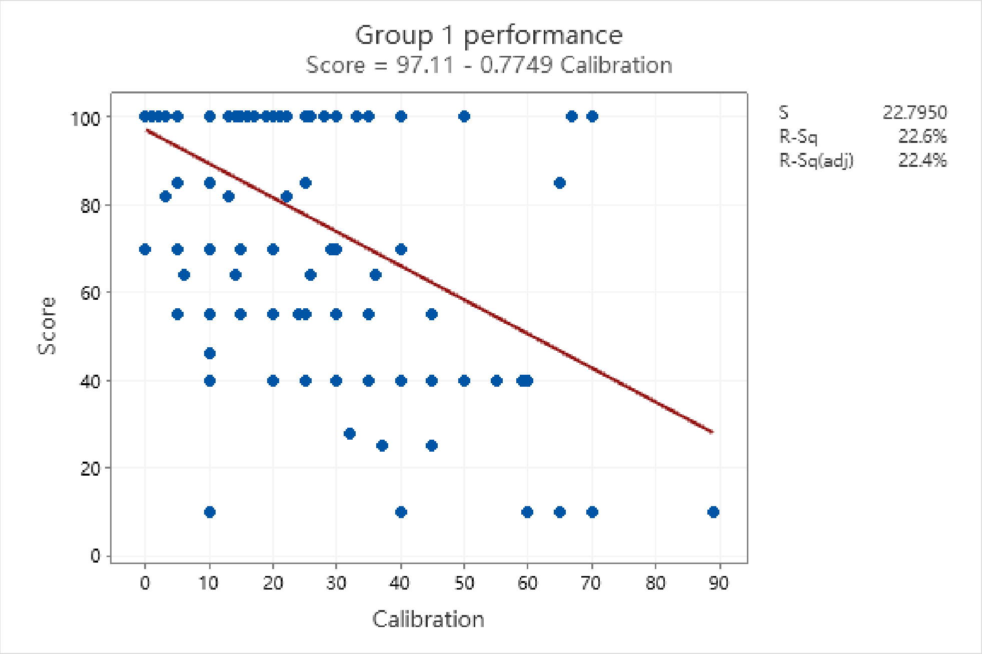


Figure 29.a: Linear regression of performance (Group 1)

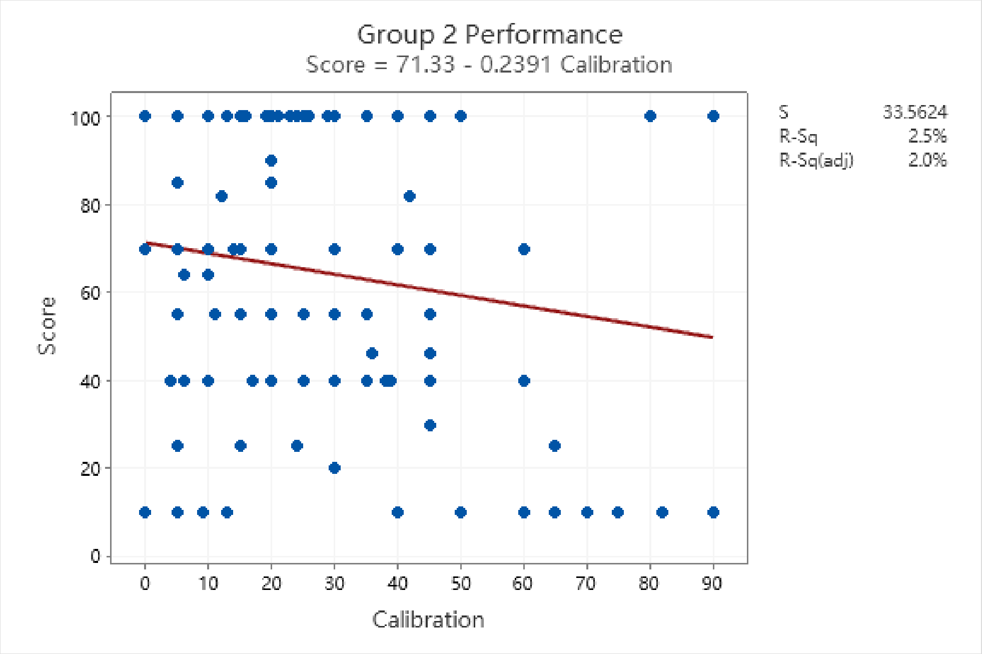


Figure 30.b: Linear regression of performance (Group 2)

5.3.2 Reviewing Time Comparison

In order to investigate if there was a relationship between the calibration (X) and reviewing time (Y), linear regression was applied to compare groups 1 and 2. Figure 30 shows the Group 1 coefficient of determination $R^2 = 18.9\%$, and Group 2 coefficient of determination $R^2 = 5.0\%$. The calibration (X) and reviewing time (Y) had a weak correlation for Group 1 and no correlation for Group 2.

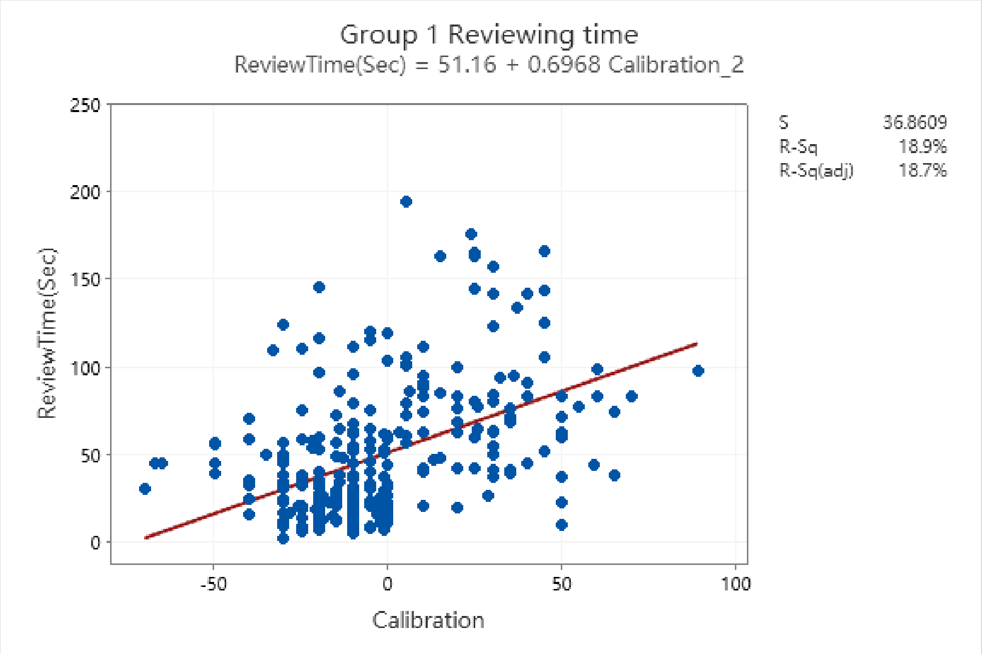


Figure 31.a: Linear regression of reviewing time (Group 1)

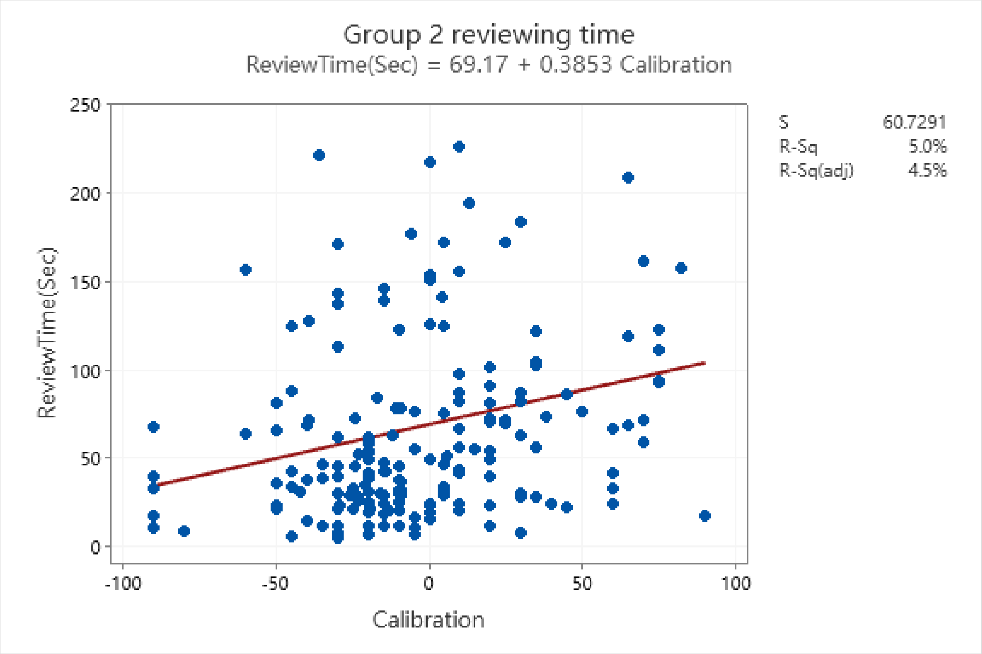


Figure 32.b: Linear regression of reviewing time (Group 2)

Descriptive statistics for reviewing feedback time are shown in Table 8. The results showed a significant difference between groups 1 and 2 for the underconfident state [F (1,304) = 18.17, p < 0.001] and no significant difference for the overconfident state.

Table 8: Descriptive statistics for reviewing feedback time (Group 1 vs. Group 2) (p<0.05)

Activity	Calibration	Group	N	Mean (sec)	StDev	F-Value	P-Value
Reviewing feedback time	Underconfident	Group 1	197	35	26.2	18.17	**<0.001**
		Group 2	108	56	59.1		
	Overconfident	Group 1	92	84	47.6	0.01	0.929
		Group 2	71	85	61.9		

Figure 31 shows the reviewing feedback time for groups 1 and 2 in the underconfident condition. Group 1 had metacognitive monitoring feedback in the figure, and Group 2 had no metacognitive monitoring feedback.

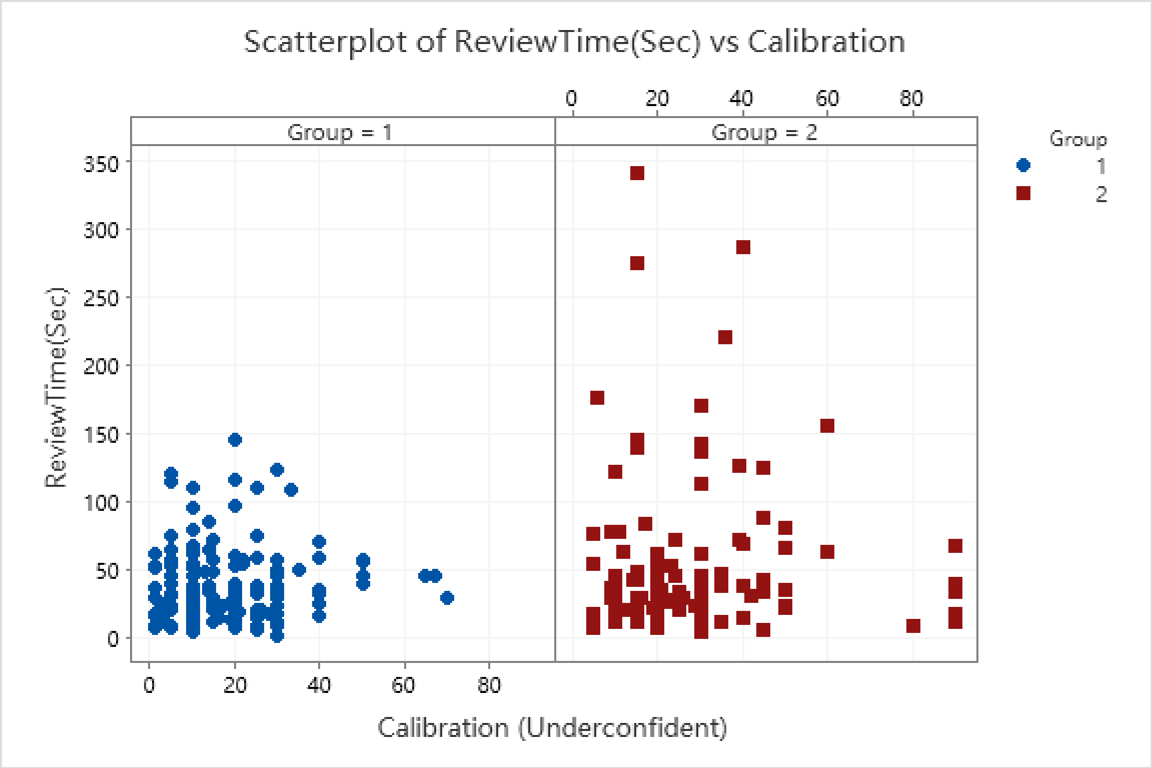


Figure 33: Scatterplot of Reviewing time (Underconfident)

Figure 32 shows the reviewing feedback time for groups 1 and 2 in the overconfident condition.

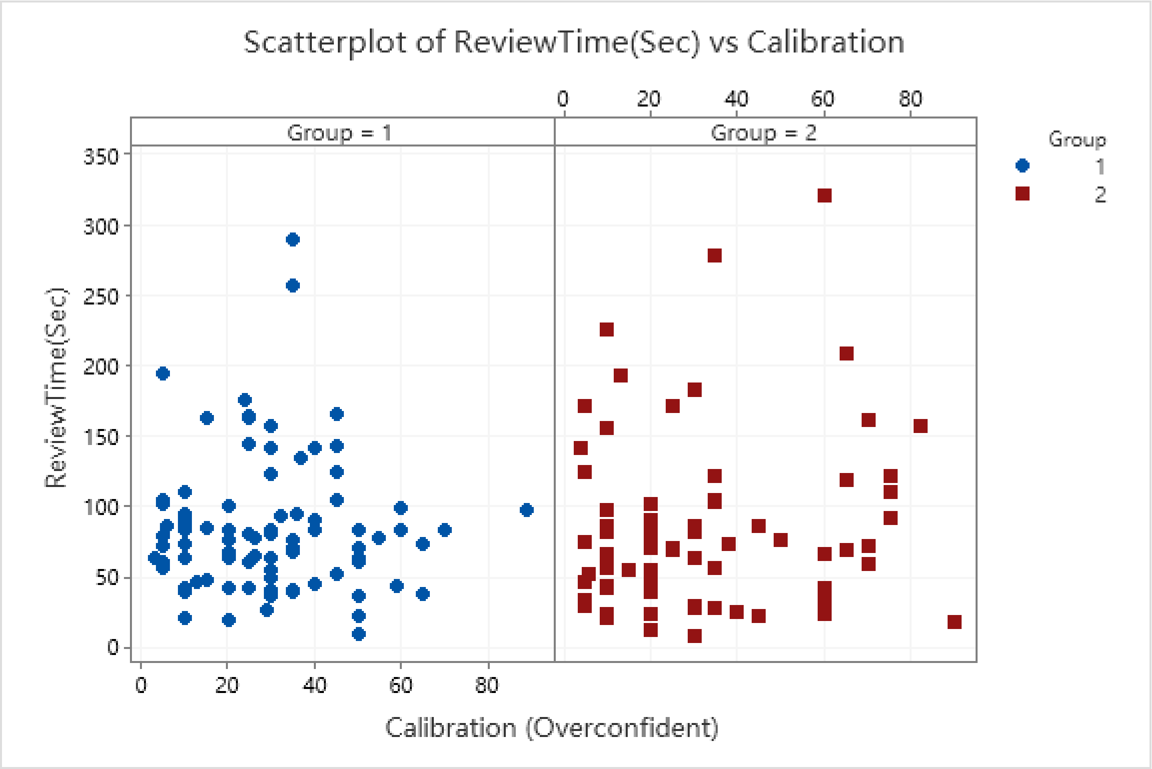


Figure 34: Scatterplot of Reviewing time (Overconfident)

Table 9 compares reviewing feedback time within subjects in Group 1 and Group 2. Reviewing feedback times showed a significant difference between underconfident and overconfident situations within subjects.

Table 9: Descriptive statistics for reviewing feedback time (within-subjects) ($p<0.05$)

Activity	Group	Calibration	N	Mean (sec)	StDev	F-Value	P-Value
Reviewing feedback time	Group 1	Underconfident	197	35	26.2	128.97	**<0.001**
		Overconfident	92	84	47.6		
	Group 2	Underconfident	108	56	59.1	10.15	**0.002**
		Overconfident	71	85	61.9		

5.3.3 Answering Time Comparison

In order to investigate if there was a relationship between the calibration (X) and answering time (Y), linear regression was applied to compare groups 1 and 2. Figure 33 shows the Group 1 coefficient of determination $R^2 = 7.0\%$, and Group 2 coefficient of determination $R^2 = 9.1\%$. The calibration (X) and answering time (Y) had a weak correlation for groups 1 and 2.

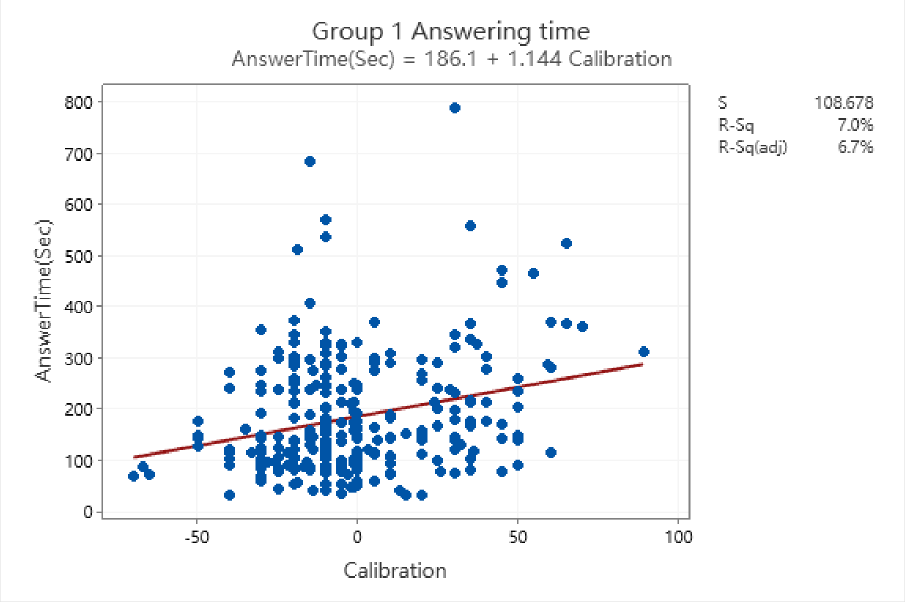


Figure 35.a: Linear regression of answering time (Group 1)

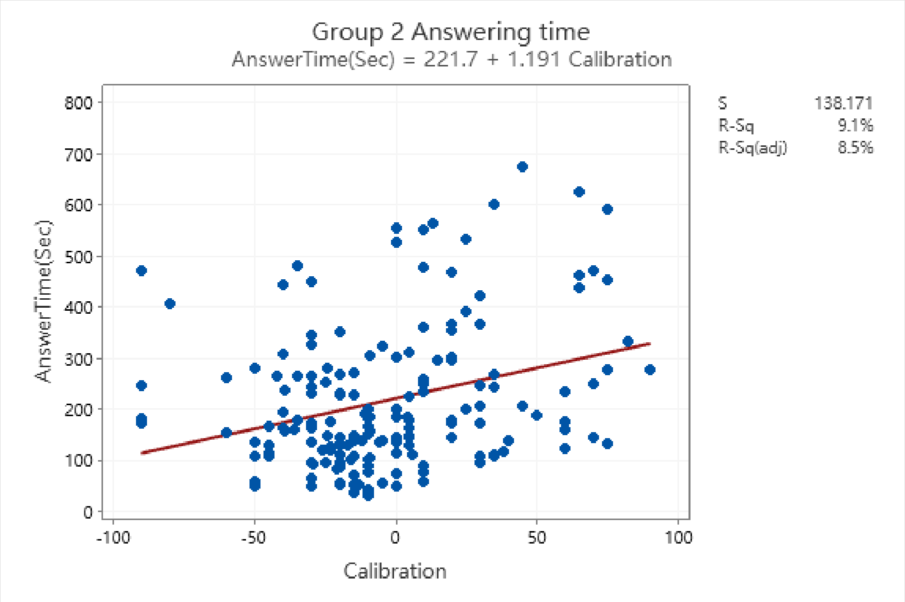


Figure 36.b: Linear regression of answering time (Group 2)

Descriptive statistics for answering question time are shown in Table 10. The results show no significant difference between groups 1 and 2 for the underconfident but significant difference for the overconfident condition [F (1,131) = 8.55, p = 0.004].

Table 10: Descriptive statistics for answering question time (Group 1 vs. Group 2) (p<0.05)

Activity	Calibration	Group	N	Mean (sec)	StDev	F-Value	P-Value
Answering question time	Underconfident	Group 1	177	173.1	104.6	0.00	0.981
		Group 2	99	173.4	100.4		
	Overconfident	Group 1	89	214.2	129.0	8.55	**0.004**
		Group 2	66	284.3	169.7		

Figure 34 shows the answering question time for Group 1 and Group 2 in the underconfident condition. Group 1 had metacognitive monitoring feedback in the figure, and Group 2 had no metacognitive monitoring feedback.

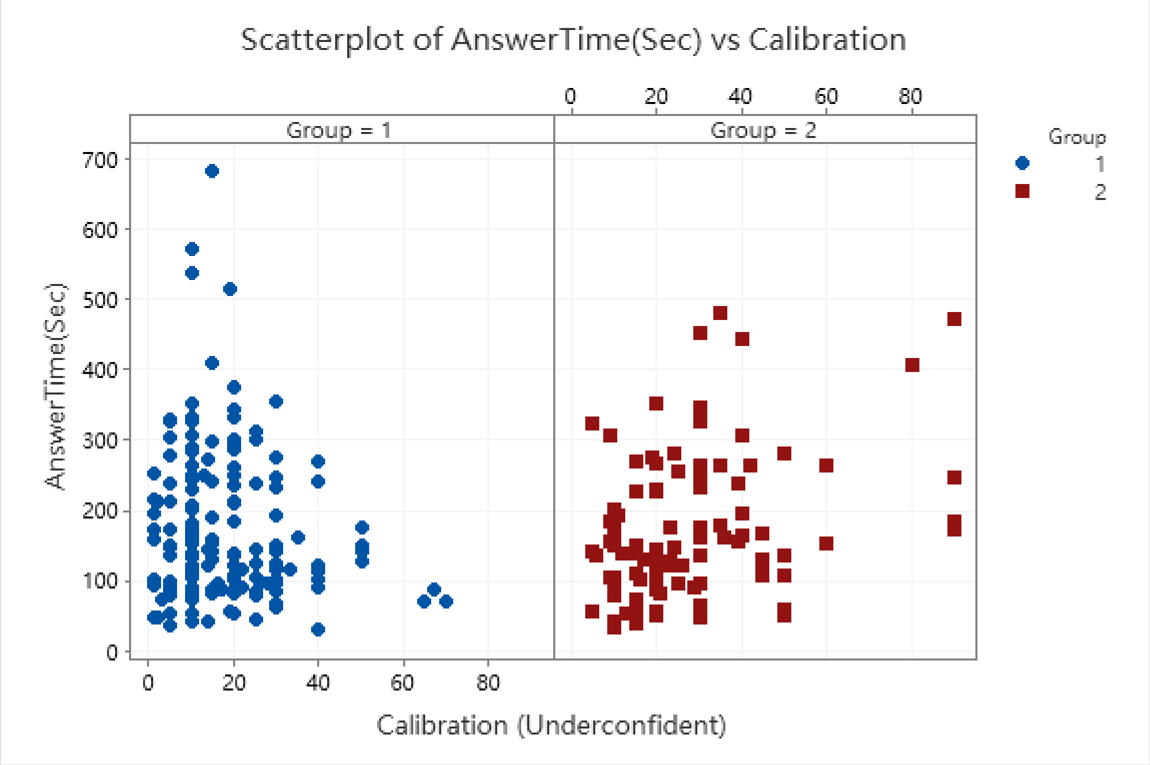


Figure 37: Scatterplot of answering time (Underconfident)

Figure 35 shows the answering question time for Group 1 and Group 2 in the overconfident condition.

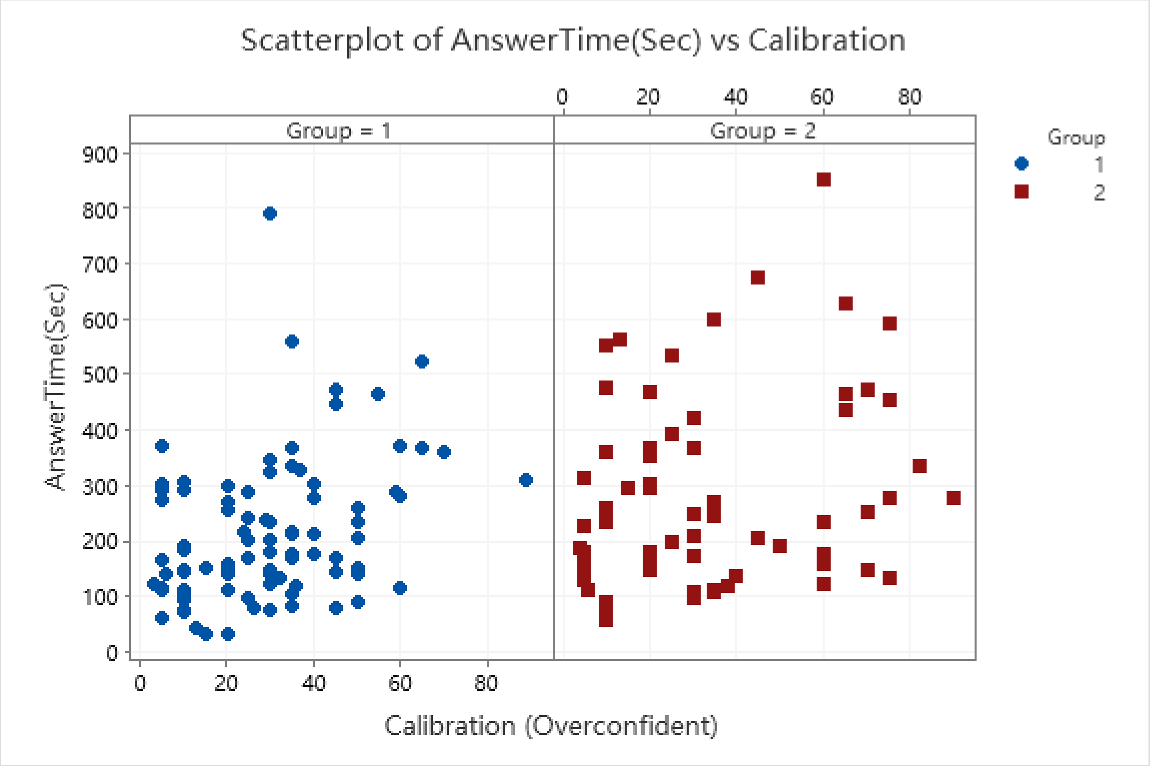


Figure 38: Scatterplot of answering time (Overconfident)

Table 11 compares the test scores between groups 1 and 2 in underconfident or overconfident conditions. There is a significant difference in test scores between groups 1 and 2 for the underconfident condition [F (1,275) = 16.20, p < 0.001] and overconfident condition [F (1,154) = 7.94, p = 0.005].

Table 11: Descriptive statistics for test score (Group 1 vs. Group 2) (p<0.05)

Activity	Calibration	Group	N	Mean	StDev	F-Value	P-Value
Test score	Underconfident	Group 1	177	84.15/100	24.11	16.20	**<0.001**
		Group 2	99	70.17/100	33.13		
	Overconfident	Group 1	89	78.36/100	26.40	7.94	**0.005**
		Group 2	66	65.47/100	30.39		

Table 12 compares answering question time within subjects in Group 1 and Group 2. Answering question times had a significant difference between underconfident and overconfident situations within subjects.

Table 12: Descriptive statistics for answering question time (within-subjects) (p<0.05)

Activity	Group	Calibration	N	Mean (sec)	StDev	F-Value	P-Value
Answering question time	Group 1	Underconfident	177	173.1	104.6	7.78	**0.006**
		Overconfident	89	214.2	129.0		
	Group 2	Underconfident	99	173.4	100.4	27.76	**<0.001**
		Overconfident	66	284.3	169.7		

5.3.4 Workload

Workload differences between the three groups were analyzed using ANOVA. No significant difference in workload was found among Group 1, Group 2, and Group3, as shown in Tables 13, 14, and 15. Figure 36 shows the interval plot of workload on six dimensions among the three groups.

Table 13: Descriptive statistics for workload comparison (Group 1 vs. Group 2) (*p<0.05)

Variable	**Group 1 (n = 26)**		**Group2 (n = 16)**		**F-Value**	**P-Value**
	Mean	**StDev**	**Mean**	**StDev**		
Mental	76.73	10.76	73.75	15.00	0.56	0.458
Physical	39.81	25.47	38.44	24.88	0.03	0.865
Temporal	45.58	18.94	40.13	25.87	0.62	0.436
Performance	67.88	18.72	64.06	25.44	0.31	0.579
Effort	70.19	16.09	73.13	19.48	0.28	0.600
Frustration	42.50	22.37	42.56	27.04	0.00	0.994
Overall	67.08	9.16	65.06	13.30	0.34	0.563

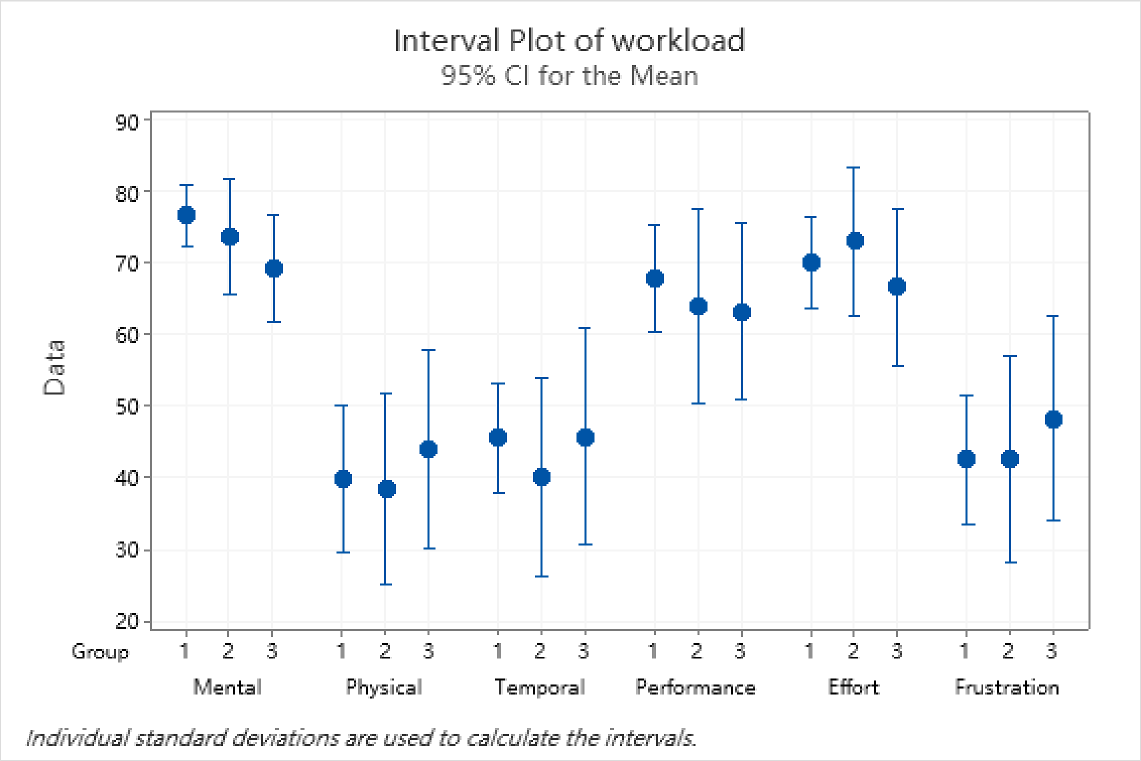
Table 14: Descriptive statistics for workload comparison (Group 2 vs. Group 3) (*p<0.05)

Variable	**Group 2 (n = 16)**		**Group3 (n = 14)**		**F-Value**	**P-Value**
	Mean	**StDev**	**Mean**	**StDev**		

Mental	73.75	15.00	69.29	12.99	0.75	0.394
Physical	38.44	24.88	44.00	24.21	0.38	0.541
Temporal	40.13	25.87	45.79	26.39	0.35	0.558
Performance	64.06	25.44	63.21	21.45	0.01	0.923
Effort	73.13	19.48	66.79	19.08	0.81	0.377
Frustration	42.56	27.04	48.29	24.94	0.36	0.554
Overall	65.06	13.30	61.16	10.15	0.80	0.380

Table 15: Descriptive statistics for workload comparison (Group 1 vs. Group 3) (*$p<0.05$)

Variable	Group1 (n = 26)		Group 3 (n = 14)		F-Value	P-Value
	Mean	StDev	Mean	StDev		
Mental	76.73	10.76	69.29	12.99	3.77	0.060
Physical	39.81	25.47	44.00	24.21	0.25	0.617
Temporal	45.58	18.94	45.79	26.39	0.00	0.977
Performance	67.88	18.72	63.21	21.45	0.51	0.479
Effort	70.19	16.09	66.79	19.08	0.36	0.553
Frustration	42.50	22.37	48.29	24.94	0.56	0.458
Overall	67.08	9.16	61.16	10.15	3.53	0.068



Interval Plot of workload

95% CI for the Mean

Individual standard deviations are used to calculate the intervals.

Figure 39: Interval plot of workload in six dimensions

5.4 Discussion and Conclusion

In this study, the effects of metacognitive monitoring feedback were investigated in a real-time location-based augmented reality learning environment. Group 1 experienced the learning modules with a metacognitive monitoring feedback tool. Groups 2 and 3 performed the learning modules without metacognitive monitoring feedback. According to Table 7, students' test scores in Group 1 were significantly higher than those in Group 2. As such, Hypothesis 2-1 could be accepted that metacognitive monitoring feedback influenced students' learning performance in an augmented reality environment. No significant difference was found between groups 2 and 3. Metacognitive monitoring feedback calibrated the students' confidence level and improved their performance. Another impact of metacognitive monitoring feedback was the answering question time or solving problem time. This feedback tool reduced the students' time to solve problems or tasks. However, retrospective confidence judgments did not influence problem-solving time. The third impact of metacognitive monitoring feedback was reviewing answers and feedback time, which decreased the students' time to review the responses and feedback. Retrospective confidence judgments were found in increasing the time of reviewing answers. Therefore, these findings supported the idea that the metacognitive monitoring feedback tool influenced the students' learning in an augmented reality learning environment. Detailed impacts of metacognitive monitoring feedback on performance, calibration, problem-solving time, and reviewing answers time is discussed in the following sections.

5.4.1 Performance and Calibration

According to the linear regression of performance in Figure 29, a weak correlation that generated calibration improved the students' performance. The results proved that metacognitive monitoring feedback used the calibration of confidence and performance to help students monitor and control their ongoing cognitive processes, ultimately leading to better performances. Therefore, the results confirmed Hypothesis 2-2, and metacognitive monitoring feedback helped learners better calibrate confidence levels and present more accurate responses in augmented reality environments. Students who received the metacognitive monitoring feedback could be more accurate in their metacognitive judgments than students who did not receive the feedback. Furthermore, students were able to regulate the gap between their actual performance and confidence level to improve their study (Figure 37). The metacognitive monitoring feedback was like an anchoring-and-adjustment heuristic (Tversky & Kahneman, 1974), which continuously monitored students' judgments. First, students evaluated themselves with an initial confidence level and adjusted their confidence levels from the first anchor. Following this, they compared their confidence levels with the actual scores. There was a dispensary between the confidence level and performance. Students repeatedly adjusted their confidence level near the initial anchor and calibrated their under- and over-confidence in the judgments. Second, metacognitive monitoring feedback influenced their performance by calibrating students' confidence judgments. Students were continuously calibrating confidence levels compared with actual test performance to help them direct to effective strategies improving test performance (Dunlosky & Metcalfe, 2008). Moreover, using metacognitive monitoring feedback, students could realize the quality of their learning and be encouraged by monitoring their achievement (Labuhn, Zimmerman, & Hasselhorn, 2010). Metacognitive monitoring feedback rewarded students' self-efficacy and increased their self-efficacy perceptions.

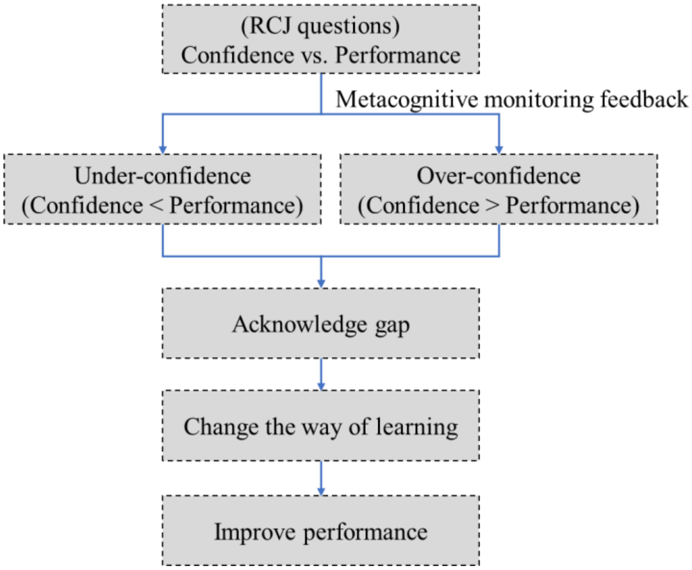


Figure 40: Calibration steps

In this study, metacognitive monitoring feedback was applied as a response-oriented technique to improve the calibration of student metacognitive judgments. This tool was used to increase learning performance by adjusting students' self-efficacy to recognize the difference between actual performance and confidence level. Self-efficacy can influence the strategies they selected while studying. Accordingly, they could not choose effective strategies to help them meet the goals if they could not master the ability to recognize their metacognitive judgments. The metacognitive monitoring feedback tool could also improve their judgment of decisions and viewing feedback efficiency. Students who experienced metacognitive monitoring feedback showed higher levels of self-efficacy in the augmented reality learning environment. They knew how to use effective strategies, such as changing their learning time to improve their performance and learning efficiency. In addition, metacognitive monitoring feedback could enhance students' awareness and sensitivity of self-judgment and self-evaluation during the learning test in the augmented reality learning environment. Therefore, the metacognitive monitoring feedback tool could improve the self-reflection of confidence judgments (Zimmerman, 2000). This self-reflection might also influence their future learning behaviors by supporting them to realize their current metacognitive status (i.e., over-confident or under-confident). Hence, the result of the present study showed that the metacognitive monitoring feedback tool could improve student learning in an augmented reality learning environment. In other words, participants could make better restudy decisions by using metacognitive monitoring feedback. Students would also increase self-monitoring and make more efforts for the augmented reality learning content. This study showed that metacognitive monitoring feedback helped students prepare for future studies in an augmented reality learning environment. The metacognitive monitoring feedback tool could influence students' metacognitive judgments to encourage a good calibration habit. The metacognitive monitoring feedback could also enhance self-efficacy to deepen their comprehension of learning materials in an augmented reality learning environment.

5.4.2 Reviewing Time

Reviewing answers and feedback time were crucial activities in metacognitive monitoring feedback. According to the linear regression of reviewing time in Figure 30, a weak correlation that generated calibration influenced reviewing answers and feedback time. Table 8 showed a significant difference between groups 1 and 2 for the underconfident state. Moreover, there was no significant difference in the overconfident state. Therefore, students who experienced metacognitive monitoring feedback reduced reviewing answer time in under-confidence but had no difference in over-confident condition. This result demonstrated that metacognitive monitoring feedback improved students' learning performance while influencing reviewing time in an underconfident status. Hence, metacognitive monitoring feedback affected students studying time of the feedback screen in augmented reality environments, and Hypothesis 2-4 was accepted.

According to the study by Townsend and Heit (2011), metacognitive monitoring influenced students' allocation of reviewing time and impacted their performance. If students could correctly monitor their learning results, they could precisely judge whether they had an accurate solution to a particular problem and recognize their understanding level of materials. In the region-of-proximal learning model (Metcalfe & Kornell, 2005), the judgment of improvement was concerned with the judgment of learning rate. Students stopped studying a particular item when their learning rate decreased. The judgment of improvement would be effective when the time was limited, and students needed to focus on more learned materials to maximize overall performance. In this study, students were sensitive to the improvement of learning performance with metacognitive monitoring feedback and made decisions to increase the learning rate. Students completed the order of priority of answers, choosing not to study the content they already understood in the underconfident condition. Metacognitive monitoring feedback provided the visual calibration between confidence level and performance, making students believe they understand solutions well to solve the questions if their calibration was acceptable. Students could focus on the items with the highest learning rate of improvement, which resulted in the maximum efficiency of reviewing feedback per unit time.

In this research, metacognitive monitoring feedback was applied to help students evaluate their confidence levels correctly and guided them to regulate processes with cognitive strategies (Dinsmore & Parkinson, 2013; Nietfeld et al., 2005). Effective goal settings involved students being aware of the current understanding of their existing knowledge. Students could also identify the gaps in their knowledge and determine the pathway to acquiring new knowledge and skills successfully. In this experiment, students took the upper arm exercise first, and they realized the problem after receiving accurate results. When they took the trunk segment exercise with the same human position, they identified the gaps between their knowledge and actual performance. They tried to solve the question using the new method or knowledge to accomplish the tasks. Further, decreasing time for the understanding part is also an effective strategy to complete the tasks efficiently. Metacognitive monitoring feedback helped students recognize their weaknesses in knowledge continuously. Hence, they spent their time more efficiently without juggling, where they should review again or what practice they should repeat.

Moreover, students who experienced metacognitive monitoring feedback showed higher levels of self-reflection. The feedback tool provided comparisons of the expected results and actual results for students. Their self-judgment was impacted by the metacognitive monitoring feedback in the augmented reality learning environment. For the overconfident state, students judged the causes of their errors if the confidence level was much higher than the actual performance. They tried to spend time on mistakes or issues. The poor results influenced their motivation, and reviewing answers was useful for them to improve performance in the following questions.

Metacognitive monitoring feedback could enhance students' awareness and sensitivity in confidence level during the learning test in the augmented reality learning environment. It influenced their future learning behaviors by supporting them to realize their current metacognitive statuses (i.e., over-confident or under-confident). Therefore, the metacognitive monitoring feedback tool affected students' reviewing answers and feedback time in an augmented reality learning environment. In other words, participants could discover their gaps between performance and confidence levels rapidly and respond adaptively with visual feedback. Students were responsible for their learning, and instructors also needed to design appropriate learning platforms to guide students to self-regulated learning, improving their learning efficiency and performance.

Metacognitive monitoring feedback and retrospective confidence judgments helped students realize that they did not need to greatly review answers in the under-confident condition to improve the learning rate. They could jump to the next question when they were underconfident and slow down the learning when they were overconfident. Therefore, metacognitive monitoring feedback may change the reviewing answers and feedback time to improve performance.

5.4.3 Answering Time

Answering time or solving problem time was another important activity related to metacognitive monitoring feedback. According to the linear regression of answering time in Figure 33, a very weak correlation that generated calibration influenced answering time for both groups 1 and 2. In the overconfident condition, the Group 1 answering time was shorter than Group 2, which affects the trend of time increasing when calibration was increasing. The line tended to be horizontal, so the correlation was very weak for Group 1. Table 10 showed a significant difference between groups 1 and 2 for the over-confident effect and no significant difference for the under-confident condition. Therefore, students who experienced metacognitive monitoring feedback reduced answering time in overconfident conditions but no significant difference in under-confident conditions. This result proved that metacognitive monitoring feedback improved the students' learning performance without increasing the answering time or problem-solving time. Metacognitive monitoring feedback influenced student problem-solving time in augmented reality environments, and Hypothesis 2-3 was accepted.

Most papers mentioned the judgment time for solving a problem and are short-term memory (Hoffman & Spatariu, 2008; Morgan, Kornell, Kornblum, & Terrace, 2014). In this research, each problem needed a large calculation and understanding of learning knowledge, which required long-term memory. The time devoted to the problems led to effective outcomes, but not all the time spent was effective for learners. Learners relied on their strategies to solve the problems or tasks based on the feedback on learners' cognition. Stolp and Zabrucky (2017) revealed that high self-monitoring students altered the amount of time they spent on studying and their metacognitive self-evaluations after receiving the first feedback. The results in Phase 2 corroborated the findings from Wäschle et al. (2014) that visual feedback decreased learners' procrastination and positively affected their self-regulated learning.

For the underconfident condition, both Group 1 and Group 2 students performed well with the questions but underestimated their performance. Metacognitive monitoring feedback did not greatly influence their answering time, and procrastination was reduced. Regarding the overconfident condition, students overestimated their performance. Based on the visual feedback, students had large discrepancies between their confidence level and current learning performance. They tried to reduce the difference between the current performance and confidence level. They were supposed to spend more time answering questions based on the correct answers. One possible explanation for this phenomenon was that students without metacognitive monitoring feedback jeopardized their performance by spending more time on content they did not understand and made efforts to learn all materials to answer questions. In contrast, students with metacognitive monitoring feedback used more strategic tactics to solve the more accessible part moving to the tricky part.

Another possible explanation was that metacognitive monitoring feedback tried to adjust students' confidence levels. It decreased their procrastination to prompt their reflective learning processes. The ability to make accurate confidence levels was essential for optimal study time behaviors. Students could make better choices with metacognitive monitoring feedback. Fiorella and Vogel-Walcutt (2011) demonstrated that effective metacognitive prompting improved learners' decision-making, which was regarding how well they could determine the appropriate method to reach the targets. However, only metacognitive prompting was hard to support self-regulated learning (Wong et al., 2019). Sitzmann and Ely (2010) concluded that continuous prompting was effective for self-regulated learning, enabling students to follow the learning process accordingly.

In this study, continuous prompting and metacognitive monitoring feedback were applied to prompt students' reflective activities. The augmented reality learning environment was a self-learning environment. Students might experience a sense of isolation, like online learning (McInnerney & Roberts, 2004). Nonetheless, feedback prompted students to foster reflective learning processes (Van den Boom, Paas, & Van Merrienboer, 2007). Hence, metacognitive monitoring feedback combined with prompting decreased the answering time in the over-confident situation, which was more promising in influencing students' learning performance. Not every student had a high ability to self-monitor and control themselves to solve the problems. But metacognitive monitoring feedback and retrospective confidence judgment prompting could improve learners' performance and adaptability to a particular problem, making them self-directed and independent, and helping them develop logical thinking and judgment (Rum & Ismail, 2017). Metacognitive monitoring feedback helped them realize the gap in confidence level and performance. Students could overcome these biases between confidence level and performance through feedback tool to improve their judgments and decisions. Furthermore, effectively identifying their learning errors could significantly influence students' answering time in decisions.

In summary, based on Figure 38, Group 2 students only used retrospective confidence judgments. The reviewing feedback time increased compared with Group 3 students, and the answering question time was the same as Group 3 students. Group 1 students applied the metacognitive monitoring feedback, which showed over-confident or under-confident status to the students. With metacognitive monitoring feedback, Group 1 students' reviewing time decreased compared with Group 2 students in the under-confident status. Moreover, answering time decreased in the over-confident status. Finally, metacognitive monitoring feedback improved test scores without increasing answering questions time and reviewing feedback time.

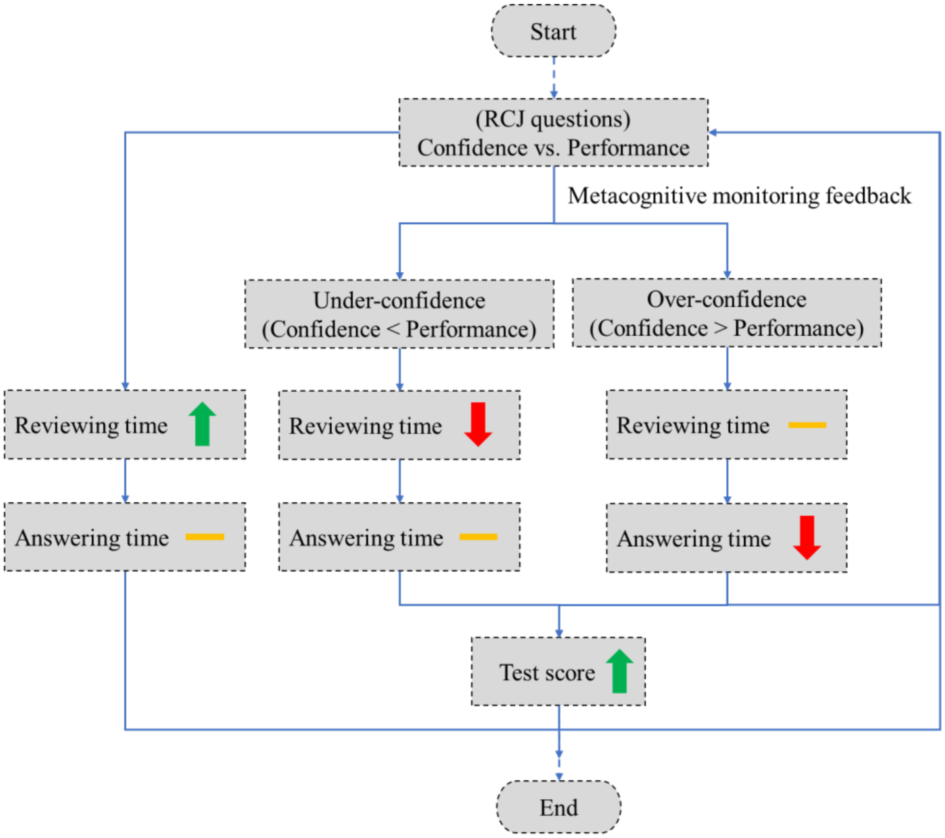


Figure 41: Effects of metacognitive monitoring feedback

5.4.4 Workload

This study found that metacognitive prompting and metacognitive monitoring feedback did not increase students' workload. So Hypothesis 2-5 was accepted, implying that these tools could be used effectively without any workload increment in the AR learning environment. The overall workload was not affected by metacognitive prompting and metacognitive monitoring feedback in an AR environment. This study advanced our understanding of metacognitive monitoring strategies on subject interaction in an AR environment. Furthermore, this study outcome could be used to develop better metacognitive monitoring strategies without increasing learners' workload in an AR environment.

In conclusion, the Phase 2 study revealed the benefits of using a metacognitive monitoring feedback tool in an AR learning environment to prompt students' academic performance without increasing their answering questions, reviewing feedback time, and overall workload. Metacognitive monitoring feedback also altered self-judgment to help students avoid making mistakes and manage their goals and motivation in the AR learning environment.

5.5 Limitations

Metacognitive monitoring feedback is one of the heuristics but is not a panacea. One of the limitations in Phase 2 is the small sample size of the experiment. Therefore, more research is required to understand effective strategies to identify students' self-efficacy, motivation, and learning efficiency. Additionally, metacognitive monitoring skills need to be explained clearly to the students to help them spend the necessary time and effort on learning processes.

CHAPTER 6. CONCLUSIONS AND FUTURE WORK

6.1 Conclusions

This study confirmed the relationship between metacognition, cognition, and behaviors in the theoretical framework (Figure 5), which was divided and verified by three layers in this study.

The first layer (Figure 39) showed the experimental design of Group 2&3 in Phase 1 and Group 3 in Phase 2, which was a ground-level and object-level loop. The Phase 1 study used this loop to demonstrate the augmented reality system's benefits compared with the in-class environment. The augmented reality environment is beneficial to the egocentric depth perception to improve students' learning performance. Based on this result, it would be constructive to apply augmented reality in the following situation, such as medical surgery collaboration and advanced industrial manufacturing systems integrating robot manipulation and humans to execute tasks in a stereoscopic environment. Furthermore, augmented reality improves the egocentric depth perception's accuracy and allows users to observe and interact in the three-dimensional space.

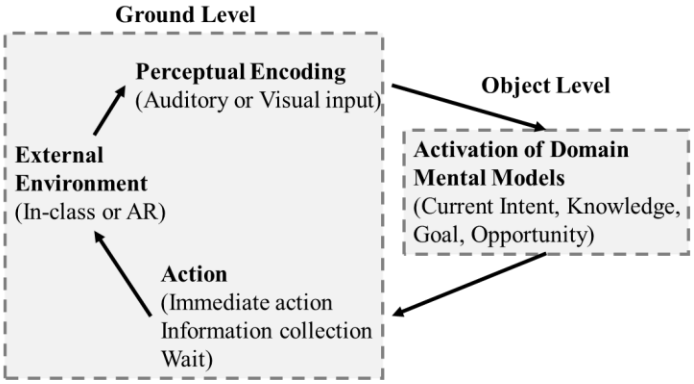


Figure 42: Ground-level and object-level loop (first layer)

The second layer (Figure 40) presents the experiment design of Group 1 in Phase 1 and Group 2 in Phase 2, which used three levels, ground-level, object-level, and meta-level. Based on the Phase 1 study, retrospective confidence judgments could positively or negatively influence student outcomes in the augmented reality environment. The Phase 1 study's findings advanced our understanding of how augmented reality and retrospective confidence judgments impacting student learning. These results would help engineers, educators, and AR content developers optimize this new technology's merits to human egocentric visualization. Therefore, asking retrospective confidence judgment probes in the augmented reality learning environment significantly impacts student learning performance.

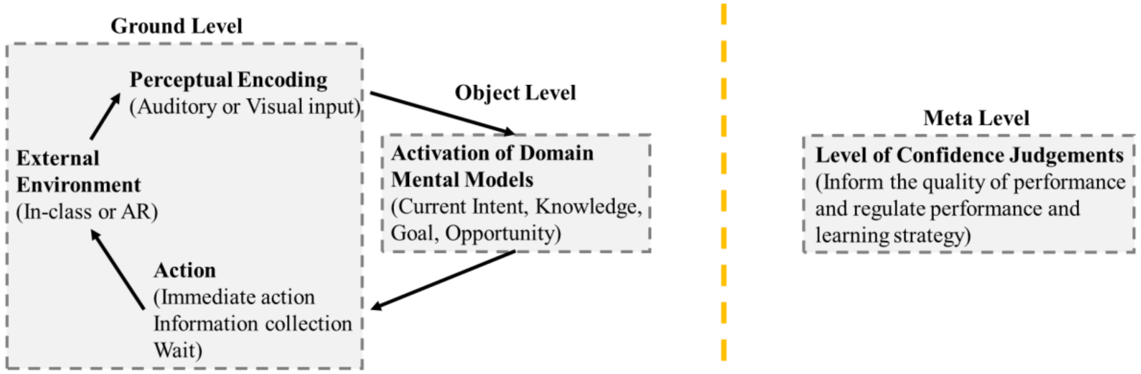


Figure 43: Ground-level, object-level loop and meta-level (second layer)

The third layer (Figure 41) revealed the experiment design of Group 1 in Phase 2, the ground-level, object-level, and meta-level loops. In the Phase 2 study, metacognitive monitoring feedback improved student learning performance in the augmented reality learning environment. Metacognitive monitoring feedback directed students to eliminate the difference between their confidence level and actual performance. Students with metacognitive monitoring feedback had better calibration, more accurate responses with less answering time in over-confident conditions, and less reviewing time in under-confident conditions.

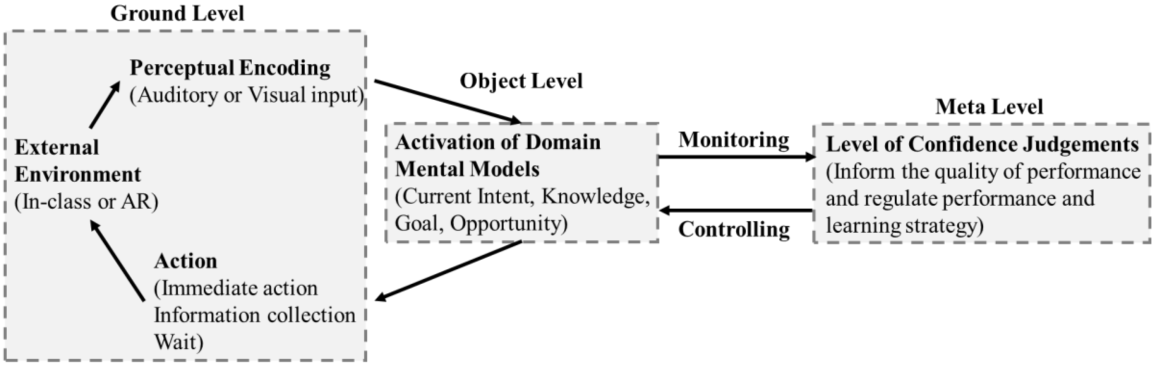


Figure 44: Ground-level, object-level, and meta-level loops (third layer)

Based on these results, we recommended combining the metacognitive monitoring feedback and augmented reality together. Students or trainees could use this system to self-pace and self-test their learning. Repeated confidence judgments and visual feedback were proved to optimize their learning progress and improve performance. In the medical surgery collaboration and advanced robot-human industrial manufacturing system training, our system had many advantages. It could locate people's positions in the working areas and showed specific learning knowledge to them. The location-based augmented reality system guided users walking and operating machines smoothly without geographical limitations. This advanced system reduced their overconfidence effect in learning and decreased the occurrence of dangerous accidents in medical surgery and advanced manufacturing.

In conclusion, this study's findings advanced our understanding of students' interactions and the learning content in an augmented reality learning environment. This study also provided a new guideline on developing more effective learning content in the augmented reality learning environment. Using a metacognitive monitoring feedback tool in an augmented reality learning environment was a valuable strategy to improve students' academic performance, calibration, and student learning.

6.2 Future Work

There are numerous fields in which metacognition has already shown the potential for improvements. Many problems must be overcome to apply metacognition into the augmented reality learning environment and optimize existing augmented reality applications, especially regarding its educational applications. Accordingly, metacognitive monitoring skills need to be explained clearly to the students to help them spend the necessary time and effort on learning processes.

This study only tested the metacognitive monitoring feedback in engineering learning content. It proved that metacognitive monitoring feedback is critical for improving learning performance and calibrating students' confidence levels. Metacognitive monitoring feedback also needs to be verified in other learning areas or disciplines such as literacy reading memory, mathematics problem-solving, and biological experiments.

Now the visual feedback has the total score, confidence level, and the actual score students received. In the future, the augmented reality learning system can provide better visual feedback to the learners. The visual feedback can show the current confidence level and the cumulative confidence level during the learning process. The continuous visual feedback offers a more apparent change in students' confidence levels. The parameters, such as the average confidence levels, actual performance comparisons, and descriptive statistics, can be provided to students and let them know their learning progress. Based on a large amount of data from students' feedback, the system predicts students who belong to the highly motivated or low motivated learner. According to different learners, the learning system can provide suggestions for students to calibrate their confidence levels and evaluate themselves correctly, thereby improving their learning efficiency and performance. Further, students can regulate their strategies to adjust their reviewing answers time and answering question time.

Metacognitive monitoring feedback is a kind of response-oriented technique using the confidence level to compare the actual performance. The learning system can also use a process-oriented approach to help students understand the specific reasons they choose particular answers. Based on their explanations, it promotes more realistic confidence judgments, and the learning system knows the processing of their decisions well. It's a natural language process skill that the learning system can understand the learners' dialog flow. The dialog flow between the learners and the learning system can help us detect the intents students want to operate and problems they met in the learning process. Therefore, learners can have good insight and allocate their time appropriately in the study with better feedback.

REFERENCES

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review, 20*, 1-11.

Andujar, J. M., Mejías, A., & Márquez, M. A. (2010). Augmented reality for the improvement of remote laboratories: an augmented remote laboratory. *IEEE transactions on education, 54*(3), 492-500.

Arkes, H. R. (1991). Costs and benefits of judgment errors: Implications for debiasing. *Psychological bulletin, 110*(3), 486.

Azevedo, R. (2005). Using hypermedia as a metacognitive tool for enhancing student learning? The role of self-regulated learning. *Educational psychologist, 40*(4), 199-209.

Azevedo, R., Behnagh, R., Duffy, M., Harley, J., & Trevors, G. (2012). Metacognition and self-regulated learning in student-centered leaning environments. *Theoretical foundations of student-centered learning environments*, 171-197.

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.

Billinghurst, M. (2002). Augmented reality in education. *New horizons for learning, 12*(5).

Billinghurst, M., & Duenser, A. (2012). Augmented reality in the classroom. *Computer, 45*(7), 56-63.

Biocca, F., Tang, A., Owen, C., & Xiao, F. (2006). *Attention funnel: omnidirectional 3D cursor for mobile augmented reality platforms.* Paper presented at the Proceedings of the SIGCHI conference on Human Factors in computing systems.

Boekaerts, M., & Corno, L. (2005). Self‐regulation in the classroom: A perspective on assessment and intervention. *Applied Psychology, 54*(2), 199-231.

Borrero, A. M., & Márquez, J. A. (2012). A pilot study of the effectiveness of augmented reality to enhance the use of remote labs in electrical engineering education. *Journal of Science Education and Technology, 21*(5), 540-557.

Brammer, S., & Clark, T. (2020). COVID‐19 and Management Education: Reflections on Challenges, Opportunities, and Potential Futures. *British Journal of Management, 31*(3), 453.

Brosch, T., Scherer, K. R., Grandjean, D. M., & Sander, D. (2013). The impact of emotion on perception, attention, memory, and decision-making. *Swiss medical weekly, 143*, w13786.

Burke, E., Felle, P., Crowley, C., Jones, J., Mangina, E., & Campbell, A. G. (2017). *Augmented reality EVAR training in mixed reality educational space.* Paper presented at the 2017 IEEE Global Engineering Education Conference (EDUCON).

Caldwell, J. A. (2005). Fatigue in aviation. *Travel Medicine and Infectious Disease, 3*(2), 85-96.

Cao, A., Chintamani, K. K., Pandya, A. K., & Ellis, R. D. (2009). NASA TLX: Software for assessing subjective mental workload. *Behavior research methods, 41*(1), 113-117.

Carbonell Carrera, C., & Bermejo Asensio, L. A. (2017). Augmented reality as a digital teaching environment to develop spatial thinking. *Cartography and geographic information science, 44*(3), 259-270.

Carbonell Carrera, C., & Bermejo Asensio, L. A. (2017). Landscape interpretation with augmented reality and maps to improve spatial orientation skill. *Journal of Geography in Higher Education, 41*(1), 119-133.

Castañeda, H.-N. (1967). On the logic of self-knowledge. *Nous, 1*(1), 9-21.

Chen, H., Feng, K., Mo, C., Cheng, S., Guo, Z., & Huang, Y. (2011). *Application of augmented reality in engineering graphics education.* Paper presented at the IT in Medicine and Education (ITME), 2011 International Symposium on.

Cheng, K.-H., & Tsai, C.-C. (2013). Affordances of augmented reality in science learning: Suggestions for future research. *Journal of Science Education and Technology, 22*(4), 449-462.

Cidota, M. A., Clifford, R. M., Lukosch, S. G., & Billinghurst, M. (2016). *Using visual effects to facilitate depth perception for spatial tasks in virtual and augmented reality.* Paper presented at the 2016 IEEE International Symposium on Mixed and Augmented Reality (ISMAR-Adjunct).

Cohen, M. S., & Thompson, B. B. (2005). *Metacognitive processes for uncertainty handling: Connectionist implementation of a cognitive model.* Paper presented at the AAAI Spring Symposium: Metacognition in Computation.

Coimbra, M. T., Cardoso, T., & Mateus, A. (2015). Augmented reality: an enhancer for higher education students in math's learning? *Procedia Computer Science, 67*, 332-339.

Coutinho, S. (2008). Self-efficacy, metacognition, and performance. *North American Journal of Psychology, 10*(1).

Cox, M., & Raja, A. J. B. T. (2007). Metareasoning: A manifesto.

Dalim, C. S. C., Kolivand, H., Kadhim, H., Sunar, M. S., & Billinghurst, M. (2017). Factors influencing the acceptance of augmented reality in education: A review of the literature. *Journal of computer science, 13*(11), 581-589.

Deshpande, A., & Kim, I. (2018). The effects of augmented reality on improving spatial problem solving for object assembly. *Advanced Engineering Informatics, 38*, 760-775.

Dinsmore, D. L., & Parkinson, M. M. (2013). What are confidence judgments made of? Students' explanations for their confidence ratings and what that means for calibration. *Learning and Instruction, 24*, 4-14.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology, 18*(1), 7-22.

Dunlosky, J., & Bjork, R. A. (2013). *Handbook of metamemory and memory*: Psychology Press.

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

Dunlosky, J., & Tauber, S. U. K. (2016). *The Oxford handbook of metamemory*: Oxford University Press.

Dunning, D. (2011). The Dunning–Kruger effect: On being ignorant of one's own ignorance *Advances in experimental social psychology* (Vol. 44, pp. 247-296): Elsevier.

Erzberger, H. (2005). Automated conflict resolution for air traffic control.

Evans, J. R., & Fisher, R. P. (2011). Eyewitness memory: Balancing the accuracy, precision and quantity of information through metacognitive monitoring and control. *Applied Cognitive Psychology, 25*(3), 501-508.

Fiorella, L., & Vogel-Walcutt, J. J. (2011). *Metacognitive prompting as a generalizable instructional tool in simulation-based training.* Paper presented at the Proceedings of the Human Factors and Ergonomics Society Annual Meeting.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American psychologist, 34*(10), 906.

Galy, E., Cariou, M., & Mélan, C. (2012). What is the relationship between mental workload factors and cognitive load types? *International Journal of Psychophysiology, 83*(3), 269-275.

Garzon, J., & Acevedo, J. (2019). Meta-analysis of the impact of Augmented Reality on students' learning gains. *Educational Research Review, 27*, 244-260.

Garzón, J., Baldiris, S., Gutiérrez, J., & Pavón, J. (2020). How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis. *Educational Research Review*, 100334.

González, N. A. A. (2018). Development of spatial skills with virtual reality and augmented reality. *International Journal on Interactive Design and Manufacturing (IJIDeM), 12*(1), 133-144.

Guo, W. (2018). *Improving engineering education using augmented reality environment.* Paper presented at the International Conference on Learning and Collaboration Technologies.

Hacker, D. J., Bol, L., Horgan, D. D., & Rakow, E. A. (2000). Test prediction and performance in a classroom context. *Journal of educational psychology, 92*(1), 160.

Hacker, D. J., Dunlosky, J., & Graesser, A. C. (2009). *Handbook of metacognition in education*: Routledge.

Hamilton, K., & Olenewa, J. (2010). Augmented reality in education [PowerPoint slides]. *Retrieved from Lecture Notes Online Web site: http://www. authorstream. com/Presentation/k3hamilton-478823-augmented-reality-in-education*.

Hart, S. G. (2006). *NASA-task load index (NASA-TLX); 20 years later.* Paper presented at the Proceedings of the human factors and ergonomics society annual meeting.

Hoffman, B., & Spatariu, A. (2008). The influence of self-efficacy and metacognitive prompting on math problem-solving efficiency. *Contemporary educational psychology, 33*(4), 875-893.

Hondori, H. M., Khademi, M., Dodakian, L., Cramer, S. C., & Lopes, C. V. (2013). *A spatial augmented reality rehab system for post-stroke hand rehabilitation.* Paper presented at the MMVR.

Hosseini, A., & Lienkamp, M. (2016). *Enhancing telepresence during the teleoperation of road vehicles using HMD-based mixed reality.* Paper presented at the 2016 IEEE Intelligent Vehicles Symposium (IV).

Hou, L., Wang, X., Bernold, L., & Love, P. E. (2013). Using animated augmented reality to cognitively guide assembly. *Journal of Computing in Civil Engineering, 27*(5), 439-451.

Huff, J. D., & Nietfeld, J. L. (2009). Using strategy instruction and confidence judgments to improve metacognitive monitoring. *Metacognition and learning, 4*(2), 161-176.

Hwang, S.-L., Lin, J.-T., Liang, G.-F., Yau, Y.-J., Yenn, T.-C., & Hsu, C.-C. (2008). Application control chart concepts of designing a pre-alarm system in the nuclear power plant control room. *Nuclear Engineering and Design, 238*(12), 3522-3527.

Jarzabkowski, P., & Wilson, D. C. (2006). Actionable Strategy Knowledge:: A Practice Perspective. *European Management Journal, 24*(5), 348-367.

Johnson, P., Johnson, H., Waddington, R., & Shouls, A. (1988). *Task-related knowledge structures: analysis, modelling and application.* Paper presented at the BCS HCI.

Kerawalla, L., Luckin, R., Seljeflot, S., & Woolard, A. (2006). "Making it real": exploring the potential of augmented reality for teaching primary school science. *Virtual reality, 10*(3-4), 163-174.

Keren, G. (1990). Cognitive aids and debiasing methods: can cognitive pills cure cognitive ills? *Advances in psychology* (Vol. 68, pp. 523-552): Elsevier.

Khan, T., Johnston, K., & Ophoff, J. (2019). The impact of an augmented reality application on learning motivation of students. *Advances in Human-Computer Interaction, 2019*.

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

Kim, J. H. (2018b). *The Impact of Metacognitive Monitoring Feedback on Mental Workload and Situational Awareness.* Paper presented at the International Conference on Engineering Psychology and Cognitive Ergonomics.

Kim, J. H. (2018c). *The Impact of Metacognitive Monitoring Feedback on Mental Workload and Situational Awareness*, Cham.

Kinateder, M., Gualtieri, J., Dunn, M. J., Jarosz, W., Yang, X.-D., & Cooper, E. A. (2018). Using an augmented reality device as a distance-based vision aid—promise and limitations. *Optometry and Vision Science, 95*(9), 727.

Klopfer, E., & Yoon, S. (2004). Developing games and simulations for today and tomorrow's tech savvy youth. *TechTrends, 49*(3), 33-41.

Labuhn, A. S., Zimmerman, B. J., & Hasselhorn, M. (2010). Enhancing students' self-regulation and mathematics performance: The influence of feedback and self-evaluative standards. *Metacognition and learning, 5*(2), 173-194.

Lai, A. F., Chen, C. H., & Lee, G. Y. (2019). An augmented reality - based learning approach to enhancing students' science reading performances from the perspective of the cognitive load theory. *British Journal of Educational Technology, 50*(1), 232-247.

Lauer, T. R., Faber, S., Richstone, D., Gebhardt, K., Tremaine, S., Postman, M., . . . Green, R. (2007). The Masses of Nuclear Black Holes in Luminous Elliptical Galaxies and Implications for the Space Density of the Most Massive Black HolesBased on observations made with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. These observations are associated with GO and GTO proposals 5236, 5446, 5454, 5512, 5943, 5990, 5999, 6099, 6386, 6554, 6587, 6633, 7468, 8683, and 9107. *The Astrophysical Journal, 662*(2), 808.

Lee, K. (2012). Augmented reality in education and training. *TechTrends, 56*(2), 13-21.

Livingston, J. A. (2003). Metacognition: An Overview.

Martin-Gutierrez, J., Guinters, E., & Perez-Lopez, D. (2012). Improving strategy of self-learning in engineering: laboratories with augmented reality. *Procedia-Social and Behavioral Sciences, 51*, 832-839.

Martin Gutierrez, J., & Meneses Fernandez, M. D. (2014). Applying augmented reality in engineering education to improve academic performance & student motivation. *International Journal of Engineering Education, 30*(3), 625-635.

McInnerney, J. M., & Roberts, T. S. (2004). Online learning: Social interaction and the creation of a sense of community. *Journal of Educational Technology & Society, 7*(3), 73-81.

Messing, R., & Durgin, F. H. (2005). Distance perception and the visual horizon in head-mounted displays. *ACM Transactions on Applied Perception (TAP), 2*(3), 234-250.

Metcalfe, J., & Kornell, N. (2005). A region of proximal learning model of study time allocation. *Journal of memory and language, 52*(4), 463-477.

Montibeller, G., & Von Winterfeldt, D. (2015). Cognitive and motivational biases in decision and risk analysis. *Risk analysis, 35*(7), 1230-1251.

Morgan, G., Kornell, N., Kornblum, T., & Terrace, H. S. (2014). Retrospective and prospective metacognitive judgments in rhesus macaques (Macaca mulatta). *Animal Cognition, 17*(2), 249-257.

Moser, S., Zumbach, J., & Deibl, I. (2017). The effect of metacognitive training and prompting on learning success in simulation‐based physics learning. *Science Education, 101*(6), 944-967.

Mourtzis, D., Zogopoulos, V., & Vlachou, E. (2018). Augmented reality supported product design towards industry 4.0: A teaching factory paradigm. *Procedia manufacturing, 23*, 207-212.

Munoz-Montoya, F., Juan, M.-C., Mendez-Lopez, M., & Fidalgo, C. (2018). Augmented reality based on SLAM to assess spatial short-term memory. *IEEE Access, 7*, 2453-2466.

Nelson, T. O. (1990). Metamemory: A theoretical framework and new findings *Psychology of learning and motivation* (Vol. 26, pp. 125-173): Elsevier.

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.

Nietfeld, J. L., Cao, L., & Osborne, J. W. (2005). Metacognitive monitoring accuracy and student performance in the postsecondary classroom. *The Journal of Experimental Educational*, 7-28.

Nietfeld, J. L., Cao, L., & Osborne, J. W. (2006). The effect of distributed monitoring exercises and feedback on performance, monitoring accuracy, and self-efficacy. *Metacognition and learning, 1*(2), 159.

Ooi, T. L., Wu, B., & He, Z. J. (2001). Distance determined by the angular declination below the horizon. *Nature, 414*(6860), 197-200.

Palinko, O., Kun, A. L., Shyrokov, A., & Heeman, P. (2010). *Estimating cognitive load using remote eye tracking in a driving simulator.* Paper presented at the Proceedings of the 2010 symposium on eye-tracking research & applications.

Pintrich, P. R., Wolters, C. A., & Baxter, G. P. (2000). 2. assessing metacognition and self-regulated learning.

Prodromou, T. (2019). *Augmented reality in educational settings*: BRILL.

Radu, I. (2012). *Why should my students use AR? A comparative review of the educational impacts of augmented-reality.* Paper presented at the Mixed and Augmented Reality (ISMAR), 2012 IEEE International Symposium on.

Radu, I. (2014). Augmented reality in education: a meta-review and cross-media analysis. *Personal and Ubiquitous Computing, 18*(6), 1533-1543.

Reid, G. B., & Nygren, T. E. (1988). The subjective workload assessment technique: A scaling procedure for measuring mental workload *Advances in psychology* (Vol. 52, pp. 185-218): Elsevier.

Rhem, J. (2013). *Using reflection and metacognition to improve student learning: Across the disciplines, across the academy*: Stylus Publishing, LLC.

Richards, E. A., Schantz, H. G., Unden, J. A., von Laven, K. A., Compston, D., & Weil, C. (2010). Electrically Small Antenna Design for Low Frequency Systems. *NOTICE AND SIGNATURE PAGE*, 315.

Rubio, S., Díaz, E., Martín, J., & Puente, J. M. (2004). Evaluation of subjective mental workload: A comparison of SWAT, NASA‐TLX, and workload profile methods. *Applied Psychology, 53*(1), 61-86.

Rum, S. N. M., & Ismail, M. A. (2017). Metocognitive support accelerates computer assisted learning for novice programmers. *Journal of Educational Technology & Society, 20*(3), 170-181.

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.

Schantz, H. G., Weil, C., & Unden, A. H. (2011). *Characterization of error in a near-field electromagnetic ranging (NFER) real-time location system (RTLS).* Paper presented at the 2011 IEEE Radio and Wireless Symposium.

Schiffeler, N., Stehling, V., Haberstroh, M., & Isenhardt, I. (2019). *Collaborative Augmented Reality in Engineering Education.* Paper presented at the International Conference on Remote Engineering and Virtual Instrumentation.

Schlösser, T., Dunning, D., Johnson, K. L., & Kruger, J. (2013). How unaware are the unskilled? Empirical tests of the "signal extraction" counterexplanation for the Dunning–Kruger effect in self-evaluation of performance. *Journal of Economic Psychology, 39*, 85-100.

Schraw, G. (1998). Promoting general metacognitive awareness. *Instructional science, 26*(1-2), 113-125.

Schraw, G. (2009a). 21 Measuring Metacognitive Judgments. *Handbook of metacognition in education*, 415.

Schraw, G. (2009b). A conceptual analysis of five measures of metacognitive monitoring. *Metacognition and learning, 4*(1), 33-45.

Seichter, H., & Schnabel, M. A. (2005). Digital and tangible sensation: an augmented reality urban design studio.

Sengupta, J., & Johar, G. V. (2002). Effects of inconsistent attribute information on the predictive value of product attitudes: Toward a resolution of opposing perspectives. *Journal of Consumer research, 29*(1), 39-56.

Shaughnessy, M. F., Veenman, M., & Kennedy, C. K. (2008). *Meta-cognition: A recent review of research, theory, and perspectives*: Nova Publishers.

Shirazi, A., & Behzadan, A. H. (2015). Content Delivery Using Augmented Reality to Enhance Students' Performance in a Building Design and Assembly Project. *Advances in Engineering Education, 4*(3), n3.

Sirakaya, M., & Kilic Cakmak, E. (2018). Effects of augmented reality on student achievement and self-efficacy in vocational education and training. *International journal for research in vocational education and training, 5*(1), 1-18.

Sitzmann, T., & Ely, K. (2010). Sometimes you need a reminder: The effects of prompting self-regulation on regulatory processes, learning, and attrition. *Journal of Applied Psychology, 95*(1), 132.

Sommerauer, P., & Müller, O. (2018). Augmented reality for teaching and learning–a literature review on theoretical and empirical foundations.

Sperling, R. A., Howard, B. C., Staley, R., & DuBois, N. (2004). Metacognition and self-regulated learning constructs. *Educational Research and Evaluation, 10*(2), 117-139.

Stewart, D. (1965). A platform with six degrees of freedom. *Proceedings of the institution of mechanical engineers, 180*(1), 371-386.

Stolp, S., & Zabrucky, K. M. (2017). Contributions of metacognitive and self-regulated learning theories to investigations of calibration of comprehension. *International Electronic Journal of Elementary Education, 2*(1), 7-31.

Strzys, M., Kapp, S., Thees, M., Kuhn, J., Lukowicz, P., Knierim, P., & Schmidt, A. (2017). Augmenting the thermal flux experiment: A mixed reality approach with the HoloLens. *The Physics Teacher, 55*(6), 376-377.

Swan, J. E., Jones, A., Kolstad, E., Livingston, M. A., & Smallman, H. S. (2007). Egocentric depth judgments in optical, see-through augmented reality. *IEEE transactions on visualization and computer graphics, 13*(3), 429-442.

Tang, Y. M., Au, K., Lau, H. C., Ho, G. T., & Wu, C. (2020). Evaluating the effectiveness of learning design with mixed reality (MR) in higher education. *Virtual reality*, 1-11.

Townsend, C. L., & Heit, E. (2011). Judgments of learning and improvement. *Memory & cognition, 39*(2), 204-216.

Tversky, A., & Kahneman, D. (1974). Judgment under uncertainty: Heuristics and biases. *science, 185*(4157), 1124-1131.

Van den Boom, G., Paas, F., & Van Merrienboer, J. J. (2007). Effects of elicited reflections combined with tutor or peer feedback on self-regulated learning and learning outcomes. *Learning and Instruction, 17*(5), 532-548.

Walker, Z., McMahon, D. D., Rosenblatt, K., & Arner, T. (2017). Beyond Pokémon: Augmented reality is a universal design for learning tool. *SAGE Open, 7*(4), 2158244017737815.

Wang, Y. H. (2017). Using augmented reality to support a software editing course for college students. *Journal of Computer Assisted Learning, 33*(5), 532-546.

Wäschle, K., Lachner, A., Stucke, B., Rey, S., Frömmel, C., & Nückles, M. (2014). Effects of visual feedback on medical students' procrastination within web-based planning and reflection protocols. *Computers in Human Behavior, 41*, 120-136.

Wei, X., Weng, D., Liu, Y., & Wang, Y. (2015). Teaching based on augmented reality for a technical creative design course. *Computers & Education, 81*, 221-234.

Werrlich, S., Eichstetter, E., Nitsche, K., & Notni, G. (2017). An overview of evaluations using augmented reality for assembly training tasks. *International Journal of Computer and Information Engineering, 11*(10), 1068-1074.

Wiegmann, D. A., & Shappell, S. A. (2001). Human error analysis of commercial aviation accidents: Application of the Human Factors Analysis and Classification System (HFACS). *Aviation, space, and environmental medicine, 72*(11), 1006-1016.

Winters, F. I., Greene, J. A., & Costich, C. M. (2008). Self-regulation of learning within computer-based learning environments: A critical analysis. *Educational Psychology Review, 20*(4), 429-444.

Wong, J., Baars, M., Davis, D., Van Der Zee, T., Houben, G.-J., & Paas, F. (2019). Supporting self-regulated learning in online learning environments and MOOCs: A systematic review. *International Journal of Human–Computer Interaction, 35*(4-5), 356-373.

Wu, H.-K., Lee, S. W.-Y., Chang, H.-Y., & Liang, J.-C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers & Education, 62*, 41-49.

Wu, P.-H., Hwang, G.-J., Yang, M.-L., & Chen, C.-H. (2018). Impacts of integrating the repertory grid into an augmented reality-based learning design on students' learning achievements, cognitive load and degree of satisfaction. *Interactive Learning Environments, 26*(2), 221-234.

Xue, H., Sharma, P., & Wild, F. (2019). User satisfaction in augmented reality-based training using microsoft HoloLens. *Computers, 8*(1), 9.

Yuen, S. C.-Y., Yaoyuneyong, G., & Johnson, E. (2011). Augmented reality: An overview and five directions for AR in education. *Journal of Educational Technology Development and Exchange (JETDE), 4*(1), 11.

Zhang, L. J. (2010). A dynamic metacognitive systems account of Chinese university students' knowledge about EFL reading. *Tesol Quarterly, 44*(2), 320-353.

Zimmerman, B. J. (2000). Attaining self-regulation: A social cognitive perspective *Handbook of self-regulation* (pp. 13-39): Elsevier.

Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory into practice, 41*(2), 64-70.

Zimmerman, B. J. (2008). Investigating self-regulation and motivation: Historical background, methodological developments, and future prospects. *American educational research journal, 45*(1), 166-183.

APPENDIX

1. Demographic Questionnaire

ID #: __________ **DATE:** ___________

Please answer the following questions regarding your background experience. This information will not be used to evaluate you personally. We are asking for this information so we are in a better position to understand how the findings may relate to operator experience or other demographic characteristics.

1. Age: ______

2. Gender: Male Female

3. Please rate your previous experience level playing computer graphic video games; 1 being Novice up to 5 being Expert in your answer.

1 2 3 4 5
Novice Expert

4. Please rate your previous experience level participating in a augmented reality task before; 1 being novice up to 5 being Expert in your answers.

1 2 3 4 5
Novice Expert

5. Which hand is your dominant hand? LEFT RIGHT

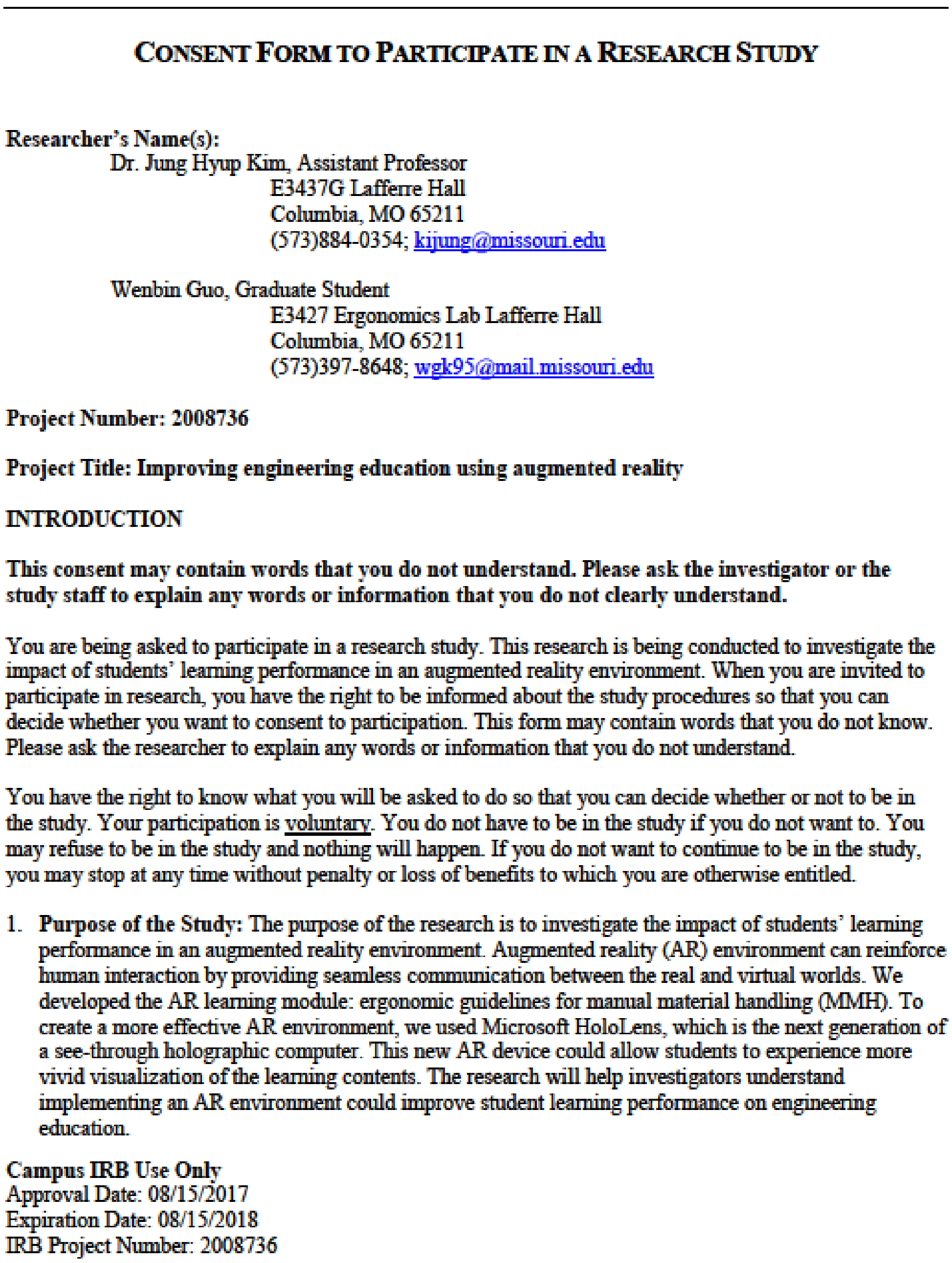
6. Today, are you wearing glasses? YES NO

7. Today, are you wearing contact lenses? YES NO

8. Do you have poor vision, or other vision problems? YES NO

9. If you answered "YES" to Question 8, please briefly explain your vison problems:

2. IRB Written Consent



CONSENT FORM TO PARTICIPATE IN A RESEARCH STUDY

Researcher's Name(s):
Dr. Jung Hyup Kim, Assistant Professor
E3437G Lafferre Hall
Columbia, MO 65211
(573)884-0354; kijung@missouri.edu

Wenbin Guo, Graduate Student
E3427 Ergonomics Lab Lafferre Hall
Columbia, MO 65211
(573)397-8648; wgk95@mail.missouri.edu

Project Number: 2008736

Project Title: Improving engineering education using augmented reality

INTRODUCTION

This consent may contain words that you do not understand. Please ask the investigator or the study staff to explain any words or information that you do not clearly understand.

You are being asked to participate in a research study. This research is being conducted to investigate the impact of students' learning performance in an augmented reality environment. When you are invited to participate in research, you have the right to be informed about the study procedures so that you can decide whether you want to consent to participation. This form may contain words that you do not know. Please ask the researcher to explain any words or information that you do not understand.

You have the right to know what you will be asked to do so that you can decide whether or not to be in the study. Your participation is voluntary. You do not have to be in the study if you do not want to. You may refuse to be in the study and nothing will happen. If you do not want to continue to be in the study, you may stop at any time without penalty or loss of benefits to which you are otherwise entitled.

1. **Purpose of the Study:** The purpose of the research is to investigate the impact of students' learning performance in an augmented reality environment. Augmented reality (AR) environment can reinforce human interaction by providing seamless communication between the real and virtual worlds. We developed the AR learning module: ergonomic guidelines for manual material handling (MMH). To create a more effective AR environment, we used Microsoft HoloLens, which is the next generation of a see-through holographic computer. This new AR device could allow students to experience more vivid visualization of the learning contents. The research will help investigators understand implementing an AR environment could improve student learning performance on engineering education.

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Expiration Date: 08/15/2018
IRB Project Number: 2008736

You will be participating with approximately 39 other students.

2. **Procedures to be followed:** Step1. Before the experiment, you will be asked to answer demographic questionnaires if they have computer experience level and the similar experience on augmented reality task in the past. And we will check whether they feel maladaptive or they are able to do the test. Because the HoloLens (579 g) is a little heavy to wear, so maybe you feel uncomfortable. And you can stop the experiment immediately if they feel sick. It is expected to last 5 minutes. Step 2. A general orientation briefing will be provided at the beginning of the experiment which covers the information including the introduction to the simulation, user interface, and your role in the tasks. During the training session, you will experience training designed by power point slides which contain how to fit the HoloLens to get the best view, gestures, scenes in HoloLens, Job Analysis Worksheet. You must understand how to use gestures to switch to the previous or next scene to learn manual material handling knowledge. It is expected to last 15 minutes. Step 3. After being trained, you will undergo the experimental test session with 18 scenes in HoloLens. The experiment test will take 40 minutes for learning materials. Step 4. After finishing each scenario, you will have a NASA-TLX workload which has six questions about the more important contributor to workload for this task. It is expected to last 10 minutes. Step 5. After learning materials about manual material handling, the participants need to take a quiz to observe their learning results. It is expected to last 15 minutes. So the total time is expected to last one and a half hours.

3. **Duration/Time:** Your participation in this research will take approximately one and a half hours to complete subject experience level questionnaires, the training, 18 scenes learning materials, NASA TLX rating test, and quiz.

4. **Benefits:** Your participation will benefit the development of augmented reality application in engineering education. We expected that students have higher learning performance and efficiency compared to traditional learning.

5. **Discomforts and Risks:** This study involves no risks to your physical or mental health beyond those encountered in the normal course of everyday life. In participating in this research, you may experience minimal fatigue from working at the computer. You are free to take a break at any time during the experiment if necessary.

6. **Payment for participation:** There is no cost to you. You will receive 1.5 extra points on your final score in IMSE 3810 Ergonomics class. Instead of being in this study, you have the alternative assignment option: literature review paper. You need to read one piece of 3-5 pages journal article about augmented reality and write two pages of summary. You also have the option of not participating in this study, and will not be penalized for your decision. Even participants who withdraw from a research study will receive the course credit that can be prorated for the time the participant spent in the study. For example, if the task is expected to take one hour, and the participant participated for a half hour then they would get 0.5 point for course credit.

7. **Statement of Confidentiality:** Your participation in this research is confidential. The data will be

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saved and secured at locked file cabinets. Information produced by this study will be stored in the investigator's file and identified by a code number only. The code key connecting your name to specific information about you will be kept in a separate, secure location. Information contained in your records may not be given to anyone unaffiliated with the study in a form that could identify you without your written consent, except as required by law.

8. **Voluntary Participation:** Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive otherwise. You will also be informed of any new information discovered during the course of this study that might influence your health, welfare, or willingness to be in this study.
9. **Right to Ask Questions:** Please contact Dr. Jung Hyup Kim (kijung@missouri.edu) at (573)884-0354 with questions, complaints or concerns about this research. You can also call this number if you feel this study has harmed you. If you have any questions regarding your rights as a participant in this research and/or concerns about the study, or if you feel under any pressure to enroll or to continue to participate in this study, you may contact the University of Missouri Campus Institutional Review Board (which is a group of people who review the research studies to protect participants' rights) at (573) 882-9585 or umcresearchcirb@missouri.edu.

A copy of this Informed Consent form will be given to you before you participate in the research.

You must be 18 years of age or older to consent to take part in this research study. If you agree to take part in this research study and the information outlined above, please sign your name and indicate the date below.

SIGNATURES

I have read this consent form and my questions have been answered. My signature below means that I do want to be in the study. I know that I can remove myself from the study at any time without any problems.

_______________________________ Subject

_______________ Date

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Expiration Date: 08/15/2018
IRB Project Number: 2008736

CONSENT FORM TO PARTICIPATE IN A RESEARCH STUDY

Researcher's Name(s):

Dr. Jung Hyup Kim, Assistant Professor
E3437G Lafferre Hall
Columbia, MO 65211
(573)884-0354; kijung@missouri.edu

Wenbin Guo, Graduate Student
E3428 Ergonomics Lab Lafferre Hall
Columbia, MO 65211
(573)397-8648; wgk95@mail.missouri.edu

Project Number: 2011645

Project Title: Using metacognitive monitoring feedback to improve engineering education in augmented reality environment

INTRODUCTION

This consent may contain words that you do not understand. Please ask the investigator or the study staff to explain any words or information that you do not clearly understand.

You are being asked to participate in a research study. This research is being conducted to investigate the impact of students' learning performance in an augmented reality environment. When you are invited to participate in research, you have the right to be informed about the study procedures so that you can decide whether you want to consent to participation. This form may contain words that you do not know. Please ask the researcher to explain any words or information that you do not understand.

You have the right to know what you will be asked to do so that you can decide whether or not to be in the study. Your participation is voluntary. You do not have to be in the study if you do not want to. You may refuse to be in the study and nothing will happen. If you do not want to continue to be in the study, you may stop at any time without penalty or loss of benefits to which you are otherwise entitled.

WHY IS THIS STUDY BEING DONE?

The purpose of this research is to use metacognitive monitoring feedback and real-time location system (RTLS) to improve engineering education in augmented reality (AR) environment. To create an effective AR environment, we used Microsoft HoloLens, which is the next generation of a see-through holographic computer. Near field electromagnetic ranging (NFER) system was applied to create the real-time locating system. From the previous experiment (IRB #2008736), we knew that AR changes the way students understand the concepts in a spatial environment and improve student learning performance in manual material handling contents. In this experiment, we developed the real-time locating AR learning module: ergonomic guidelines for biomechanics.

HOW MANY PEOPLE WILL BE IN THE STUDY?

About 30 people will take part in this study from IMSE 4110/7110 Engineering Statistics class.

WHAT AM I BEING ASKED TO DO?

Step1: Before the experiment, you will be asked to fill the demographic questionnaire and take a pretest to determine if you are able to handle the augmented reality environment and if you have the similar experience on simulation task in the past. Step 2: A general orientation briefing will be provided at the beginning of the experiment which covers the information including the introduction to the simulation, user interface, and your role in the tasks. It is expected to last 15 minutes. During the training session, you will experience training designed by power point slides which contain how to fit the HoloLens to get the best view, scenes in HoloLens. You must understand how to switch to the previous or next scene to learn biomechanics knowledge. Step 3: After being trained, you undergo the experimental test session with 14 different scenes. The experiment test will take 70 minutes for every participant learning materials. During the experiment, you will also be asked to complete 12 questions about biomechanics. Step 4: After the experiment, you will have a NASA-TLX workload which has six questions about the more important contributor to workload for this task. So the total time is expected to last one and a half hours.

HOW LONG WILL I BE IN THE STUDY?

This study will take approximately one and a half hours to complete subject experience level questionnaires, the training, 14 scenes learning materials, NASA TLX rating test. You can stop participating at any time without penalty.

WHAT ARE THE BENEFITS OF BEING IN THE STUDY?

Your participation will benefit the development of augmented reality application in engineering education. We expected that students have higher learning performance and efficiency compared to traditional learning.

WHAT ARE THE RISKS OF BEING IN THE STUDY?

This study involves no risks to your physical or mental health beyond those encountered in the normal course of everyday life. In participating in this research, you may experience minimal fatigue from working at the computer. You are free to take a break at any time during the experiment if necessary.

WHAT ARE THE COSTS OF BEING IN THE STUDY?

There is no cost to you.

WHAT OTHER OPTIONS ARE THERE?

Instead of being in this study, you have the alternative assignment option: literature review paper. You need to read one piece of 3-5 pages journal article about augmented reality and write two pages of summary. You also have the option of not participating in this study and will not be penalized for your decision.

CONFIDENTIALITY

Information produced by this study will be stored in the investigator's file and identified by a code number only. The code key connecting your name to specific information about you will be kept in a separate, secure location. Information contained in your records may not be given to anyone unaffiliated with the study in a form that could identify you without your written consent, except as required by law. A statement that the subject's information collected as part of the research, even if identifiers are removed, will not be used or distributed for future research studies.

WILL I BE COMPENSATED FOR PARTICIPATING IN THE STUDY?

You will receive 1.5 extra points on your final score in IMSE 4110/7110 Engineering Statistics class. Even participants who withdraw from a research study will receive the course credit that can be prorated for the time the participant spent in the study. For example, if the task is expected to take one hour, and the participant participated for a half hour then they would get 0.5 point for course credit.

WHAT ARE MY RIGHTS AS A PARTICIPANT?

Participation in this study is voluntary. You do not have to participate in this study. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive otherwise. Your decision to be in this research is voluntary. You will also be informed of any new information discovered during the course of this study that might influence your health, welfare, or willingness to be in this study.

WHO DO I CONTACT IF I HAVE QUESTIONS, CONCERNS, OR COMPLAINTS?

If you want to talk privately about your rights or any issues related to your participation in this study, you can contact University of Missouri Research Participant Advocacy by calling 888-280-5002 (a free call), or emailing MUResearchRPA@missouri.edu. Also, you can contact Dr. Jung Hyup Kim (kijung@missouri.edu) at (573)884-0354 if you have questions about the research. Additionally, you may ask questions, voice concerns or complaints to the research team.

WHOM DO I CALL IF I HAVE QUESTIONS OR PROBLEMS?

You can also contact the MU IRB contact information 573.882.3181or emailing MUResearchRPA@missouri.edu. For questions about the study or a research-related injury, contact Dr. Jung Hyup Kim (kijung@missouri.edu) at (573)884-0354.
A copy of this Informed Consent form will be given to you before you participate in the research.

SIGNATURES

I have read this consent form and my questions have been answered. My signature below means that I do want to be in the study. I know that I can remove myself from the study at any time without any problems.

Subject

Date

IRB Approved Date 12/20/2019

3. NASA-TLX Cognitive Workload Questionnaire

NASA Task Load Index

Hart and Staveland’s NASA Task Load Index method assesses the workload on six scales (1-100). Circle the value and evaluate your workload after the experiment.

ID #:	**Date:**

Mental Demand

How mentally demanding was the task?

1 10 20 30 40 **50** 60 70 80 90 **100**

Very Low Average Very High

Physical Demand

How physically demanding was the task?

1 10 20 30 40 **50** 60 70 80 90 **100**

Very Low Average Very High

Temporal Demand

How hurried or rushed was the pace of the task?

1 10 20 30 40 **50** 60 70 80 90 **100**

Very Low Average Very High

Performance

How successfully were you in accomplishing what you were asked to do?

1 10 20 30 40 **50** 60 70 80 90 **100**

Very Low Average Very High

Effort

How hard did you have to work to accomplish your level of performance?

1 10 20 30 40 **50** 60 70 80 90 **100**

Very Low Average Very High

Frustration

How insecure, discouraged, irritated, stressed, and annoyed were you?

1 10 20 30 40 **50** 60 70 80 90 **100**

Very Low Average Very High

Sources of Workload Comparison Cards

(Circle the more important item)

Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any correct pattern, we are only interested in your opinions.

Effort Or Performance	Temporal Demand Or Frustration	Frustration Or Effort	Performance Or Mental Demand
Temporal Demand Or Effort	Physical Demand Or Frustration	Performance Or Temporal Demand	Mental Demand Or Effort
Performance Or Frustration	Physical Demand Or Temporal Demand	Mental Demand Or Physical Demand	Effort Or Physical Demand
Physical Demand Or Performance	Temporal Demand Or Mental Demand	Frustration Or Mental Demand	

VITA

Wenbin Guo is a Ph.D. candidate in the Industrial and Manufacturing Systems Engineering (IMSE) Department at the University of Missouri. He obtained his M.S. degree in Industrial Engineering at the University of Missouri in 2016 and acquired his B.E. in Industrial Engineering at Zhejiang Sci-Tech University in 2014. His research focuses on human-computer interaction, metacognition, and healthcare. He uses HoloLens to develop advanced augmented reality learning environments to improve users' spatial recognition and learning performance. He is interested in human cognition research and hopes to continue to explore the benefits of metacognition. He is also motivated to improve personnel performance in the healthcare system. He was so glad to join the Mizzou family. Once a Tiger, always a Tiger!