IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received September 14, 2018, accepted October 18, 2018, date of publication October 26, 2018,
date of current version November 30, 2018.

Digital Object Identifier 10.1109/ACCESS.2018.2878270

The Effects of Immersion and Interactivity on College Students' Acceptance of a Novel VR-Supported Educational Technology for Mental Rotation

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This research was supported by Beijing Xijia Great Education Technology Co., Ltd.

ABSTRACT The current experimental study examined whether different degrees of immersive and interactive experience made a difference in users' perceptions and intention to adopt a novel VR-based MR training system. In this paper, virtual reality was used as an educational technology that allowed users to virtually rotate 3-D objects and helped to enhance their spatial ability, which would be particularly useful in future careers in STEM. A 2 (display) × 2 (controller) × 2 (gender) experimental design was conducted. Researchers used a 2-D monoscopic display and a stereoscopic display to manipulate two different conditions of immersion, while a computer mouse and a hand-held controller were applied to measure the effects from two different levels of interactivity. Gender was examined due to prior research suggesting that males were better at MR tasks than females. The dependent variables were various perceptions and behavioral intentions developed from relevant theories in technology acceptance. The results showed that users' positive perceptions and intention to use the novel MR system were amplified whenever better immersive and interactive experiences were provided simultaneously, or when the inferior immersive and interactive experiences were offered at the same time. Females under a better immersive environment perceived better feelings of enjoyment, confirmation, satisfaction, and behavioral intention, compared with their male counterparts. Theoretical contributions in perceptions and use intention of educational technology, with a specific focus on VR, were discussed. Practical implications for developers of educational technology and K-12/college educators were provided.

INDEX TERMS Virtual reality, educational training technology, immersion, interactivity, technology acceptance.

I. INTRODUCTION

Mental rotation (MR) is an individual's spatial ability to mentally rotate an object and identify its 3-dimensional traits [1]. An individual's MR ability influences his/her performance in areas requiring science, technology, engineering, and mathematics (STEM) or relevant professions in medical, engineering, and artistic fields [2]. There are certain approaches to train MR ability. The most common approach is traditional paper and pencil-based training in which trainees are provided with 3-dimensional objects and are asked to mentally rotate them to match a replicate with different geometric forms on a 2-dimensional sheet. Video games, such as Tetris, provide trainees an alternative way to complete MR tasks by allowing players to rotate the objects on a 2-dimensional plane. The outcomes of MR training are usually measured by the accuracy and time spent for individual MR tasks. The shorter the time spent for each task, the better spatial ability the trainee has. Previous studies generally support the utility of training, such that MR performance enhances after training [3]. Studies have also suggested that men are likely to outperform women on spatial tasks, such as MR [4]–[7].

Since MR ability is directly related to one's performance in STEM and relevant professions, there is a need, especially in K-12 and college education, to consider incorporating MR training into the regular curriculum. One potential outcome is in equalizing the gender imbalance in spatial ability. In the wake of new educational technology and systems, novel ways to train MR ability are now readily available. For example, virtual reality (VR) technology encompassing stereoscopic 3D image and physical motion control provides virtual experience and immediate feedback to the users, which makes the training experience more immersive and interactive. Although studies have suggested that VR technology enhances MR ability [2], [8], whether VR technology affects one's intention to accept the new MR training system is still unclear. The current study, therefore, intends to investigate how the features of VR technology (e.g., immersion and interactivity) influence users' adoption intention of the newly invented MR training system. The goals of this study are to: 1) examine how immersion and interactivity affect users' perceptions and intention to use the VR-supported MR training system, 2) provide theoretical implications to the psychological outcomes of technology adoption, with a specific focus on VR educational technology, and 3) offer practical implications to educators and educational technology developers. Directions of future research are also provided.

II. IMMERSIVE AND INTERACTIVE VIRTUAL EXPERIENCE FOR LEARNING

The concept of immersion can be traced back to Flow Theory proposed by [9], which describes a psychological state where one is fully immersed in an activity. Under the state of immersion, the person is so focused on the interested activity that he/she is unconscious of other distractions and temporarily loses focus on other unrelated stimuli. Recent technology, such as 360-degree video and VR head-mounted displays (HMD), has made immersive environments accessible to users. On the other hand, interactivity is derived from the relationship between users and the information system being used. Following the advent of motion controllers, such as those used by the Nintendo Wii, Sony PlayStation Move and PS3, and Microsoft's XBOX360 Kinect, users are capable of interacting with the system intuitively and with immediate feedback. VR technology, due to its simulated ability, has been applied to video games and educational training programs and has received attention in recent research (e.g. [10]–[12]). For digital learning, VR creates an environment similar to that in real life. Through this simulated reality, learners are more likely to concentrate on the training activity and, therefore, receive better training results (e.g., [8]).

Although prior studies have suggested that VR technology could enhance users' learning outcomes, how the virtual experience influences learners' psychological responses and intention to use the novel educational technology itself is still unclear. To better understand the effects of immersion and interactivity on the acceptance of VR educational technology, the current research team created a novel MR training system to assist trainees in the completion of MR tasks. MR objects and the representations of each object's 3-dimensional traits were compared to those created for paper-based training activities. The trainees were capable of rotating the controlled object to match the target object within the VR. To increase immersive experience, trainees opted to use either a 2D monoscopic display (less immersive) or stereoscopic display (more immersive), which both enhanced the perception of visual stimuli and the mental coding processes involved in training. At the same time, trainees were provided with either a computer mouse (less interactive) or a 6-degrees-of-freedom (6-DOF) handle controller (more interactive) to accomplish the tasks, both of which offered interactive experience between their rotation behavior and the feedbacks of the system (for the details of system mechanism, see Figure 1).

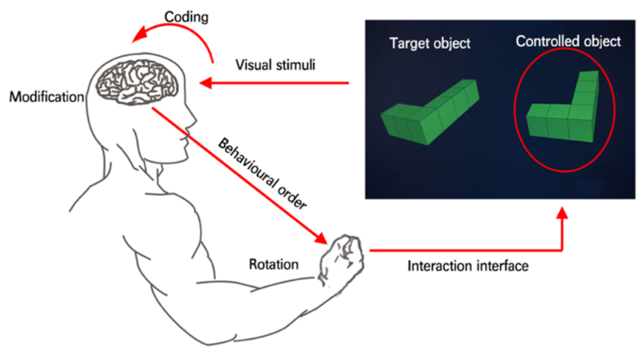

FIGURE 1. The mechanism of a novel VR-based MR training system.

III. RESEARCH FRAMEWORK

This study aims at exploring the effects of immersive and interactive experiences on users' various perceptions and use intention driven from prior literature and theories. A research question for gender differences in MR system adoption, based on the assumption that young males are better at MR tasks and more interested in emerging technologies than females, is also proposed.

A. PERCEIVED USEFULNESS (PU), PERCEIVED EASE-OF-USE (PEOU), AND ATTITUDE

According to the Technology Acceptance Model (TAM; [13]), perceived usefulness (i.e., users' perception regarding whether the use of a specific technology would be advantageous for a task, job, or in their everyday lives) and perceived ease-of-use (i.e., whether the adoption of a new technology is effortless) are the two main factors affecting user' attitude toward a specific technology. Because attitude serves as a strong predictor for behavioral intention, it is explicit that PU and PEOU play crucial roles in technology acceptance. Besides, TAM suggests that PU directly affects users' intention to adopt an information system. Users who regard a new technology as being useful are more prone to adopt it. A prior study has verified that users perceive immersive and interactive experience to be useful while conducting MR tasks [2]. Since the VR-supported MR training system provides users better representations of 3-dimensional MR objects and the ability to virtually rotate the MR objects, the current study believes that the system with an advanced immersive and interactive design is perceived to be more effortless to use, especially when compared to less advanced VR-supported or traditional paper-based MR tasks. Based on the rationale above, the current study hypothesizes that immersive and interactive experiences of VR technology would have an effect on PU, PEOU, and attitude toward the MR training system.

B. PERCEPTIONS OF INTERNAL CONTROL TOWARD THE SYSTEM

Perception of internal control, or computer self-efficacy, similar to the concept of perceived behavioral control from Theory of Planned Behavior [14], is users' belief in whether they are capable of using a new information system [15]. Venkatesh suggests that perceptions of internal control serve as the predictor of perceived-ease-of-use [15]. Early literature also found that computer self-efficacy directly affects intention to adopt computer systems [16]. Because the VR-supported MR training system provides users with a virtual experience and human-computer interaction, the actual level of immersion and interactivity would likely affect users' perception of visual stimuli and control over the system in accomplishing each task. Therefore, this study assumes that better immersive and interactive design would enhance users' perceptions of internal control toward the MR training system.

C. PERCEIVED ENJOYMENT

Researchers suggest that users' hedonic motivation (i.e., perceived enjoyment) also, not only utilitarian motive, serves as the determinant for intention to adopt a computer system [17]. In the context of MR training, an early study has shown that stereovision and motion control together provide users with a better perceived enjoyment while conducting MR tasks, compared to a condition that stereovision and interactivity are absent [2]. The current study, therefore, reasonably hypothesizes that the same positive effect on perceived enjoyment exists, when a higher level of immersive and interactive experience is provided via the VR-supported MR training system.

D. CONFIRMATION AND SATISFACTION

According to Expectation and Confirmation Theory of IS (information system) Continuance [18], how the performance of an information system lives up to users' expectation would predict users' satisfaction of IS use and, in turn, influence their continuance of the IS system. Due to the nature of a VR-supported system, users would naturally expect to have an advanced virtual experience. When their experience confirms the expectation, they are likely to show intention to use the system. Hence, this study assumes that immersive and interactive MR experience would influence the degree of confirmation of users as well as their satisfaction with the MR system.

E. INTENTION TO USE

In behavioral science, intention serves as the strong predictor of actual behavior. Because of this reason, prior research on the acceptance of novel information systems usually concern about reasons influencing intention to adopt/use a new information technology. Similarly, in this study we regard intention to use as the dependent factor and test how other variables interact with it. The conditions described above (e.g., PU, attitude, perceived enjoyment, satisfaction, etc.) serve as the predictors of intention to use, according to the aforementioned theories and models of technology acceptance. If there are effects from immersion and interactivities on these perceptions, the intention to use technology should also be predicted by the degree of VR experience. This study, therefore, hypothesizes that immersive and interactive experiences improve users' behavioral intention to use the MR system.

F. GENDER DIFFERENCE IN TECHNOLOGY ADOPTION

Gender serves as a crucial factor in MR-related research. Prior studies about mental rotation have found that male students are better at spatial ability than female students (e.g., [19]). In addition, there is a gender difference in technology acceptance. Younger men are often the early adopters of new technology compared to their female counterparts [20]. Since men and women perform differently in MR and technology adoption, it would be plausible to assume that the same difference holds true in their perceptions and intention to use a new MR training system. Accordingly, the present researchers propose a research question for gender difference.

G. HYPOTHESES AND RESEARCH QUESTION

Based on the literature discussed above, the current study proposes the following hypotheses and research question:

H1a: The stereoscopic 3D display is more effective than the 2D monoscopic display in improving trainees' subjective evaluations of the MR training system (i.e., 1. perceived usefulness, 2. perceived ease-of-use, 3. positive attitude, 4. perceptions of internal control toward the system, 5. perceived enjoyment, 6. confirmation, 7. satisfaction, and 8. behavioral intention to use the system).

H1b: The 6-DOF handle controller is more effective than the computer mouse in improving trainees' subject evaluations of the MR training system.

H1c: The type of controller moderates the effects of the stereoscopic 3D display on trainees' subjective evaluation of the MR training system.

RQ: Would there be a gender difference in the DVs?

IV. METHOD

To test the hypotheses and address the research question, a mental rotation experiment was conducted in a large-scale research university in Shanghai, China in January 2018.

A. STIMULI

The stimuli used in this study was developed based on the mental rotation tasks created by [21]. The research team created two sets of MR tasks based on 2D and stereoscopic displays. Users were capable of freely rotating the controlled object on one side of the screen, either by a computer mouse or handle controller, and dragging the controlled object to the other side of the screen in order to match the target object, which was exactly the same but in a different geometric form. Once the two objects perfectly matched, the participant accomplished the task (see Figure 1 for mechanism details). Twelve tasks were created for each condition. Figure 2 and Figure 3 demonstrate four different combinations of VR technologies applied to each experimental condition.

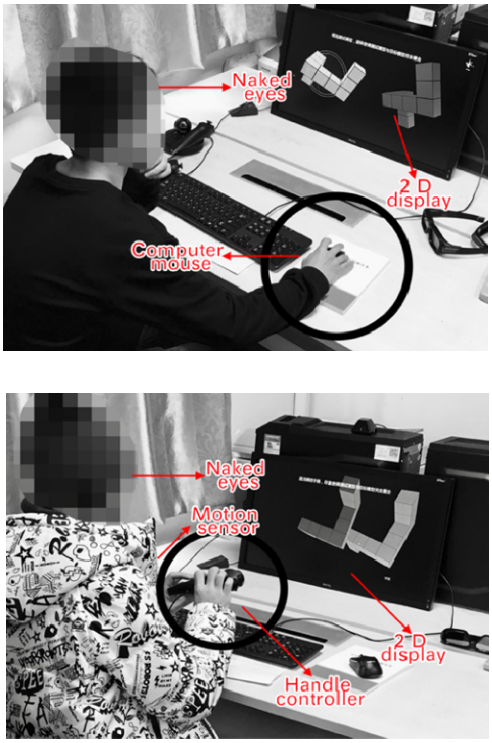

FIGURE 2. MR tasks designed for the 2D display and computer mouse/handle controller.

B. EXPERIMENTAL DESIGN

A 2 (display) × 2 (controller) × 2 (gender) factorial design was used to measure the effects of different immersive and interactive MR training experiences. Two different displays (i.e., 2D monoscopic display vs. stereoscopic display) represented two different levels of immersion, with the assumption that the stereoscopic display provided a better immersive experience, similar to the design of study by [22]. On the other hand, two different controllers (i.e., computer mouse vs. 6-DOF handle controller) were used to measure the effect of interactivity, with the handle controller being more interactive than the traditional computer mouse. To control for the effect of gender difference, gender was included as the third factor

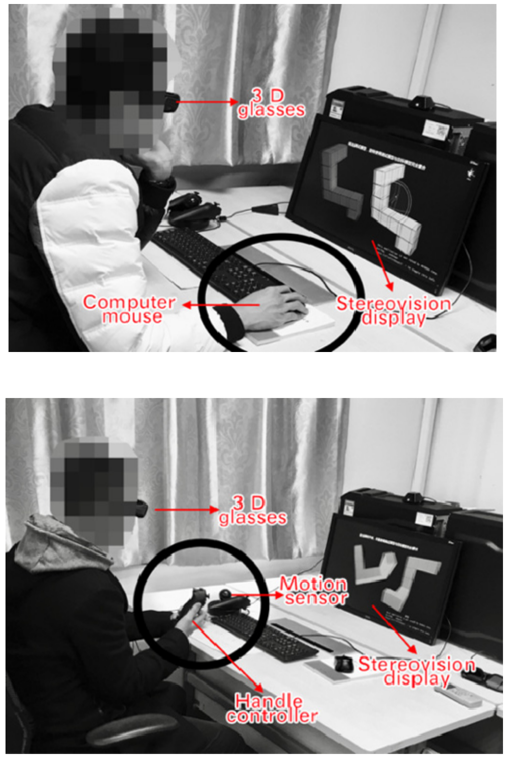

FIGURE 3. MR tasks for the stereoscopic display and computer mouse/handle controller.

in the experimental design. The DVs measured several of the participants' perceptions and their intention to adopt the MR training systems.

C. MEASUREMENT OF DEPENDENT VARIABLES

All DVs were measured by scales borrowed and revised from prior studies (see Table 1). Perceived usefulness, perceived-ease-of-use, perceived enjoyment, confirmation, and behavioral intention to use were measured by a 7-point Likert scale (1: strongly disagree; 7: strongly agree). Perception of internal control was measured by a 10-point Likert scale (1: not at all confident; 10: totally confident). Attitude and satisfaction were measured by a 7-point semantic scale. Basic demographic information, including age, gender, educational level, traditional/international student, major, and prior experience with MR training, were also collected.

D. PARTICIPANTS AND PROCEDURE

A total of 111 students were recruited from a large-scale research university in Shanghai, China. To control the effect of gender on each condition, an equal number of male and female was assigned to each condition (condition 1: 27 females and 28 males; condition 2: 27 females and 28 males; condition 3: 27 females and 29 males; condition 4: 27 females and 29 males). They were rewarded 10 RMB (about 1.5 US dollars) for their participation.

Upon arrival at the MR lab, participants were asked to fill out a form asking basic personal information and were then

TABLE 1. Measurement scales and dependent variables.

Psychometric Construct (Variable)	Items (Questions Asked)	Measurement Reference(s)	Coefficient of Reliability (Cronbach's alpha)
Perceived Usefulness (PU)	1. I could improve my task performance by using this MR system. 2. I could enhance my task proficiency by using this MR system. 3. I could increase my task productivity by using this MR system. 4. I think using this MR system helps me accomplish the tasks.	[23]	0.809
Perceived-Ease-of-USE (PEOU)	1. My interaction with this MR system was clear and understandable. 2. Interacting with this MR system did not require a lot of my effort. 3. I found this MR system to be easy to use. 4. I found it easy to get this MR system to do what I want it to do.	[15]	0.668
Attitude	1. Using this MR system is a good/bad idea. 2. Using this MR system is a wise/foolish idea. 3. I like/dislike the idea of using this MR system. 4. Using this MR system would be: unpleasant/pleasant.	[24]	0.796
Perceived Enjoyment	1. I found using this MR system to be enjoyable. 2. The actual process of using this MR system was pleasant. 3. I had fun using this MR system.	[17]	0.822
Perceptions of Internal Control	Assuming I had this MR system…. I could complete the MR tasks…. 1. if there was no one around to tell me what to do as I go. 2. if I had never used a system like it before. 3. if I had only the manuals for reference. 4. if I had seen someone else using it before trying it myself. 5. if I could call someone for help if I got stuck. 6. if someone else had helped me get started. 7. if I had a lot of time to complete the job for which the system was provided. 8. if I had just the built-in help facility for assistance. 9. if someone showed me how to do it first. 10. if I had used similar systems before this one to do the same job. (1-10 Likert-Scale: Not at all confident <-> Totally Confident)	[15] (borrowed and revised from [25] [26])	0.934
Confirmation	1. My experience with using this system was better than what I expected. 2. The service level provided by the system was better than what I expected. 3. Overall, most of my expectations from using the system were confirmed.	[18]	0.772
Satisfaction	How did you feel about your overall experience of this MR system? 1. Very dissatisfied/Very satisfied. 2. Very displeased/Very pleased. 3. Very frustrated/Very contented. 4 Absolutely terrible/Absolutely delighted.	[18]	0.868
Behavioral Intention to Use	1. Assuming I had access to this MR system, I intend to use it. 2. Given that I had access to this MR system, I predict that I would use it.	[15]	0.772

randomly assigned to either conditions (e.g., the 2D display or stereoscopic display). Prior to conducting MR tasks, they were asked to watch an instructional video that showed an introduction to mental rotation and guidance for using the training technology. The participants were then invited to familiarize themselves with the MR system by performing 2 practice tasks; afterward, they were asked to conduct a total of 12 formal and more complex MR tasks. Once the participants completed all the tasks, they were asked to fill out an online questionnaire. Each participant repeated the same procedure for two conditions (i.e., computer mouse/handle controller). To prevent potential order effects, counterbalanced order was applied for the repeated measures. The entire process for each participant took 25-30 minutes.

V. RESULTS

A. QUESTIONNAIRE ANALYSIS

To investigate a three-way interaction effect among the display (2D vs. stereovision), controller (computer mouse vs. 6-DOF handle controller) and gender in explaining trainees' subjective evaluations, several three-way analyses of variance (ANOVAs) were conducted. Each 2 x 2 x 2 ANOVA was a between-within mixed-design, with the type of display (i.e. 2D vs stereovision) and gender as between-subjects variables and the type of controller (i.e. computer mouse vs handle controller) as a within-subjects variable. Trainees' evaluations on the mental rotation training system included the following aspects: perceived usefulness (PU), perceived ease-of-use (PEOU), attitude, perceptions of internal control (PIC), perceived enjoyment (PE), confirmation, satisfaction, and behavioral intention to use (BIU).

B. PERCEIVED USEFULNESS (PU)

The results of ANOVA indicated that there were no significant main effects of type of display, type of controller, or gender. However, type of display significantly interacted with type of controller, $F(1, 107) = 43.293$, $p < 0.001$, partial $\eta 2 = 0.288$. This effect showed that users' ratings of perceived usefulness on different type of controller were affected differently by the type of visual display. Further simple effects analyses were conducted to break down this interaction, looking at the effect of type of display on the usage of a mouse and handle controller. The results of ANOVA revealed that the level of perceived usefulness across dimensions of display was significantly different for the usage of a handle controller [$F(1, 107) = 15.037$, $p < .001$] and the usage of a mouse [$F(1, 107) = 13.976$, $p < .001$]. Specifically, users perceived that the handle controller was more useful on MR tasks when using the stereoscopic display (M = 6.058, SD = 0.938), compared to that with the 2D display (M = 5.264, SD = 1.216); in contrast, users believed that a traditional mouse would be more useful in the 2D (M = 5.923, SD = 0.961), relative to the stereoscopic (M = 5.063, SD = 1.406), visual environment. Last, no other two-way interactions or three-way interaction were found.

C. PERCEIVED EASE-OF-USE (PEOU)

Another user perception on technology, perceived ease-of-use, was investigated by using the three-way ANOVA. The results showed that there were no significant main effects of all three factors. On the other hand, the significant interaction between type of display and type of controller was found, $F(1, 107) = 67.169$, $p < 0.001$, partial $\eta 2 = 0.386$, indicating that the different levels of ease-of-use were perceived across different types of controller for the 2D and stereovision of visual learning environment. To further examine the source of this interaction, simple effects analyses were conducted. The results of ANOVA showed that the significantly increased perceived ease-of-use in the stereoscopic compared to 2D visual learning environment was found for the condition of handle controller, $F(1, 107) = 28.214$, $p < 0.001$; contrarily, the significantly increased perceived ease-of-use in the 2D compared to stereoscopic visual learning environment was found when the mouse was used, $F(1, 107) = 25.401$, $p < 0.001$. This interaction effect implied that the higher ratings of perceived ease-of-use were perceived for the condition that a handle controller with a stereoscopic visual environment were used (M = 5.844, SD = 0.811); otherwise, the higher perceived ease-of-use was found for the condition that a computer mouse was accompanied by a 2D visual environment (M = 5.786, SD = 0.932). No further significant effects were found.

D. ATTITUDE

A $2 \times 2 \times 2$ mixed-design factorial ANOVA was conducted to examine the effect of display and controller on trainees' attitude toward the MR system. Among the insignificant results of main effects and insignificant three-way interaction effect, only one two-way interaction effect between type of controller and type of visual display was statistically significant, $F(1, 107) = 121.087$, $p < 0.001$, partial $\eta 2 = 0.531$. This effect indicated that the type of controller had an effect on the level of attitude toward the MR training system, depending on which type of visual display was adopted alongside. To verify the details of this interaction effect, additional simple effects analyses were used. The results of ANOVA revealed that the degree of attitude was significantly higher when the handle controller was used under the stereoscopic visual learning environment (M = 5.970, SD = 0.735), $F(1, 107) = 62.575$, $p < 0.001$. In contrast, trainees believed that a traditional mouse was more useful in the 2D (M= 5.873, SD = 0.929), $F(1, 107) = 24.080$, $p < 0.001$, relative to stereoscopic (M = 4.795, SD = 1.364), visual environment.

E. PERCEPTION OF INTERNAL CONTROL TOWARD THE SYSTEM

To examine the effects from different displays and controllers on trainees' perceived internal control toward the MR system, a $2 \times 2 \times 2$ three-way ANOVA was conducted. The results showed that only one two-way interaction effect of type of controller and type of display was detected, $F(1, 107) = 28.227$, $P < 0.001$, partial $\eta 2 = 0.209$. This indicated that trainees' response of perceived internal control on different types of controller were affected differently by the type of visual display. To better understand the details of this two-way interaction effect, simple effects ANOVA analyses were conducted. The results revealed that the degree of perceived internal control across different type of display was significantly different for the use of a handle controller [$F(1, 107) = 6.835$, $p < .05$] and computer mouse [$F(1, 107) = 5.304$, $p < .05$]. Trainees using the handle controller perceived better internal control toward the MR system while using a stereoscopic display (M= 6.398, SD = 0.601), compared to that with a 2D display (M = 6.069, SD = 0.743); in contrast, trainees adopting the computer mouse believed that they had a better control over the system in the 2D (M = 6.355, SD = 0.617), relative to stereoscopic (M = 6.054, SD = 0.760), visual display. No other main effects, two-way interaction, or three-way interaction effects were found.

F. PERCEIVED ENJOYMENT (PE)

In addition to perceived usefulness and perceived ease-of-use as examples of extrinsic motivation to perform an activity, perceived enjoyment, similar to attitude, was recognized as an intrinsic motivation [17]. Because of a significant effect of enjoyment on usage behavior [17], the effects of type of controller, type of visual display, and gender difference on users' ratings of perceived enjoyment was investigated by a $2 \times 2 \times 2$ mixed-design factorial ANOVA. Except for two significant interaction effects, no other main effects, two-way interaction, or three-way interaction effects were found. Following the same pattern of the pervious results, the significant interaction effect showed that type of controller interacted with different visual learning environment, $F(1, 107) = 115.301$, $p < 0.001$, partial $\eta 2 = 0.519$. This effect implied that the influence of type of controller on perceived enjoyable feeling depended on the type of visual learning environment. To further break down the source of interaction effects, simple effects analyses were adopted. First, the results revealed that the significantly higher perceived enjoyment for the usage of a handle controller was under the stereoscopic visual learning environment ($M = 6.066$, $SD= 0.863$) than under the 2D visual learning environment ($M = 4.661$, $SD = 1.274$), $F(1, 107) = 46.970$, $p < 0.001$; besides, the other ANOVA results indicated that the significantly higher perceived enjoyment for the usage of a mouse was under the 2D visual learning environment ($M = 5.861$, $SD = 1.020$), than under the stereoscopic visual learning environment ($M = 4.881$, $SD = 1.339$), [$F(1, 107) = 18.645$, $p < 0.001$]. Additionally, the second significant interaction effect between gender and type of display was found, $F(1, 107) = 4.289$, $p < 0.05$, partial $\eta 2 = 0.039$, revealing that the ratings of perceived enjoyment across different type of visual learning environments were different for men and women. The results of the further ANOVA examining the source of the interaction effect showed that female users had significant higher ratings of perceived enjoyment, $F(1, 107) = 5.235$, $p < 0.05$, in the stereoscopic visual environment ($M = 5.667$, $SD = 1.011$) than in the 2D visual environment ($M = 5.062$, $SD = 1.091$).

G. CONFIRMATION

A $2 \times 2 \times 2$ mixed-design factorial ANOVA was conducted to examine the effect of visual display and controller on trainees' degree of confirmation. Except for two significant two-way interaction effects, no other main effects, two-way interaction effect, or three-way interaction effect were found. The first significant interaction effect showed that type of controller interacted with different type of visual display, $F(1, 107) = 96.263$, $P < 0.001$, partial $\eta 2 = 0.474$. This effect implied that the influence of type of controller on perceived confirmation depended on the type of visual display. To break down the source of interaction effects, simple effects analyses were adopted. The results revealed that there was a significantly higher perceived confirmation for the usage of a handle controller, whenever it was under the stereoscopic visual learning environment ($M = 5.869$, $SD = 0.968$) than under the 2D visual learning environment ($M = 4.370$, $SD = 1.386$), $F(1, 107) = 45.019$, $p < 0.001$; besides, the other ANOVA results indicated that there was a significantly higher perceived confirmation for the usage of a computer mouse, whenever it was under the 2D visual learning environment ($M = 5.630$, $SD = 1.018$), than under the stereoscopic visual learning environment ($M= 4.512$, $SD= 1.452$), [$F(1, 107) = 22.265$, $p < 0.001$]. Additionally, the second significant interaction effect between gender and visual learning environment was found, $F(1, 107) = 7.174$, $P < 0.01$, partial $\eta 2 = 0.063$, revealing that the level of perceived confirmation across different type of visual display was different for men and women. The results of the further ANOVA examining the source of the interaction effect showed that female users had significant higher responses of confirmation, $F(1, 107) = 6.923$, $p < 0.5$, in the stereoscopic visual environment ($M = 5.444$, $SD = 0.990$) than in the 2D visual environment ($M = 4.741$, $SD = 1.312$).

H. SATISFACTION

To examine the effects from different displays and controllers on trainees' satisfaction with the MR system, a $2 \times 2 \times 2$ mix-design ANOVA was conducted. The results showed that the two-way interaction effect of type of controller and type of display was detected, $F(1, 107) = 76.550$, $P < 0.001$, partial $\eta 2 = 0.417$. This indicated that trainees' response of satisfaction on different types of controller were affected differently by the type of visual display. To better understand the details of this two-way interaction effect, simple effects ANOVA analyses were conducted. The results revealed that the degree of satisfaction across different types of display was significantly different for the use of a handle controller [$F(1, 107) = 33.849$, $p < .001$] and computer mouse [$F(1, 107) = 10.366$, $p < .01$]. Trainees adopting the handle controller had a better satisfaction with the MR system while using the stereoscopic display ($M = 5.781$, $SD = 1.064$), compared to that with the 2D display ($M = 4.577$, $SD = 1.186$); in contrast, trainees had a higher degree of satisfaction with a traditional mouse in the 2D ($M= 5.600$, $SD = 1.420$), relative to the stereoscopic ($M = 4.728$, $SD = 1.407$), visual display. Additionally, the second significant interaction effect between gender and visual learning environment was found, $F(1, 107) = 6.217$, $P < 0.05$, ($p = 0.014$), partial $\eta 2 = 0.055$, revealing that the rating of satisfaction across different type of visual display was different for men and women. The results of the further ANOVA examining the source of the interaction effect showed that female users had significant higher satisfactions with the system, $F(1, 107) = 5.485$, $p < 0.05$, in the stereoscopic visual environment ($M = 5.519$, $SD = 1.121$) than in the 2D visual environment ($M = 4.819$, $SD = 1.116$). Last, no other main effects, two-way interaction, or three-way interaction effects were found.

I. BEHAVIOR INTENTION TO USE

The results of ANOVA indicated that there were no significant main effects of type of display, type of controller, or gender. However, type of display significantly interacted with type of controller, $F(1, 107) = 85.143$, $P < 0.001$, partial $\eta 2 = 0.443$. This result showed that users' behavioral intention on different types of controller were affected differently by the type of visual display. Further simple effects analyses were conducted to break down this interaction, examining the effect of type of display on the usage of a mouse and handle controller. The results of ANOVA revealed that the level of behavioral intention across dimensions of display was significantly different for the usage of a handle controller [$F(1, 107) = 38.403$, $p < .001$] and the usage of a mouse [$F(1, 107) = 14.770$, $p < .001$]. Specifically, users perceived that the handle controller leaded to a higher degree of behavioral intention to use the system when using the stereoscopic display ($M = 5.741$, $SD = 0.929$), compared to that with 2D display ($M = 4.335$, $SD = 1.524$); in contrast, users believed that a traditional mouse would lead to a higher level of behavioral intention in the 2D (M = 5.591, SD = 1.144), relative to stereoscopic (M = 4.633, SD = 1.595), visual environment. Additionally, the second significant interaction effect between gender and visual learning environment was found, $F(1, 107) = 19.500$, $P < 0.001$, partial $\eta 2 = 0.154$, suggesting that the rating of behavioral intention across different type of visual display was different for men and women. The results of the further ANOVA examining the source of the interaction effect showed that female users had a significant higher behavioral intention to use the system, $F(1, 107) = 14.889$, $p < 0.001$, in the stereoscopic visual environment (M = 5.546, SD = 1.005) than in the 2D visual environment (M = 4.435, SD = 1.390). In contrast, male users had a significant higher behavioral intention to use the system, $F(1, 107) = 5.602$, $p < 0.05$, in the 2D visual environment (M = 5.491, SD = 1.032) than in the stereoscopic visual environment (M = 4.828, SD = 1.384). Last, no other two-way interactions or three-way interaction were found.

VI. DISCUSSION

A. KEY FINDINGS AND INTERPRETATION

The current study examined whether different degrees of immersive and interactive experiences made a difference in users' perceptions and intention to adopt the VR-based MR training technology. Researchers used 2D monoscopic displays and stereoscopic displays to manipulate two conditions of immersion, while computer mice and handle controllers were used to measure the effect of two different levels of interactivity. The results suggested that the immersion x interactivity two-way interaction hypothesis was supported. The stereoscopic display was effective in enhancing participants' perceptions and usage intention for the MR training system when the handle controller was concurrently used with the display. Interestingly, the 2D display also enhanced participants' positive feedback to the MR system when the traditional mouse was used jointly. These findings suggested that the level of immersion needed to match that of interactivity in order to induce users' positive responses. In other words, users' perceptions toward and usage intention for the MR system was amplified when the immersive and interactive technologies were paired together appropriately. Regarding the gender differences, females displayed better psychological outcomes than males, including perceived enjoyment, confirmation, satisfaction, and behavioral intention, when the stereoscopic display was used. Males using the 2D display had higher behavioral intentions than females. Gender discrepancy in spatial ability might explain such differences.

B. THEORETICAL CONTRIBUTION

The empirical findings suggest that the variables drawn from relevant theories can be explained by the joint effect of immersion and interactivity. This study therefore expands our understanding of how adopting new technology (e.g., VR) into a MR training system would affect people's perceptions as well as usage intention for the education technology system.

Perceived usefulness, perceived ease-of-use, and attitude, which serve as the three crucial factors of technology adoption according to the Technology Acceptance Model, can be better understood. In this case, users perceive that the right combination of a display and controller is helpful in fulfilling their utilitarian needs and is more effortless to use while conducting MR tasks. These effects also reflect on their positive attitude toward the system. Therefore, the current study confirms that the use of VR-supported MR system affects PU, PEOU, and attitude. Likewise, either a combination of the stereoscopic display and handle controller or the concurrent use of the 2D display and computer mouse leads to better perceptions of internal control toward the system.

Aligning with prior literature on technology adoption, the current finding supports that an MR system applying VR educational technology ensures users' better perceived enjoyment. This empirical evidence extends the finding of [2] from a VR vs non-VR comparison to different degrees of immersion and interactivity in VR-supported systems. It also enriches the research area in users' hedonic motivation in adopting educational technologies, with a specific contribution in VR-supported interfaces.

Furthermore, the finding suggests that users have a better confirmation and satisfaction with the MR system under the circumstances that a set of technologies that matched is used. That is, when a right combination of immersive and interactive technologies is used simultaneously, users feel that the MR system matches their expectations better, and thus increases their satisfaction with the system. This helps explain the key constructs proposed by Expectation and Confirmation Theory of IS Continuance, specifically in the context of VR educational technology.

Most significantly, a higher degree of intention to use the MR system is attributed to the well-matched VR experiences. The theoretical contribution that the joint effect of perceived immersion and interactivity serving as the crucial predictor for MR system adoption sheds light on future research in creating a model explaining how the VR experience has direct and indirect effects (via prior discussed perceptions) on adopting relevant educational technologies.

The current study also extends prior literature regarding the gender difference in MR ability to the acceptance of MR training system. It is likely that women's relatively poor spatial ability leads them to hold a better psychological response in more immersive conditions. Future research should explore this potential causal effect and gauge the reason why immersion rather than interactivity plays an important role in women's specific psychological responses.

C. PRACTICAL IMPLICATIONS

The current study suggests that the VR experiences via the 2D monoscopic display/computer mouse or the stereoscopic display/handle controller would both enhance users' positive perceptions and intention to adopt the MR training technology. To ensure positive responses, including intention to use, VR technology developers must ensure the degrees of immersive and interactive experiences should be at the similar level, which is the key finding of the current experiment. Because female participants showed better psychological feedbacks when using the advanced immersive VR technology, this study therefore urges technology developers to continue refining advanced VR-compatible MR systems for the training of spatial ability. Possible innovations can focus on the head-mounted display, which completely separates the real and virtual realities, which might help enhance the immersive experience. Along with better immersion, another possibility for interactive design might be in developing motion sensors that rely completely on body movements, which might enrich the interactive experience. For educators, this study encourages K-12 schools/colleges to invest in the novel MR training system, so that students can benefit from its' training in spatial abilities useful for STEM professions. By adopting this VR educational technology, students would be more willing to do the MR practice, when the immersive and interactive technologies are paired appropriately. With its stereoscopic display, the system would also help reduce the gender imbalance in STEM majors in colleges as well as the practitioners in STEM related industries, as females had stronger positive responses toward the immersive system according to the results of this study.

D. LIMITATIONS AND FUTURE RESEARCH

As with any study, this study has its limitations. First, the participants are consisted of around 20 STEM students, who might possess better spatial ability. Future studies might consider controlling college major, a potential confounding variable in this study. Second, a lack of interactive design along the z-axis (i.e., depth) for the current MR training systems might have reduced the perceptions of immersive and interactive experiences. Future studies are therefore encouraged to develop a new MR training system using a motion sensor, allowing users to intuitively accomplish the tasks by moving themselves alongside the x-, y-, and z- axis, and retest the theories and variables gauged by the current study. Third, this study does not comprehensively test the theoretical models regarding the causation paths among various variables. Future studies capable of collecting a large sample size are encouraged in order to model the acceptance of a technologically advanced MR system.

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