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Effects of Wearable Hybrid AR/VR Learning Material on High School Students' Situational Interest, Engagement, and Learning Performance: the Case of a Physics Laboratory Learning Environment

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Abstract
This study investigates the effect of incorporating different learning materials (paper textbooks, wearable AR material, and wearable hybrid AR/VR material) in a physics laboratory education on the situational interest, engagement, and learning performance of high school students. The study utilized a quasi-experimental research design. The participants were 105 students, who were assigned to three groups: the traditional learning group, wearable AR group, and wearable hybrid AR/VR group. The instruments included a situational interest scale, an engagement scale, a learning performance test, and an open-ended questionnaire. The results showed that the situational interest and learning performance of the wearable hybrid AR/VR group were significantly higher, compared with that of the traditional learning group. The engagement of the wearable hybrid AR/VR group was significantly higher, compared with that of the other two groups. The wearable hybrid AR/VR material increased situational interest, engagement, and learning performance in the physical laboratory course. This study suggests that instructors can use wearable hybrid AR/VR to enhance situational interest, engagement, and learning performance among learners in science laboratory learning environments.

Keywords Wearable technologies · Augmented reality · Virtual reality · Situational interest · Engagement · Learning performance

Introduction

Compared with their growing entertainment applications, augmented reality (AR) and virtual reality (VR) have fewer applications in education (Statista, 2016), thereby suggesting their considerable development potential in this field. The use of AR and VR technologies will be applied for higher education (Johnson et al., 2016) and basic education (Adams Becker et al., 2016) in the near future. In particular, head-mounted display (HMD) provides features, such as simulation and first-person perspective, thereby enhancing engagement and presence, and hands-free access for operation (Bower & Sturman, 2015). The immersive experience created by combining wearable HMD, AR, and VR technologies can improve the learning performance and engagement of users by stimulating their senses, cognition, and emotion through visual and auditory feedback (Suh & Prophet, 2018).

Bajpai (2013) stated that laboratory teaching plays a key role in physics education because students can observe and understand various scientific phenomena in the experimental process. Studies have incorporated AR technologies in physics laboratory courses, including resistive electric circuits (Reyes-Aviles & Aviles-Cruz, 2018), general physics laboratory (Akçayır et al., 2016), and electromagnetism (Ibáñez et al., 2014) experiments, and noted significant improvements in learning performance. Therefore, we can examine the effects of immersive experiences created by combining AR and HMD on learning performance and engagement among students.

Virtual experiments can embody unobservable scientific phenomena and provide adapted instructions, providing

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more suitable learning content for different learning requirements (De Jong et al., 2013). Parong and Mayer (2018) applied immersive VR technology in biology courses, and their results showed that immersive VR can stimulate more interest among learners, compared with traditional media; however, it did not necessarily have an advantage in learning performance. However, empirical research studies regarding the use of immersive VR in education were insufficient (Parong & Mayer, 2018). Dede (2009) stated that the interface-shifting design based on multiple perspectives can enhance the immersive experience in the learning process, thereby promoting learning fluency and knowledge transfer. In an in-depth review of immersion technologies, Suh and Prophet (2018) suggested that the combination of wearable technologies, AR, and VR can shift between different immersive learning perspectives and environments. Therefore, this study aimed at examining the differing effects of wearable hybrid AR/VR on situation interest, engagement, and learning performance among high school students in a physics laboratory by combining wearable HMD technologies with AR and VR. The research framework is presented in Fig. 1. The following research questions are addressed in this study:

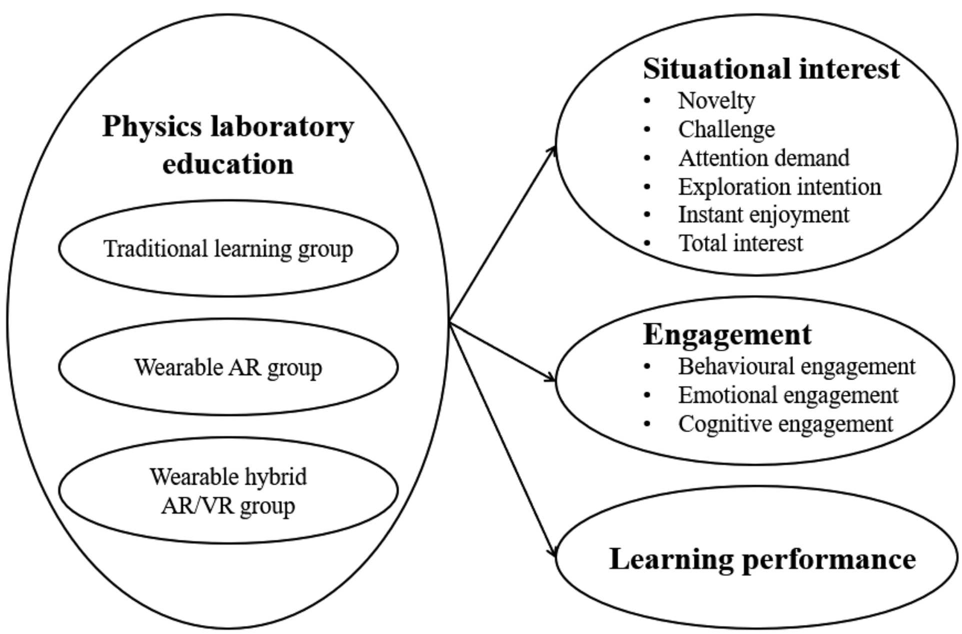
Question 1: Are there significant differences in situational interest (novelty, challenge, attention demand, exploration intention, instant enjoyment, and total interest) among high school students using traditional learning, wearable AR, and wearable hybrid AR/VR for learning physics laboratories?
Question 2: Are there significant differences in engagement (behavioral, emotional, and cognitive engagement) among high school students using traditional learning, wearable AR, and wearable hybrid AR/VR for learning physics laboratories?
Question 3: Are there significant differences in learning performance among high school students using traditional learning, wearable AR, and wearable hybrid AR/VR for learning physics laboratories?

Related Work

AR- and VR-Based Wearable Learning

Wearable technologies refer to wearable digital devices that seamlessly provide corresponding information and interactions through wireless networks (Bower & Sturman, 2015). Some studies have examined the application of wearable technologies in education (Chen et al., 2016; Clegg et al., 2017; Kang et al., 2016; Kuhn et al., 2016; Yu et al., 2019). Fung (2015) noted that the first-person perspective of experimental operation videos would allow students to observe the details of actual operations, and have improved memorization and understanding of the operation. Lindgren (2012) found that in comparison with the third-person perspective, the first-person perspective may substantially improve learning performance, promote the memorization of important tasks and key elements, and reduce the occurrence of errors. The wearable HMD technologies can provide the first-person perspective and enhance presence. The hands-free access facilitates operators to simultaneously receive commands and operation (Bower & Sturman, 2015). The results of a study by Suh and Prophet (2018) showed that immersive

Fig. 1 Research framework



technologies can promote creativity and engagement by enhancing the cognitive and emotional responses of users by stimulating their visual and auditory senses.

AR integrates and overlaps virtual information with the real world, and enables users to obtain additional information in the real environment (Chang et al., 2014), thereby increasing user interaction with and engagement in the context, as well as enhancing their immersive experience (Dunleavy et al., 2009). According to Kuhn et al. (2016), when Google Glass was used as the AR-based wearable, the results showed that in physics laboratory education, this approach substantially improved wondering and curiosity among students. Yu et al. (2019) noted that AR-based wearables could significantly improve students' learning performance and situational interest, whereas learning processes that serve to enhance memory can facilitate acquiring declarative knowledge (Hong et al., 2018). On the contrary, Di Serio et al. (2013) argued that the shaking of AR pictures may cause uncomfortable experiences, which may affect learning. VR creates virtual situations by simulating the real world, thereby allowing users to interact with virtual content in the virtual environment (Lee & Wong, 2014). Studies have also suggested that immersive VR technology can increase the sense of the presence of learning content (Makransky et al., 2017). Parong and Mayer (2018) suggested that immersive VR can improve the stimulation of learning motivation, interest, and engagement among students, compared with traditional media. Markowitz et al. (2018) applied a VR-based wearable to marine biology teaching to materialize abstract concepts and improve learning and interest among high school students. Therefore, this paper will discuss the application of wearable hybrid AR/VR in education, as well as the differences in the effects of various learning methods on situational interest, engagement, and learning performance among students.

Situational Interest

Renninger et al. (1992) classified interest into two types: situational interest and individual interest. Situational interest refers to the interest aroused by the learning situation or materials, whereas individual interest refers to the specific preferences of students regarding the subject or content. Chen et al. (1999) argued that situational interest can be aroused based on six dimensions—novelty, challenge, attention demand, exploration intention, instant enjoyment, and total interest—wherein instant enjoyment is most effective for enhancing situational interest and has a positive predictive power for total interest (Chen et al., 2001). Interest in science among teenagers tends to decline with every passing year (Barmby et al., 2008). Because this phenomenon has implications for subsequent science learning among students, it is important to improve the motivation for science learning among teenagers (Itzek-Greulich & Vollmer, 2017). A real laboratory environment is associated with higher situational interest among students and in comparison with students with high learning performance, those with low learning performance are more affected by the laboratory learning environment, due to their situational interest (Itzek-Greulich & Vollmer, 2017). Tapola et al. (2013) noted that for teaching circuit functions, concrete images in the virtual environment facilitated the enhancement of situational interest among students, thus indicating that the concrete presentation of abstract scientific concepts affected situational interest. Research has shown that AR-based wearables can substantially enhance situational interest, and situational interest was positively correlated to learning performance (Yu et al., 2019). Lin et al. (2019) indicated that wearable VR can improve learners' novelty. Parong and Mayer (2018) also concluded that immersive VR education technologies increased interest, engagement, and motivation among students, as well as their attention and interactions with the course.

Engagement

In the learning process, "acting without feeling engaged is just involvement or even compliance; feeling engaged without acting is dissociation" (Trowler, 2010, p. 5). Therefore, Fredricks et al. (2004) examined how learning activities are associated with perception and classified engagement into the behavioral, emotional, and cognitive engagement. Behavior engagement refers to the input of positive conduct into the learning activities of students and their perseverance. Emotional engagement refers to the positive or negative emotions of individuals toward their school. The VR environment (Wang & Sun, 2021) and novel perception (Sun & Hsieh, 2018) can improve learners' emotional engagement. Cognitive engagement refers to the state wherein students exert efforts to understand difficult ideas and master challenging skills. There is a positive correlation between situational interest and all three dimensions of engagement (Sun & Rueda, 2012). Furthermore, the engagement of students will affect their learning performance (Fredricks et al., 2004; Sinatra et al., 2015).

Because achievements in high school science courses affect the continuous development of students in science-related fields (Wang, 2013), it is important to understand high school students' engagement in science learning and their learning performance. Schmidt et al. (2018) found that laboratory learning activities had the potential to promote the level of engagement, because the activities may attract students. If the learning activities can solve students' subjective problems with science learning or help them understand complex scientific phenomena, they would more likely enhance students' engagement in science learning. On the other hand, with the feature of the first-person perspective, immersive technology makes learning contents more concrete and easier to understand, and the students can become more easily engaged in the learning environment (Dede, 2009).

Method

Participants

The study participants were 110 national high school freshmen with basic physics knowledge in Taiwan. The effective sample comprised 105 (95.45%) students, who were assigned to the following three groups: traditional learning group ($n = 34$), wearable AR group ($n = 36$), and wearable hybrid AR/VR group ($n = 35$). There were 53 male participants (50.48%) and 52 female participants (49.52%), with an average age of 15.72 years ($SD = 0.51$).

Experimental Procedure

Before partaking in the study, participants were required to fill out the study consent form to understand the study procedures and their rights. First, the participants were requested to complete the pre-test of learning performance test, which lasted for 15 min. They were then divided into five groups. The instructor spent approximately 10 min teaching the participants how to use the different learning tools and explaining the learning activity process. In addition, the instructor also solved learners' problems during the learning. The traditional learning group used paper textbooks to learn the names and functions of the experimental equipment and watched a video to learn the experimental operation process. The wearable AR group learned about the names, functions, and operation processes of the experimental equipment by using AR-based wearables. The wearable hybrid AR/VR group learned about the names and functions of the experimental equipment by using the VR-based wearables and learned about the operation processes by using the AR-based wearables. Each group spent approximately 20 min on this learning process. At the end of the learning activities, the groups were required to complete real physics experiments in approximately 20 min and the post-test of learning performance test, situational interest scale, and engagement scale were completed in approximately 25 min. The research process is presented in Fig. 2.

Instrument

AR-Based Wearables and VR-Based Wearables

The HMD wearables used in this study were the second-generation pocket VR produced by JetRock (2016) and were

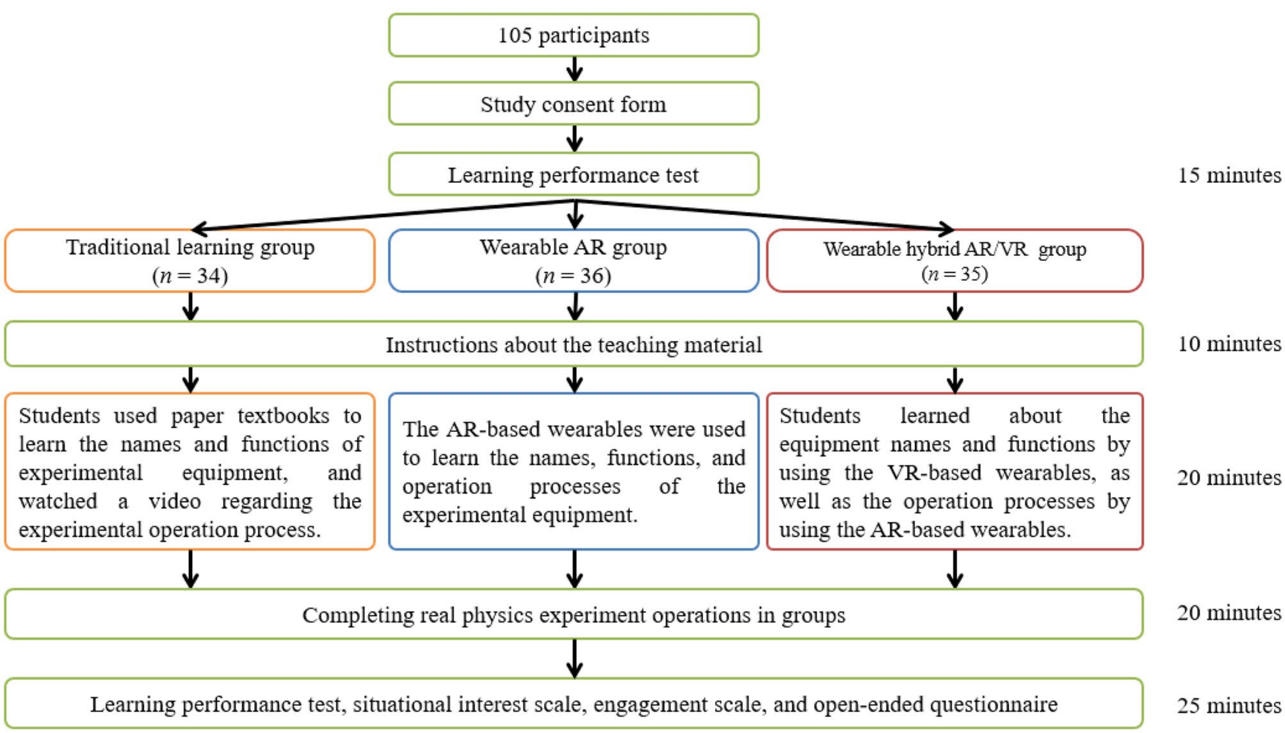


Fig. 2 Research process

Fig. 3 AR-based wearables and VR-based wearables

used together with smartphones (Fig. 3). The learning materials were presented by the HP Reveal Application (App) (HP, 2018) for AR effects and the Tour Creator (Google, 2018) for VR effects. After a user scans real objects using an AR-based wearable, it will display corresponding virtual feedback in real-time (Fig. 4). Meanwhile, the VR-based wearable will present a 360-degree VR situation through the Google Poly webpage. Students could touch virtual buttons in VR using their fingers to obtain virtual feedback in real-time (Fig. 5).

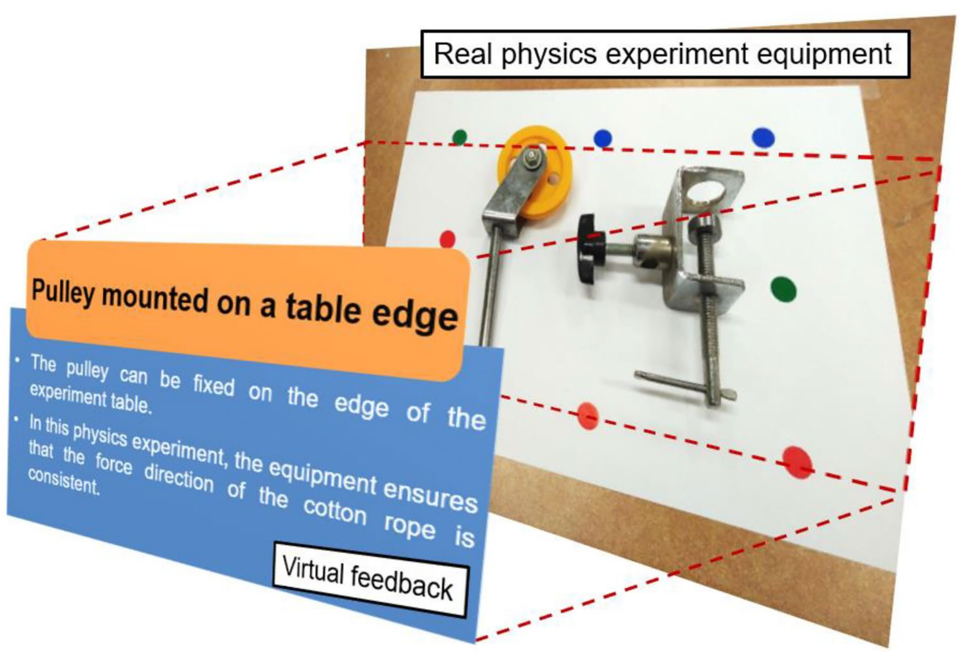
Situational Interest Scale

The situational interest scale was modified from Yu et al. (2019) based on the measure proposed by Chen et al. (1999); the names of activities were revised for the topic of this study. The situational interest scale contains six sub-dimensions: novelty, challenge, attention demand, exploration intention, instant enjoyment, and total interest. With four questions for each sub-dimension, a total of 24 questions were included. A six-point Likert scale was used, wherein 1 indicates “strongly disagree” and 6 indicates “strongly agree.” Cronbach's alpha values of the sub-dimensions are in the order of 0.94, 0.94, 0.97, 0.93, 0.95, and 0.97, with the general result of 0.94 (Nunnally & Bernstein, 1994).

Engagement Scale

The engagement scale was modified from Sun and Hsieh (2018) based on the measure proposed by Fredricks et al. (2005). The engagement scale was divided into three sub-dimensions: behavioral engagement (5 questions), emotional engagement (6 questions), and cognitive engagement (8 questions), with 19 questions in total. A six-point Likert scale was used, wherein 1 indicates “strongly disagree” and 6 indicates “strongly agree.” Cronbach’s alpha values of the sub-dimensions are in the order of 0.79, 0.94, and 0.92, with the general result of 0.93 (Nunnally & Bernstein, 1994).

Fig. 4 The user interface of AR-based wearables



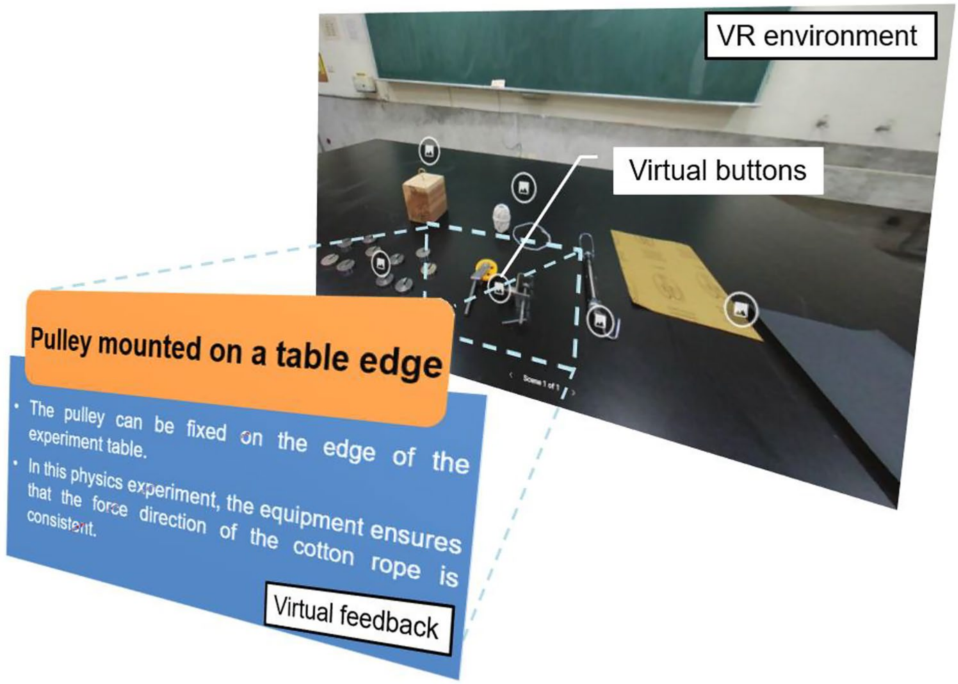


Fig. 5 The user interface of VR-based wearables

Learning Performance Test

The learning performance was divided into two parts (prior knowledge and learning performance tests). The tests used in this study were developed by the researchers. The prior knowledge test was similar to the learning performance test, except for the order of the options. The test questions were reviewed by two professors from a national university in the field of digital learning and an expert in the physical science subject in high school. According to the pre-test results, the difficulty level of the test was maintained at 0.74 ± 0.2 (Aiken, 1997), and the discriminating power was higher than 0.2 (Ebel & Frisbie, 1991). The design of questions was based on declarative knowledge, such as the equipment function and knowledge. One point was awarded for a correct answer, and incorrect ones were not accounted for. There were four questions and the maximum potential score was four points.

Open-Ended Questionnaire

The open-ended questionnaire aimed to understand learners' experiences and suggestions among the three groups. It also reveals critical information about the impacts of the different technologies to assist the explanation of quantitative results. Each group was assigned a code to display the participants, i.e., A refers to the traditional learning group, B refers to the wearable AR group, C refers to the wearable hybrid AR/VR group, and the number refers to participants' ID.

Results

The IBM SPSS Statistic 20 was used for statistical analysis in this study. The analysis of variance (ANOVA) was employed to identify the differences in situational interest (novelty, challenge, attention demand, exploration intention, instant enjoyment, and total interest) and engagement (behavioral, emotional, and cognitive engagement) among different groups (traditional learning group, wearable AR group, and wearable hybrid AR/VR group). The results were used to address RQs 1 and 2. Analysis of variance (ANOVA) and Welch's test were also performed to analyze differences in learning performance of the three groups to address RQ 3.

Situational Interest

The samples of total situational interest, along with the situational interest subscales of novelty, challenge, attention demand, instant enjoyment, and total interest for the three groups, conformed to the normal distributions (Kline, 2011) and did not reach the significant level (F (2,102) = 0.36, p = 0.70, F (2,102) = 0.92, p = 0.40, (F (2,102) = 0.65, p = 0.53), (F (2,102) = 0.28, p = 0.75), (F (2,102) = 0.95, p = 0.39), and (F (2,102) = 1.09, p = 0.34)) in Levene's test for equality of variances. Therefore, one-way ANOVA could be performed and the results are shown in Table 1. The results show significant differences in situational interest among the three groups (F (2, 102) = 7.19, $p < 0.01$, $\eta^2 = 0.12$) and achieve medium effect size (Cohen, 1988). The results of

Table 1 Descriptive statistics and a summary of one-way ANOVA for situational interest, novelty, challenge, attention demand, instant enjoyment, and total interest

Variables	Groups			F	η^2	Post hoc
	Traditional learning ($n=34$)	Wearable AR ($n=36$)	Wearable hybrid AR/VR ($n=35$)			
	M (SD)	*M (SD)*	*M (SD)*			
Total Situational interest	3.53 (0.68)	3.85 (0.63)	4.15 (0.73)	7.19**	0.12	(C) > (A)
Novelty	3.65 (0.94)	4.47 (1.10)	4.76 (1.00)	11.01***	0.18	(B) > (A) (C) > (A)
Challenge	2.41 (0.89)	2.62 (0.98)	2.16 (1.10)	1.85	0.04	-
Attention demand	3.76 (1.18)	3.89 (1.08)	4.47 (1.09)	4.03**	0.07	(C) > (A)
Instant enjoyment	3.74 (0.91)	4.05 (0.97)	4.55 (1.15)	5.64**	0.10	(C) > (A) (C) > (B)
Total interest	3.57 (0.94)	4.19 (0.82)	4.67 (0.98)	12.60***	0.20	(B) > (A) (C) > (A)

(A) = traditional learning; (B) = wearable AR; (C) = wearable hybrid AR/VR

** $p < .01$; *** $p < .001$

Scheffe's post hoc comparison show that the results of the wearable hybrid AR/VR group ($M = 4.15$, $SD = 0.73$) is significantly higher, compared with those of the traditional learning group ($M = 3.53$, $SD = 0.68$), thus indicating that the wearable hybrid AR/VR approach was more effective for enhancing situational interest among students.

In terms of novelty, the results show significant differences among the three groups (F (2, 102) = 11.01, $p < 0.001$, $\eta^2 = 0.18$) and achieve large effect size (Cohen, 1988). The results of Scheffe's post-hoc comparison show that the results for the wearable AR group ($M = 4.47$, $SD = 1.10$) were significantly higher, compared with those of the traditional learning group ($M = 3.65$, $SD = 0.94$), and the results of the wearable hybrid AR/VR group ($M = 4.76$, $SD = 1.00$) were also significantly higher, compared with that of the traditional learning group, thereby indicating that in comparison with the traditional approach, the wearable AR approach and the wearable hybrid AR/VR approach were more effective for enhancing novelty among students. In terms of a challenge, the results show no significant differences among the three groups (F (2, 102) = 1.85, $p = 0.16$, $\eta^2 = 0.04$).

For attention demand, the results show significant differences among the three groups (F (2, 102) = 4.03, $p < 0.01$, $\eta^2 = 0.07$) and achieve medium effect size (Cohen, 1988). The results of Scheffe's post hoc comparison show that the results for the wearable hybrid AR/VR group ($M = 4.47$, $SD = 1.09$) were significantly higher, compared with those of the traditional learning group ($M = 3.76$, $SD = 1.18$), thus indicating that the wearable hybrid AR/VR approach was more effective for enhancing attention demand among students.

For instant enjoyment, the results show significant differences among the three groups (F (2, 102) = 5.64, $p < 0.01$, $\eta^2 = 0.10$) and achieve medium effect size (Cohen, 1988). The results of Scheffe's post hoc comparison show that the results for the wearable hybrid AR/VR group ($M = 4.55$, $SD = 1.15$) were significantly higher, compared with those of the traditional learning group ($M = 3.74$, $SD = 0.91$) and wearable AR group ($M = 4.05$, $SD = 0.97$), thus indicating that in comparison with the traditional learning approach and the wearable AR approach, the wearable hybrid AR/VR approach was more effective for enhancing instant enjoyment among students.

For total interest, the results show significant differences among the three groups (F (2, 102) = 12.60, $p < 0.001$, $\eta^2 = 0.20$) and achieve large effect size (Cohen, 1988). The results of Scheffe's post-hoc comparison show that the results for the wearable AR group ($M = 4.19$, $SD = 0.82$) were significantly higher, compared with those of the traditional learning group ($M = 3.57$, $SD = 0.94$), and the results of the wearable hybrid AR/VR group ($M = 4.67$, $SD = 0.98$) were also significantly higher, compared with that of the traditional learning group, thus indicating that compared to the traditional approach, the wearable AR approach and the wearable hybrid AR/VR approach were more effective for enhancing total interest among students.

For exploration intention, the samples for the three groups conformed to the normal distributions (Kline, 2011). However, the results of Levene's test for equality of variances reached a significant level (F (2,102) = 3.85, $p < 0.05$). Therefore, Welch's test was conducted instead. The results in Table 2 show no significant differences in exploration

Table 2 Descriptive statistics and a summary of Welch's test analysis for exploration intention

Group	*N*	*M*	*SD*	*F*
Traditional learning	34	3.78	0.79	1.39
Wearable AR	36	4.03	0.83	
Wearable hybrid AR/VR	35	3.52	1.08	

Table 4 Descriptive statistics and a summary of Welch's test analysis for emotional engagement

Group	*N*	*M*	*SD*	*F*	Post hoc
(A) Traditional learning	34	3.71	0.68	9.70***	(C) > (A) (C) > (B)
(B) Wearable AR	36	4.15	0.63		
(C) Wearable hybrid AR/VR	35	4.68	0.73		

***$p < .001$

intention among the three groups (F (2, 67.03) = 1.39, p = 0.26).

Engagement

The samples of total engagement, along with the engagement subscales of behavioral engagement and cognitive engagement for the three groups, conformed to the normal distributions (Kline, 2011) and did not reach the significant level (F (2,102) = 1.26, p = 0.29, (F (2,102) = 0.33, p = 0.72), (F (2,102) = 1.10, p = 0.34)) in Levene's test for equality of variances. Therefore, one-way ANOVA was performed and the results are shown in Table 3. The results show significant differences in engagement among the three groups (F (2, 102) = 5.88, $p < 0.01$, $\eta^2 = 0.10$) and achieve medium effect size (Cohen, 1988). The results of Scheffe's post hoc comparison show that the results for the wearable hybrid AR/VR group (M = 4.39, SD = 0.78) were significantly higher, compared with those of the traditional learning group (M = 3.84, SD = 0.58) and wearable AR group (M = 3.94, SD = 0.76), thus indicating that compared with the traditional learning approach and the wearable AR approach, the wearable hybrid AR/VR approach was more effective for enhancing student engagement. The sub-dimensions of engagement (behavioral, emotional, and cognitive engagement) were analyzed in this study. For behavioral engagement, the results show no significant differences among the three groups (F (2, 102) = 2.18, p = 0.12, $\eta^2 = 0.04$). For cognitive engagement, the results show no significant differences among the three groups (F (2, 102) = 2.26, p = 0.11, $\eta^2 = 0.04$).

For emotional engagement, the samples for the three groups conformed to the normal distributions (Kline, 2011) and the results of Levene's test for equality of variances reached a significant level (F (2,102) = 4.31, $p < 0.05$). Therefore, Welch's test was conducted instead. The results in Table 4 show significant differences in emotional engagement among the three groups (F (2, 66.80) = 9.70, $p < 0.001$, $\omega^2 = 0.14$) and it achieves large effect size (Kirk, 1996). The results of Dunnett's T3 post hoc comparison show that the results of the wearable hybrid AR/VR group (M = 4.68, SD = 0.73) were significantly higher, compared with those of the traditional learning group (M = 3.71, SD = 0.68) and wearable AR group (M = 4.15, SD = 0.63), thus indicating that in comparison with the traditional learning approach and the wearable AR approach, the wearable hybrid AR/VR approach was more effective for enhancing emotional engagement among students.

Learning Performance

According to the result of paired t-test in Table 5, traditional learning (t = -3.06, $p < 0.01$, Cohen's d = 0.53), wearable AR (t = -4.64, $p < 0.001$, Cohen's d = 0.78), and wearable hybrid AR/VR (t = -5.59, $p < 0.001$, Cohen's d = 0.94) are useful

Table 3 Descriptive statistics and a summary of one-way ANOVA for engagement, behavioral engagement, and cognitive engagement

Variables	Groups			*F*	η^2	Post hoc
	Traditional learning (n = 34)	Wearable AR (n = 36)	Wearable hybrid AR/VR (n = 35)			
	M (SD)	*M (SD)*	*M (SD)*			
Total engagement	3.84 (0.58)	3.94 (0.76)	4.39 (0.78)	5.88**	0.10	(C) > (A) (C) > (B)
Behavioral engagement	4.60 (0.74)	4.47 (0.83)	4.87 (0.86)	2.18	0.04	-
Cognitive engagement	3.46 (0.80)	3.45 (1.09)	3.87 (0.90)	2.26	0.04	-

(A) = traditional learning; (B) = wearable AR; (C) = wearable hybrid AR/VR.

**$p < .01$

Table 5 Descriptive statistics and a summary of paired *t*-test

Group	*N*	Pre-test		Post-test		*t*	Cohen's *d*
		M	*SD*	*M*	*SD*		
(A) Traditional learning	34	0.79	0.23	0.91	0.12	-3.06**	0.53
(B) Wearable AR	36	0.80	0.19	0.97	0.09	-4.64***	0.78
(C) Wearable hybrid AR/VR	35	0.74	0.25	0.98	0.07	-5.59***	0.94

** $p < .01$; *** $p < .001$

strategies to improve learning performance significantly, and the effect size are in the order of medium, medium, and large (Cohen, 1988). Furthermore, the learning performance was analyzed in this study to identify the differences among the three groups. The sample shows that the results reached the significant level (F (2,102) = 15.75, $p < 0.001$) in Levene's test for equality of variances. Therefore, conducting ANCOVA was not appropriate. In the ANOVA conducted, the pretested samples for the three groups conformed to the normal distributions (Kline, 2011) and did not reach the significant level (F (2,102) = 1.62, $p = 0.20$) in Levene's test for equality of variances. Therefore, the analysis results in Table 6 show no significant differences among the three groups in pre-test scores (F (2, 102) = 0.67, $p = 0.51$, $\eta^2 = 0.01$); thus, their prior knowledge level is consistent. The post-test results were analyzed. Since the significant level (F (2,102), = 17.57, $p < 0.05$) was reached in Levene's test for equality of variances, the analysis was performed using Welch's test instead. The analysis results in Table 7 show significant differences among the three groups in the post-test (F (2, 64.90) = 3.85, $p < 0.05$, $\omega^2 = 0.05$), and it achieves a small effect size (Kirk, 1996). The results of Dunnett's T3 post hoc comparison show that the results for the wearable hybrid AR/VR group ($M = 0.98$, $SD = 0.07$) were significantly higher, compared with those of the traditional learning group ($M = 0.91$, $SD = 0.12$), thus indicating that the wearable hybrid AR/VR was better than the traditional learning in improving the learning performance.

Discussion

RQ 1 examines the differences in situational interest among the three groups. Based on the results, the wearable hybrid AR/VR group is significantly higher than the traditional learning group. In terms of sub-dimensions, the wearable hybrid AR/VR group and the wearable AR group are significantly higher than the traditional learning group for novelty. This may be due to that the interactive experience from AR-based wearables increases curiosity about the topic among students (Kuhn et al., 2016; Yu et al., 2019). The wearable hybrid AR/VR is newer technology and thus provides a different experience, compared with traditional learning (Chen et al., 1999). Therefore, the wearable hybrid AR/VR group and the wearable AR group experience increased novelty. Participants also indicated that the wearable hybrid AR/VR and the wearable AR are novel experiences for them. As supported by the following participants' comments:

> "This is my first time to use AR, and I feel novelty." (B29)
> "It is different from the usual way to have class. The AR adds a chance to interact more with the scene." (B28)
> " The learning approach is different from the past in today's activity so that it triggers my curiosity." (C20)

In addition, the wearable hybrid AR/VR group has increased attention demand and instant enjoyment. Due to the first-person perspective and presence, students pay more attention to the learning contents and enjoy the interactive process (Bower & Sturman, 2015; Parong & Mayer, 2018; Yu et al., 2019). Furthermore, the wearable hybrid AR/VR reduces the movement need of students and mitigates the uncomfortable experience from unstable images and dizziness (Di Serio et al., 2013). Therefore, it is plausible that this is why they worked better than AR-based wearables in terms of instant enjoyment. In addition, the wearable hybrid AR/VR group triggers the key role of instant enjoyment in situational interest so that it also

Table 6 Descriptive statistics and a summary of one-way ANOVA for pre-test

Group	*N*	*M*	*SD*	*F*	η^2
(A) Traditional learning	34	0.79	0.23	0.67	0.01
(B) Wearable AR	36	0.80	0.19		
(C) Wearable hybrid AR/VR	35	0.74	0.25		

Table 7 Descriptive statistics and a summary of Welch's test analysis for post-test

Group	*N*	*M*	*SD*	*F*	Post hoc
(A) Traditional learning	34	0.91	0.12	3.85*	(C) > (A)
(B) Wearable AR	36	0.97	0.09		
(C) Wearable hybrid AR/VR	35	0.98	0.07		

*$p < .05$

has improved total interest (Chen et al., 2001). Participants' feedback proved that the wearable hybrid AR/VR makes them enjoy the learning environment. As supported by the following participants' comments:

> "It feels like experiencing the scene in person when I use the wearable hybrid AR/VR." (C25)
> "This teaching approach can let me focus on learning and remember steps well so I can complete this mission." (C35)

RQ 2 examines differences in engagement among the three groups. The results show that the wearable hybrid AR/VR group is significantly higher than the wearable AR group and the traditional learning group. Further examination of the sub-dimensions shows the wearable hybrid AR/VR group's emotional engagement is significantly higher, compared with that of the traditional learning group and the wearable AR group. The analysis of sub-dimensions of situational interest in this study suggests that the wearable hybrid AR/VR can enhance students' instant enjoyment and sense of novelty, whereas the AR component can improve the curiosity and quest for knowledge (Kuhn et al., 2016). Both AR and VR can motivate students to change their learning behavior to increasingly engaged learning (Suh & Prophet, 2018). The result is consistent with the prior study (Sinatra et al., 2015), wherein the positive emotions of students enhanced their engagement in further learning. As supported by the following participants' comments:

> "I am interested in this new learning approach. The interesting things let me put greater attention and engagement on learning." (C35)
> "The unfamiliar technology equipment in this activity triggers my high curiosity and let me have positive engagement." (C37)

RQ 3 examines the differences in learning performance among the groups. The results show that the wearable hybrid AR/VR group has significantly improved performance compared with the traditional learning group. Studies have suggested that in addition to the benefits of learning transfer, immersion systems could help students exert more effort and enhance their cognitive processing and participation in learning activities, thereby establishing a link between the learning materials and past learning experience of students (Makransky et al., 2017). Moreover, the content of learning performance is based on declarative knowledge, the learning process for which underscores the importance of memorizing and understanding (Hong et al., 2018). The AR-based wearable can improve learning performance for remembering knowledge (Yu et al., 2019), and the VR-based wearables can facilitate the learning of science concepts (Markowitz et al., 2018). Hence, the wearable hybrid AR/VR is more suitable for improving the learning of declarative knowledge.

Conclusions

This study examined the effects of incorporating wearable hybrid AR/VR immersive education technologies into a physics laboratory course on situational interest, engagement, and learning performance among high school students. The results showed that the wearable hybrid AR/VR approach was more superior to the traditional approach in situational interest, engagement, and learning performance. Moreover, this approach significantly enhanced engagement, compared with the wearable AR approach. The wearable hybrid AR/VR approach facilitated students' interaction with physical and virtual experiment equipment through AR- and VR-based wearables to improve situational interest among students. In comparison with AR-based wearables alone, the wearable hybrid AR/VR could present stable learning images and mitigate uncomfortable experiences from moving around with the AR-based wearables. The increased positive emotion of the students toward learning content could increase emotional engagement. In addition, wearable hybrid AR/VR could accelerate the memorizing process of science concepts, thereby could improve learning performance. The application of the wearable hybrid AR/VR approach in science laboratory learning environments positively affected learning performance in science courses among students and improved learning motivation. Therefore, applying the approach in science education was a useful strategy. Because this study covered only one single science concept in high school science education, using self-report scales, and the course duration was short, future studies can examine the pedagogical strategy for different age groups, subjects, and science concepts as well as the long-term learning process. Delayed tests can be employed to understand the long-term learning performance of students and methods for maintaining learning motivation. Learning behavior and brainwave signal can be objective data to explain self-report data and the physics experiment operations.

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Declarations

Ethics Approval In order to ensure that the confidentiality and human subjects requirement was met, the study's institutional review board (IRB#NCTU-REC-108-007F) process was approved by the National Chiao Tung University before data collection was initiated.

Informed Consent All participants were voluntarily engaged in this research, and all the participants' parents or guardians also signed the study consent forms for their participation.

Conflict of Interest The authors declare no competing interests.

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