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Application of multi-touch gestures in science education: Interactive digital simulation for improving students' understanding of optical imaging and learning motivation

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Abstract: This study aimed to examine the effects of prior science knowledge levels and computer simulation modes (gesture and button) on the optical learning outcomes of students. Fifty-one sixth-grade students were allocated to high-score and low-score groups based on their achievements in the natural science course at school. They were randomly assigned to the gesture group on a tablet and the button group on a desktop PC. The study considered cognitive concepts, learning motivations, and brainwaves (attention and relaxation) as dependent variables and prior knowledge levels and computer simulation modes as independent variables. The results showed that, irrespective of whether they belonged to gesture- or button-based simulation groups, students with different prior levels of knowledge showed a significant increase in cognitive concept scores. Gesture-based simulations made it easier for the students with high prior levels to relax and improve their learning motivation. For students with lower prior levels, gesture-based simulations improved attention; however, their learning motivation is not high. The increase in cognitive load caused by gesture simulations may have affected the measurement of motivation at the end of learning, although students concentrate on learning during the learning process.

Keywords: computer simulations, prior knowledge levels, brainwave, learning motivation

1. Introduction

In the process of optical teaching, traditional education has always neglected students' misconceptions, due to which students are frequently unable to connect the concepts taught in class with practical applications (Goldberg & Mcdermott, 1987). These misconceptions are based on students' incomplete or incorrect understanding of concepts through daily observations prior to scientific study. Since the concept is personal, stubborn, and tough, the misconception is hard to change (Pfundt & Duit, 1991). Vosniadou (1994) proposed to create the problem-solving situation involving observation, experimentation, and hypothesis in order to correct their original misconception. Some studies (Lee, Plass, & Homer, 2006; Rieber, Tzeng, & Tribble, 2004) show that learning environments created by computer simulations help students learn complex tasks and study phenomena that are difficult to observe and manipulate in real space. Therefore, this study used computer simulations to create a scientific situation for students to actively experiment and correct their misconceptions.

Today, due to advanced computer technology, mobile terminals represented by tablet PCs are being extensively used. The touch screen, the basic input device for tablets, has intuitiveness and convenience. Researches have shown that students find touch screen simulations very attractive and immersive (Ardito, Lanzilotti, Costabile, & Desolda, 2013; Furió, González-Gancedo, Juan, Seguí, & Rando, 2013; Hung, Kuo, Sun, & Yu, 2014). A study by Furió (2013) showed that students prefer using tablet PCs to traditional computers, which means that gesture-based simulation can be more motivating for students to learn. In addition, relevant research shows that prior knowledge is an important factor that affects learning effects (Baek et al., 2015; Jie & Hui, 2013; Raghubir, 2010). Jie and Hui (2013) conducted an empirical study of 55 sixth-grade students and concluded that prior knowledge affects students' ability to effectively acquire knowledge in game learning. However, few studies have explored the impact of these two computer simulations (gesture vs. button) on learners with different levels of achievement (high vs. low). This study aims to address this gap and used the electroencephalogram (EEG) to observe the changes in students' attention and relaxation values during the learning process by examining cognitive concepts, learning motivations, and brainwaves of students with different achievement levels on computer simulations that run on tablets and PCs. The following three research questions were examined:

1. Is there a difference in cognitive concepts among students with different prior knowledge levels (high vs. low) through gesture- and button-based simulations?
2. Is there a difference in learning motivation among students with different prior knowledge levels (high vs. low) through gesture- and button-based simulations?
3. Is there a difference in brainwaves (attention and relaxation) among students with different prior knowledge levels (high vs. low) through gesture- and button-based simulations?

2. Literature Review

2.1 Computer Simulation

Computer simulation can provide learners with an open, active, and exploratory learning environment. Milrad (2002) believed that students can observe, experiment, and interpret or predict events in this interactive environment, which results in the constant correction of their original misconceptions. Optical knowledge is more abstract for primary students, which easily lead them to generate misconceptions. Several studies have shown that computer simulation can help students overcome the difficulty of learning physics, improve learning motivation and achieve better cognitive performance (Chang, Peng, & Chao, 2010; Nugraha, Kirana, Kaniawati, & Rusdiana, 2016). With pretest–posttest design, Nugraha (2016) found that compared with traditional teaching methods (teacher centered), students can better understand physical concepts through simulation. In addition, learning motivation can be improved through computer simulation (Chang, Peng, & Chao, 2010; Koh et al., 2010). Using the data of 114 students studying simulation systems, Koh (2010) discovered that computer simulations enabled students to feel mental satisfaction, as well as improving intrinsic motivation. Furió (2013) has shown that tablets based on the touch gesture can stimulate students' learning motivation compared to button-based learning in desktop PCs, through 84 students (8–10 years old) studying in iPhone game. Therefore, in this study, computer simulation was applied in optical teaching to correct their misconceptions, improve cognitive concepts, and learning motivation.

The use and effects of computer simulation are influenced by the student's prior level. Among 72 fifth-grade students, Hung (2014) found that students with high prior levels profit more easily in high-interactive simulations, whereas those with low prior levels are more efficient in low-interactive simulations. The simulation effect can be measured using brainwaves, as well. Derbali (2010) used 33 subjects in serious game simulation and examined it using brainwaves. However, only a few studies have examined the effects of prior levels of students on simulations in optical learning, which is further examined by this study through brain waves.

2.2 Prior Knowledge

Prior knowledge refers to an individual's existing knowledge reserve before learning, which affects students' learning outcomes (Baek et al., 2015; Raghubir, 2010). By studying a total of 140 students, Baek (2015) determined the impact of prior knowledge and learning motivation on students' achievement. Attention is also related to prior knowledge. An eye tracking study showed that prior knowledge affects the learning category of students and that attention affects the optimal integration of prior knowledge, thus affecting learning outcomes (Kim & Rehder, 2011). Therefore, in this study, the effects of prior knowledge on learning achievement, learning motivation and brainware (attention and relaxation) were explored.

2.3 Learning Motivation

Learning motivation is a complex psychological process that can drive students to learn actively. Students with high motivation showed a strong curiosity or interest in learning (Moè, 2015), which directly affected their learning effects. A study by Gomez (2010) that involved 73 students found that highly motivated students enjoyed the learning process more and achieved better learning outcomes than students with lower motivation. Learning attitude can be reflected by the scale, but Derbali (2010) believed that brainwaves are also a valid and objective index for measuring it. Therefore, in this study, objective biological signals and scales were used to measure the state of a student's learning process and changes in his or her attitude after participating in the study

Learning motivation is affected by complex factors. From a study involving 182 students, Yusri et al. (2012) concluded that students with high levels have higher motivations in language learning than those with low levels. Furthermore, computer simulation can influence students' learning motivation (Chang, Peng, & Chao, 2010; Koh et al., 2010), and gesture simulation (on tablet) greatly improves learning motivation compared to button simulation (on desktop PC) (Furió, 2013). However, studies that examine the combined effects of prior knowledge levels and simulation models on learning motivation are lacking, which is the research gap addressed by this study.

2.4 Brainwave

A brainwave is a bioelectric signal generated by the brain. By collecting and analyzing brainwaves, one can understand a person's learning state and improve the learning process. Attention and relaxation are the comprehensive manifestations of brainwaves. Attention reflects the degree of concentration, whereas relaxation refers to the relaxed state of the mind.

At present, due to its rapid development, brainwave technology is extensively used in education research. The study by Derbali (2010) shows that the brainwave is associated with increased motivation. Computer, especially gesture simulations can greatly enhance students' motivation for learning (Chang et al., 2010; Koh et al., 2010; Furió, 2013). Hence, it can be inferred that computer simulation has a significant impact on brainwaves. Moreover, since brainwaves have complex and variable characteristics, they vary greatly from person to person. However, previous studies on brainwaves do not examine the prior levels of individuals. Hence, this study observes changes in the attention and relaxation values of students and examines the effects of prior levels and simulation models on brainwave values.

3. Material and Methods

3.1 Computer Simulation System

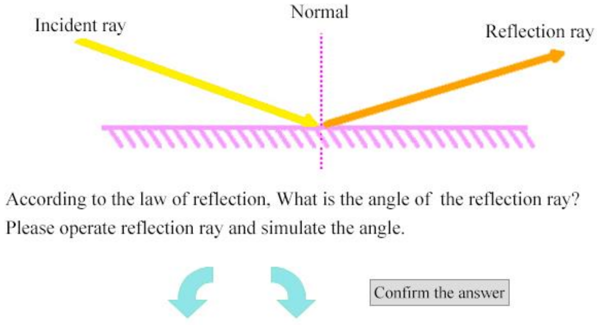

Figure 1. Control group page: button-based computer simulation for learning light reflection

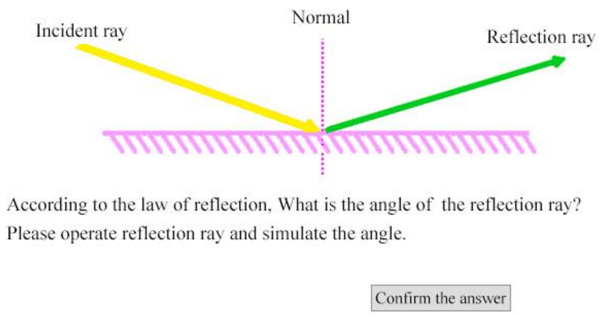

Figure 2. Test group page: simulation-based computer simulation for learning light reflection

This study used HTML5, PHP, and MYSQL to develop a computer simulation system, including online theoretical learning, experimental simulation, and evaluation functions, as well as real-time recording of students' learning behavior. Since the concepts that must be mastered by primary school students are reflection and refraction propagation of light and the path of light through a plane mirror or a convex lens, this system includes three optical parts, which are light reflection and refraction, plane mirror, and convex lens with a maximum of 4, 2, and 4 points, respectively. Students in the control group (Figure 1) adjusted the angle of reflected light by clicking the blue icon on computer, whereas those in the experimental group simulated the path of reflected light through touch gestures on a tablet PC (Figure 2).

3.2 Participants

In this study, the participants were 51 sixth-grade students (24 male and 27 female students) from two primary schools. According to the test on previous optical knowledge, participants were divided into high group of prior knowledge (HPK) and low group of prior knowledge (LPK) and, subsequently, distributed into two experimental programs randomly: a test group based on gesture simulations (TG) and a control group based on button simulations (CG). The final numbers for each group were TG-HPK:13, CG-HPK:13, TG-LPK:13, and CG-LPK:12. From each of the four groups, one student was randomly selected to wear an EEG to observe the changes in brainwave values during learning. With respect to the cognitive concept scores and learning motivation pretests, the two high groups did not show any difference ($t = .44$, $p > .05$; $t = .81$, $p > .05$), and no significant difference was observed between the two low groups ($t = .82$, $p > .05$; $t = -.58$, $p > .05$).

3.3 Procedure

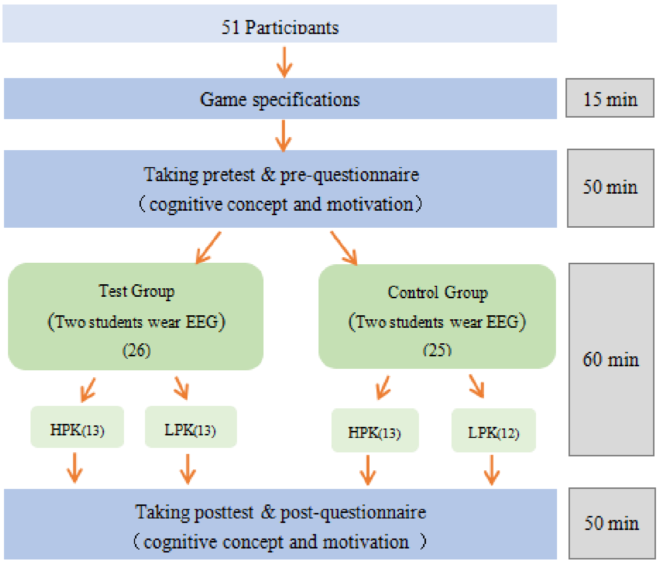

Figure 3. Experimental procedure

As shown in Figure 3, prior to conducting the study, students attended a 15-minute explanation of the game rules, including instructions regarding the system and studying on the tablet PC or desktop PC. Four of them wore an EEG. Then, participants attended an optical concept test and answered a motivation questionnaire for 50 minutes. Subsequently, they spent 60 minutes on optical learning. Finally, they attended a 50-minute learning motivation questionnaire and a cognitive concept posttest.

3.4 Research Tools

3.4.1 Electroencephalograph(EEG)

The EEG used in this experiment was Mindwave Mobile manufactured by Neurosky, which has three main advantages: low cost, light weight, and convenience. Yasui (2009) pointed out that this device can obtain highly sensitive brain signals and is not obstructed by other noises in the brain. The data acquisition software (EmotivPro License) was used to monitor and acquire the brainwave data of the participants in real time, and the psychological state of the subjects was quantified as attention and relaxation. The parameter values were between 0 and 100 (“40–60” for “normal range,” “<40” for “low zone,” and “>60” for “high zone”).

3.4.2 Cognitive Concept Test in Optics

The cognitive concept test (Cronbach’s alpha = .80) comprised 21 basic questions to assess students’ knowledge of optical concepts (e.g., “A painting is hung in the classroom. When we stand in a classroom that is completely dark, can we see this picture? (a) visible, (b) a blurred picture can be seen, (c) a small part of the picture can be seen, (d) completely invisible”). This test, which was developed by university researchers and primary school science teachers, included 21 questions, with a total of 41 points.

3.4.3 Questionnaire on Learning Motivation

According to the Motivated Strategies for Learning Questionnaire (Pintrich et al., 1991), the learning motivation test (Cronbach’s alpha = .90) comprised 18 item questionnaires. For example, “the most important thing is to improve my grade; hence, I am very concerned about getting good grades.” Participants were required to answer the degree of agreement or disagreement to assess their learning motivations (1, strongly disagree and 6, strongly agree).

3.5 Data Analysis

We used two-way analysis of variance (ANOVA) to test the effects of prior levels and simulation modes on students’ understanding of cognitive concepts and learning motivation. Subsequently, a paired sample t test was performed on the cognitive concept. In addition, the brain wave data of the four students were collected, and a line chart was drawn to facilitate the visual observation of changes in brain waves. Then, the averages of the attention and relaxation of the four students in the process of learning the three optical parts were calculated along with their respective scoring rates.

4. Results

To test the influence of prior level and simulation modes on students’ cognitive concepts and learning motivation, we performed two-way analysis of variance (ANOVA). Prior levels and computer simulation were fixed factors. Table 1 depicts the descriptive statistics of the two fixed factors in each group.

Table 1

Mean and Standard Deviation for Cognitive Concepts and Learning Motivation

	HPK group			LPK group		
	N	M	SD	N	M	SD
Cognitive concept						
TG	13	15.46	3.73	13	12.92	3.40
CG	13	12.38	3.91	12	12.75	4.71
Motivation						
TG	13	4.85	0.41	13	4.18	0.60
CG	13	4.27	1.25	12	4.67	0.72

Note: TG, test group; CG, control group; HPK, high group of prior levels; LPK, low group of prior levels

4.1 Cognitive Concept

By using two-way ANOVA to analyze cognitive concepts, the Levene's test indicated the homogeneity of variance ($F = .60$, $p = .620 > .05$), the results demonstrated that the high and low score groups did not show remarkable difference ($F(1,47) = .96$, $MS = 15.034$, $p = .331 > .05$, $\eta^2 = .020$), and there was no significant difference between the two computer simulations ($F(1,47) = 2.16$, $MS = 33.628$, $p = .149 > .05$, $\eta^2 = .044$). No interaction effects were found between high-low groups and the simulation modes ($F(1,47) = 1.72$, $MS = 26.846$, $p = .196 > .05$, $\eta^2 = .035$). Subsequently, the paired sample t-test on cognitive concepts showed a statistically significant difference between pretest and posttest among students in the high group ($t = -7.29$, $p < .001$) and among those in the low group ($t = -6.20$, $p < .001$).

4.2 Learning Motivation

By using two-way ANOVA to analyze learning motivation, the Levene's test indicated the homogeneity of variance ($F = 2.33$, $p = .086 > .05$), the results demonstrated that high-low score groups did not show remarkable difference ($F(1,47) = .35$, $MS = .226$, $p = .560 > .05$, $\eta^2 = .007$), and there was no significant difference between the two computer simulations ($F(1,47) = .03$, $MS = .021$, $p = .858 > .05$, $\eta^2 = .001$). An interaction effect between high-low groups and simulation modes was observed ($F(1,47) = 5.55$, $MS = 3.625$, $p = .023 < .05$, $\eta^2 = .106$). High achievers demonstrated higher learning motivation scores in the test group ($M = 4.85$, $SD = .41$) than in the control group ($M = 4.27$, $SD = 1.25$). In contrast, low achievers presented lower learning motivation scores in the test group ($M = 4.18$, $SD = .60$) than in the control group ($M = 4.67$, $SD = .72$).

4.3 Attention and Relaxation

Figures 4 and 5 depict the changes in the attention and relaxation values, respectively, of four students during the learning process. The blue, green, gray, and yellow lines represent TG-HPK, TG-LPK, CG-HPK, and CG-LPK, respectively. Figure 4 indicates that the overall low group attention (LPK) was higher, especially for the second student (TG-LPK), which was significantly improved in the process of gesture-based simulation. It is noted that high group students (HPK) had low attention. The attention of the first student (TG-HPK) increased during the process of gesture-based simulation. The attention of the third student from the button-based simulation group decreased slightly. It indicates that learning attention is affected by both computer simulation and prior level. As shown in Figure 5, low group students (LPK) remained in a state of relaxation, with little fluctuation. The first student (TG-HPK) showed more relaxation in learning. The third student's relaxation (CG-HPK) was slightly lower than that of other students. This observation implies that computer simulations can be conducive to relaxation. Through different simulation models, brainwave maps show that students with different prior levels have greater differences in attention and relaxation.

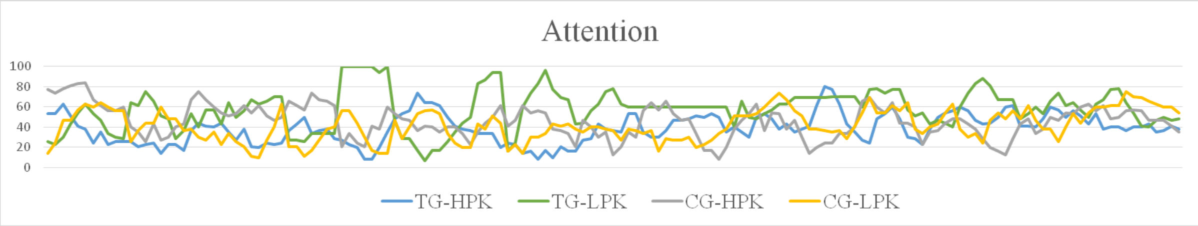

Figure 4. Fluctuations in attention over time.

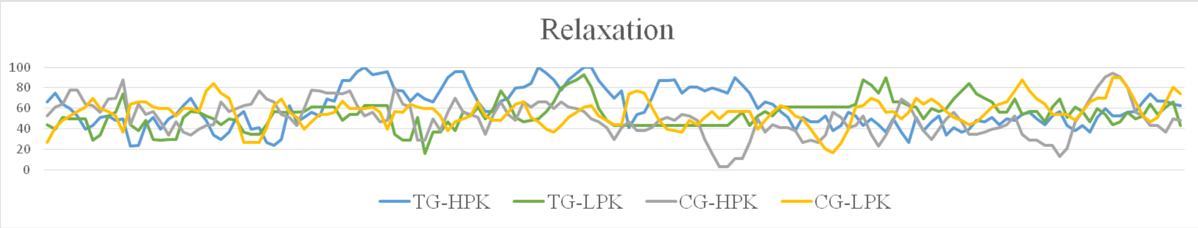

Figure 5. Fluctuations in relaxation over time

Table 2

The results of brain wave index and scores (accuracy)

	Optical refraction & reflection	Plane mirror	Convex lens	Average (4 students)
Gesture-based simulations(high level)				
attention	33.80	30.61	45.39	36.60
relaxation	76.39	46.46	55.74	**59.53**
score(accuracy)	4 (100%)	2 (100%)	4 (100%)	10 (100%)
Gesture-based simulations(low level)				
attention	56.94	50.11	61.26	**56.10**
relaxation	53.51	47.68	57.31	52.83
score(accuracy)	3 (75%)	2 (100%)	4 (100%)	9 (90%)
Button-based simulations(high level)				
attention	46.39	53.11	42.66	47.39
relaxation	57.73	56.43	42.70	52.29
score(accuracy)	4 (100%)	2 (100%)	3 (75%)	9 (90%)
Button-based simulations(low level)				
attention	39.12	32.29	46.97	39.46
relaxation	53.18	56.29	57.53	55.67
score(accuracy)	2 (50%)	1 (50%)	0 (0%)	3 (30%)
Average values of three sections				
attention	44.06	41.53	**49.07**	
relaxation	**60.20**	51.71	53.32	
score(accuracy)	13 (81%)	7 (88 %)	11 (69%)	

Table 2 depicts the brainwave index and game scores (accuracy) of the three optical sections. First, in terms of the three optical parts, students had the highest relaxation values for the refraction and reflection of light, and the accuracy was relatively high, as well. While learning convex lenses, although the attention of students was high, accuracy was relatively low. This was probably because the concepts of refraction and reflection of light are relatively more easily understood and that of convex lens is relatively less easily understood by primary students. In addition, high-group students had higher attention values (M=53.33) in this part of the study than low-group students (M=44.82), and their accuracy rate was higher than that of low-group students. This shows that prior knowledge does have a certain degree of impact on the learning category of students. However, the attention value is affected by factors such as difficulty in learning content. Second, the first student (TG-HPK) with a very relaxed state showed low attention, but high accuracy (100%). The second student (TG-LPK) whose accuracy in the game was 90% had the highest attention, but only moderate relaxation.

The third student (CG-HPK) had a moderate degree of attention and relaxation, with 90% accuracy. The fourth student (CG-LPK) had a low attention and a relaxed state, with a game accuracy of 30%. This indicated that students with high prior levels are more relaxed during the learning process based on gesture simulations compared to that based on button simulations, and the final game score is relatively high. For students with low prior levels, it is easier to improve their attention during the learning process by gesture-based simulations.

5. Discussion and Conclusions

This study examined the influence of students' prior knowledge levels and simulation modes on their cognitive concepts, learning motivation, and brainwave values. Our results imply the following:

First, the two-way ANOVA showed that computer simulation modes and prior levels had little influence on the cognitive concept. However, t-test showed that computer simulations could significantly improve the optical cognition concept of students, regardless of their prior levels. This is consistent with previous research findings, which revealed that computer simulations can promote students' scientific concepts (Chang et al., 2010; Nugraha, Kirana, Kaniawati, & Rusdiana, 2016). By using the computer simulation, students can intuitively learn about and manipulate optical phenomena; this is impossible for traditional education, and students can thus constantly correct their original misconceptions engaging with the simulation. Therefore, we recommend that computer simulations should be used in optical learning, thus making full use of the active and exploratory learning environment that a computer can provide to help students overcome misconceptions and gain a better understanding of cognitive concepts.

Second, experimental results reveal that learning motivation is highly influenced by factors such as prior level and simulation mode. This verifies that computer simulations based on gestures can improve students' learning motivation (Furió et al., 2013) and enables the examination of differences in learning motivation between students with different prior levels. The two-way ANOVA showed that students with high prior levels were more motivated to learn based on gesture simulations than button simulations, whereas students with low prior levels were less motivated to learn based on gesture simulations than button simulations. The reason for this may be that gesture-based simulations are more intuitive and closer to life than button simulations. Gesture operations can help students recall life experiences and make it easier to combine new knowledge with old experiences, thus improving their thinking skills. Students with higher achievement levels may have high-order thinking skills and may thus be able to use these gestures more accurately to understand optical concepts. Therefore, they can enjoy this intuitive learning method and gain higher learning motivation. Students with lower achievement levels may have low-order thinking skills and prefer to use traditional learning methods. In gesture-based simulations, their preferred learning methods may lead to incompatibility, thus increasing their additional cognitive load and reducing their learning motivation. Therefore, when teachers use gesture simulations for teaching, they should pay more attention to students with lower achievement levels. On the one hand, teachers can give students sufficient time to adapt to such teaching methods during formal classes. However, when students encounter difficulties in simulation learning, the computer simulation system can provide scaffolding for students in a timely manner, thereby reducing students' frustration regarding learning and increasing their learning motivation.

Third, the brainwave map reflected the changes in the attention and relaxation of four students during the experiment. The results showed that students with different prior levels show large differences in their attention and relaxation. Students with high achievement are more likely to be relaxed and obtain better game scores based on gesture simulations. Students with low achievement find it easier to improve attention based on gesture simulations, and attention is crucial to the improvement of game scores. Therefore, it is recommended that teachers should pay attention to individual differences in the teaching process. Moreover, in terms of learning content, the optical part of the convex lens is more difficult to understand for primary students, and students have higher attention values when they study this part of the content. The high-group students have higher attention values in this part of the content regarding convex lenses than the low-group students; this is consistent with previous research that prior knowledge has a certain degree of impact on the individual learning category that each student is concerned with (Kim & Rehder, 2011). Therefore, it is recommended that teachers should identify the convex lens section of the learning content as a difficult point for teaching. Furthermore, computer simulations should exhibit more intelligent functionalities, such as the functionality to choose appropriate scaffolding and learning resources for students with different prior levels in a timely manner; this will help to achieve better learning results.

Finally, the number of students wearing EEG in this study was small; therefore, the brainwave data may not be sufficiently comprehensive. Meanwhile, the brainwave threshold was set to specific values without considering the differences between individuals. Furthermore, since this study does not consider the long-term effects of computer simulation, future research should include these aspects to generate more comprehensive findings.

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