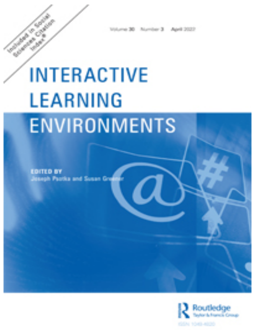

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Applying Augmented reality to enhance physics laboratory experience: does learning anxiety matter?

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ABSTRACT

Augmented reality (AR) recently shows great potential to facilitate students' learning, especially their learning performance and motivation. However, few studies considered learners' emotional factors such as learning anxiety, which may influence the learning results. This study aims to explore how different experimental conditions (AR & Non-AR) may affect the learning performance and motivation of students with different levels of learning anxiety. An AR-based magnetism experimental tool entitled "MagAR" was proposed to support junior high school students' physics learning. The results indicated that, when compared to traditional experimental materials, AR can effectively improve students' learning performance and motivation. Moreover, regardless of their anxiety, students in AR condition performed better on transfer test than those in Non-AR group. AR can also significantly motivate students with high anxiety. Besides, all students hold a positive attitude towards MagAR.

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Augmented reality; physics education; learning anxiety; motivation

1. Introduction

In physics education, laboratory experience plays an important role in constructing and cultivating students' specialized aptitudes and skills (Singh et al., 2019). Through experimenting, students could make intuitive observations and inquiries, thus achieving an in-depth understanding of learning contents, especially those abstract and complicated concepts (Fidan & Tuncel, 2019; Kapici et al., 2020; Thees et al., 2020). However, there exist obstacles in organizing physical experiments for schools and educators, such as expensive experimental materials, lack of equipment, and unreachable objects (Fidan & Tuncel, 2019; Liu et al., 2021), which largely restrict learners' hands-on experience. Since physics learning requires higher-order cognitive skills (Sahin et al., 2015), students would easily present negative perceptions when the experimental needs are not met. In this regard, the learning anxiety of students may increase (Sahin, 2014; Sahin et al., 2015), which could further lead to decreased motivation and poor learning performance (Chen, 2019; Liu, 2012).

Augmented reality (AR) technology, which can combine the virtual elements with physical environment (Azuma, 1997), has become a potential solution by representing those abstract concepts in an intuitive manner (Singh et al., 2019). Since AR can run on portable devices, it has gained growing interest for educational use (Maas & Hughes, 2020; Sırakaya & Alsancak Sırakaya, 2020), especially for large-scale classes. The unique attributes of AR, such as providing embodied interaction between physical and virtual objects (Azuma, 1997), bring unlimited possibilities for

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enriching the laboratory experience. Literature has shown that AR could promote students' learning performance and increase their motivation (Fidan & Tuncel, 2019; Sahin & Yilmaz, 2020; Singh et al., 2019; Tomara & Gouscos, 2019). However, few studies have considered the emotional factors (e.g. self-efficacy, learning style, anxiety), which may influence students' learning results in the AR environment (Cheng & Tsai, 2013). Among those factors, learning anxiety is one of the most ignored in physics discipline (Sahin et al., 2015).

Anxiety is perceived as one of the most common negative affective factors that may influence learning (Chen & Hwang, 2020; Sahin, 2014). Researchers have indicated there is a significant correlation between anxiety and learning efficacy; that is, a low level of anxiety promotes learning, while high anxiety impedes learning (Chen, 2019; Hsu, 2017). Meanwhile, in math learning, anxiety is deemed as an essential factor that significantly influences students' learning motivation and performance by interfering with individuals' ability to manipulate numbers and spatial graphics (Chen, 2019). However, the role of anxiety in learning was still not clear in physics class; whether and how AR can moderate the negative effect that anxiety created is needed to be further explored.

Therefore, based on the abovementioned research gap, we aimed to investigate whether the use of AR could impact students' learning according to their anxiety levels. An AR-based learning tool was designed based on our previous version (Liu et al., 2021) to facilitate students' magnetic field learning. A 2*2 quasi-experiment (AR & Non-AR vs. Low & High anxiety) was conducted among junior high school students. Several measuring tools were utilized to assess their physics anxiety, learning motivation, and learning performance.

2. Literature review

2.1. AR and physics education

By dynamically integrating virtual objects into the physical environment (Azuma, 1997), AR technology affords a flexible and intuitive manner to visualize abstract concepts and link them into students' prior knowledge (Lai et al., 2019; Singh et al., 2019). It brings great convenience to teaching difficult knowledge and carrying out hands-on activities. From synthesized results of previous studies (e.g. Ibáñez & Delgado-Kloos, 2018; Maas & Hughes, 2020; Sırakaya & Alsancak Sırakaya, 2020), AR has shown a positive influence on educational outcomes such as learning gains, motivation, self-efficacy, attitude, and retention in the learning process. Moreover, with the advancement of mobile technologies, the cost of AR has fallen quickly (Cai et al., 2019). Therefore, it is possible to adopt AR in large classes in elementary or secondary schools.

In physics discipline, studies have shown AR can enhance students' hands-on laboratory experience by providing natural interaction, scaffolding collaboration, and visualizing the relationship between physical objects to their symbolic representation (Bujak et al., 2013; Cai et al., 2021; Fidan & Tuncel, 2019; Tomara & Gouscos, 2019). From the perspective of cognition, researchers (Bujak et al., 2013; Chang et al., 2019) indicated that the spatiotemporal alignment of information generated by AR could prevent students from using unnecessary cognitive resources to process disjoint pieces of elements, thus helping them develop a deeper understanding of the abstract concept (Sweller, 2010). Based on these advantages, researchers have already adopted AR in various physics topics, such as heat thermo experiment (Thees et al., 2020), electrical experiment (Altmeyer et al., 2020), and optical experiment (Cai et al., 2021). For example, Cai et al. (2021) developed an AR-based optical simulation experiment (AROSE) to support students' learning of the photoelectric effect. By combining the virtual button and 3D model on the AR marker, AROSE provided natural interaction. The results showed that AROSE could effectively stimulate students' self-efficacy and promote their high-level conceptions in physics learning. Thees et al. (2020) indicated that the AR-glass-based application created for the heat conduction experiment could significantly decrease students' cognitive load. Likewise, in Altmeyer et al.'s (2020) work, an AR application was designed based on the contiguity principle to facilitate electrical circuit experimental operation; the participants reported lower cognitive load and higher usability as well as slightly higher conceptual knowledge achievement compared to the non-AR condition. This study also indicated that AR design would benefit from the rational instructional strategy. However, while AR has shown great potential in the physics field, few studies considered the individual's emotional difference, which may influence the learning outcomes (Ling et al., 2021). Among them, learning anxiety is an essential factor that was easily ignored by researchers (Sahin et al., 2015).

2.2. Learning anxiety

Anxiety is an emotional state of tension, uneasiness, and self-doubt when someone experiences threat or uncertainty (Woolfolk, 2016). It is regarded as a negative factor that may paralyze students' learning if not controlled well (Sahin, 2014). Studies indicated that some degree of anxiety would be conducive to improving academic achievement, while excessive anxiety may severely impede it (Chen, 2019; Sahin et al., 2015). González et al. (2017) also suggested that learning performance was negatively predicted by anxiety in physics learning. According to Sahin et al. (2015), learning anxiety (LA) in the physics field may derive from several sources, including test anxiety, lack of domain knowledge, and laboratory operation anxiety. Accordingly, LA may greatly vary among students according to their profiles such as gender, major, and prior academic performance (Sahin, 2014). To this end, how to provide a suitable learning environment that can alleviate the adverse effects LA generates is always assumed to be an essential task for educational practitioners (Chen, 2019; Sahin, 2014). According to previous empirical studies, AR has the potential to solve this problem by arousing learners' learning interests (Hsu, 2017; Sahin & Yilmaz, 2020). Chen (2019) indicated that students with different anxiety may demonstrate different learning outcomes in an AR environment. In their study (Chen, 2019), the role of anxiety was examined in AR-based mathematics learning, with 137 six-grade students being divided into two groups according to their math anxiety (i.e. low and high). The results showed that AR could moderate the effect of anxiety; when treated with AR, students with high anxiety showed a larger reduction in anxiety, higher learning gains, and perceptions. However, few studies focused on LA in physics learning, and its role was still unexplored in the AR environment.

Since the unstable individual differences may generate insistent outcomes in an AR environment (Ling et al., 2021), this paper was interested in the learning performance of students with different levels of LA in AR-supported physics experimental class.

2.3. Learning motivation

Previous researchers have indicated that LA was negatively related to motivation and academic achievement (Liu, 2012; Sahin et al., 2015); this highlights another factor that this study focused on, learning motivation. Learning motivation is usually defined as an essential factor that drives students to engage in learning activities toward a specific goal (Reeve, 2017). Promoting students' learning motivation has consistently been recognized as a challenge for teachers. With the development of computer simulation technologies, AR has become a potential tool to attract students' learning interest and stimulate their learning motivation by providing novel experiences in the virtual-real mixed environments (Chang et al., 2019; Lai et al., 2019; Sahin & Yilmaz, 2020). Some literature reviews (e.g. Ibáñez & Delgado-Kloos, 2018; Sırakaya & Alsancak Sırakaya, 2020) suggest that motivation is one of the most frequently occurring advantages in research on AR learning. Among these studies, Keller's ARCS model (Keller, 2010) was commonly used for designing and evaluating computer-based learning. This model consists of four motivational factors for facilitating and maintaining persistent learning interest step by step: 1) *Attention*: stimulating students' curiosity on the learning materials, 2) *Relevance*: providing reverent learning content that meets the students' goal. 3) *Confidence*: assisting students in building beliefs about the learning success. 4) *Satisfaction*:

enhancing satisfaction with learning through internal or external incentives. Each component of ARCS plays a crucial role in the motivation generation of the learning process.

Some AR studies examined students' motivation based on the ARCS model. For example, Chang et al. (2019) designed an AR application named "AR-PEclass" to assist students' motor skills learning by interacting with a 3D character model. Students reported significantly greater attention, relevance, confidence when compared to those assigned with video materials. In Lai et al. (2019)'s work, AR was utilized to promote elementary school students' science learning. The results also indicated that AR significantly improved students' motivation in all four dimensions of ARCS. However, while previous studies confirmed the positive effect of AR on motivation and learning, few of them pay attention to the motivational design in AR-based learning, which may also influence the learning result (Chen, 2019; Di Serio et al., 2013). According to Chen (2019), AR-based learning materials would also benefit from applying Keller's ARCS model. To this end, this study aimed to provide an AR learning tool based on Keller's ARCS model. We were interested in the impact of LA on learning motivation and learning performance when students were contextualized in the AR or Non-AR environment.

2.4. Research questions

This study aimed to explore how the use of AR (i.e. AR & Non-AR) could influence the learning performance and motivation of students with different levels of LA (i.e. high LA & low LA). An AR experimental learning tool based on our previous version (Liu et al., 2021) was proposed to support junior high school students' magnetism learning. Moreover, students' attitudes towards the tool were also examined to understand their laboratory experience further. The research questions were constructed as follows:

RQ1. Does the use of AR, LA level, or the interaction of them have any impact on students' learning performance (i.e. knowledge retention and transfer)?

RQ2. Does the use of AR, LA level, or the interaction of them have any impact on students' learning motivation?

RQ3. What are the students' attitudes toward the AR experimental tool?

3. Experiment design

3.1. Learning materials

This study employed an AR experimental tool to facilitate students' learning on magnetism, an important topic in junior high school physics discipline. Due to the invisible nature of the magnetic induction line, students' understanding of this abstract concept may be hampered. In our former study (Liu et al., 2021), an AR manipulative was designed to visualize the magnetic induction line on the real magnets, and results initially indicated this virtual-real interaction benefits learning. However, it was only applied for some sub-topics of magnetism in one lesson and lacked the guidance of educational theory; further optimization was thus needed (Liu et al., 2021). In the current study, following the junior high school physics syllabus, the application was further upgraded based on Keller's ARCS model (Keller, 1987) to promote students' learning motivation and entitled as "MagAR". First, the authentic 3D model and well-designed user interface were designed to attract students' attention. Second, The MagAR severs the real magnet as the AR marker, which is the same as the traditional class, to ensure the laboratory experience relates to our real life. Moreover, some cases in this app are also closely linked to real life (e.g. exploring which kinds of material can be attracted with magnets) to enhance students' perception of relevance. Third, after upgrading, the MagAR can run smoothly on a portable tablet or mobile. The stable operation can avoid unnecessary mistakes of students, thereby building their confidence. Forth, to generate students' satisfaction, the magnetic indication line calculation algorithm was tested in devices with different configurations to make sure it could be accurately visualized, thus providing real-time feedback of the changing magnetic field derived from the learners' interaction between magnets and the system.

The MagAR consists of three modules that align with the three phases of the class instruction (see section 3.3). The detailed technological structure and typical system modules are shown in Figure 1. Leaners can start by scanning the real magnet with their mobile device's camera. The corresponding virtual magnet model will be superimposed on the real magnet through feature matching. Then the force and the direction of the magnetic field will be calculated in real-time by the visualization algorithm, through which students can easily interact with the three modules:

Magnetic world introduction. Students can interact with virtual objects (e.g. wood sticks, iron plates, and copper coins) to understand which can be attracted by a magnet. Besides, they can use the real magnet to interact with the virtual magnet to initially experience the attraction and repulsion between different poles of magnets.

Magnetic field inquiry. This module can display the iron filings' distribution around the magnet and the magnetic induction lines aligned with one or two magnets, thereby providing students with an embodied hands-on experience.

Knowledge extension & recall. Students can further understand the geomagnetic field by interacting with an AR-marker. Moreover, a knowledge conclusion sub-module and magnetic field drawing board were afforded to students to recall the overall conceptions of magnetism.

As for the Non-AR experimental materials, the physical magnets, iron filings, small magnetic needles, and some small objects (the same as the virtual objects in module 1 of the AR application) were included. Students can observe the magnetic field by spreading the iron filings on a paper under which the magnet was used to interact with them.

3.2. Participants

Participants in this study were 96 students aged 14–16 from a public junior high school in ZunYi, China, and they were randomly selected from 2 out of 6 classes. All the students had not learned

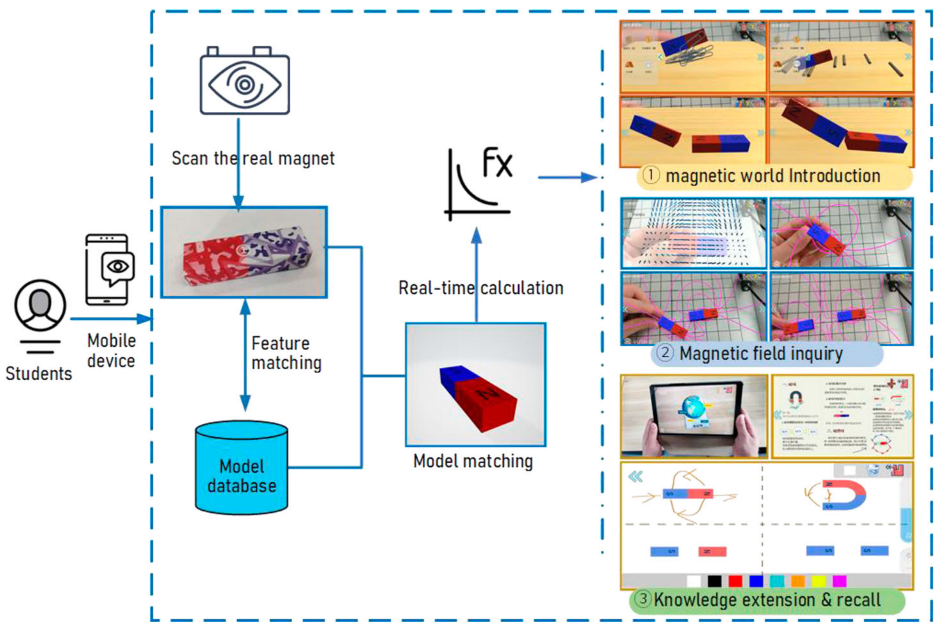

Figure 1. The structure of the AR-based experimental tool and user experience scenarios.

the knowledge of magnetism before the experiment. Students were randomly divided into AR group and Non-AR group, each with 48 students. During the experiment, 4–6 students would collaborate in a sub-group to carry out the experimental operation. The same batch of tablets (IOS system, 9.7-inch screen) was utilized to run the MagAR. Additionally, both groups were taught by the same teacher with a teaching experience of 10 years, and participants were informed that their participation was voluntary.

3.3. Procedure

A 2 × 2 factorial quasi-experiment design was adopted in this study. The first factor under investigation is the experimental condition (AR or Non-AR), and the second factor is LA level (low or high). The detailed procedure was described as follows (see Figure 2):

One week before the experiment, a randomized grouping and pre-test were conducted. At first, the 96 students were randomly assigned to the two groups (AR & Non-AR). Then, a prior knowledge test and a physics anxiety (PA) scale were administered to all the students. According to the PA results of students, we conducted a cluster analysis to dichotomize them into high PA and low PA students. After that, students in the AR group were given another educational AR application to familiarize the basic operations involved in the MagAR.

In the second week, students learned magnetism through three lessons, namely, Introduction to the Magnetic World (40 min), Magnetic Field Inquiry (40 min), and Knowledge Extension & Recall (25 min). The participants in the AR group performed hands-on experiments with the guidance of three

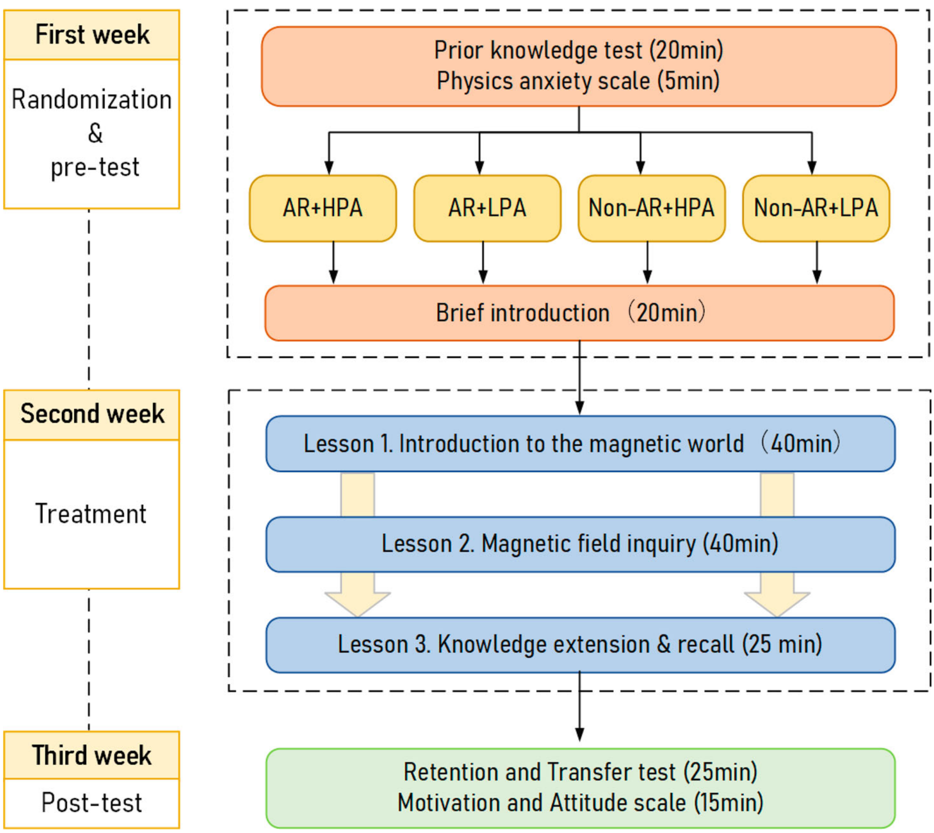

Figure 2. The experiment procedure.

modules in the MagAR, while those in the Non-AR group learned with traditional experimental materials.

One week later, students' learning performance (retention & transfer), motivation, and attitude were collected.

3.4. Instruments

3.4.1. Assessment tools

In this study, students' learning performance was reflected by the scores of magnetism knowledge quiz, including prior knowledge test before treatment, as well as retention test and transfer test after treatment. All questions were jointly designed by three senior physics teachers who had more than ten-year teaching experience and researchers based on the junior high school physics curriculum syllabus. The quizzes were piloted with a cohort of 30 students to check whether the difficulty and the total finishing time were reasonable. After a few rounds of polishing and modifying based on the test results, the items were believed to reflect the students' true level of knowledge concerning magnetism.

Prior knowledge test. The prior knowledge test aimed to examine students' prior knowledge related to the topic of the magnetic field, including four multiple-choice items and five fill-in-the-blanks items with total scores of 18 (2 points for each item). Given that students have not learned this topic before, the questions were situated in some common real-life contexts. For example, one multiple-choice item was "The claw hammer has a cross structure with a magnet embedded in the middle. During operation, the magnet will attract the nail firmly, so what can be chosen as the material of the nail: A. iron; B. copper; C. plastic; D. aluminium."

Retention test. This test was developed to assess students' retention of key concepts after the intervention. To prevent students from remembering the answers of the pre-test, we kept the main items of the pre-test but changed the order of the answer or items, and added some new items regarding the knowledge of magnetism that was taught in class. The finalized retention test consists of two types of questions (26 points in total): multiple-choice questions (6 items, 2 points each) and fill-in-the-blanks questions (7 items, 2 points each).

Transfer test. The transfer test developed by teachers and researchers aimed to examine learners' deeper understanding of magnetism and the ability to apply it to new situations (Barnett & Ceci, 2002). In addition to multiple-choice questions (2 items, 2 points each) and fill-in-the-blank questions (2 items, 2 points each), the graphic question was also included in the transfer test. As shown in Figure 3, students should tag the right N-S pole of the magnet on the picture (2 points), and the direction of the magnetic induction line should be drawn (2 points). Therefore, the total mark for the transfer test was 12 points.

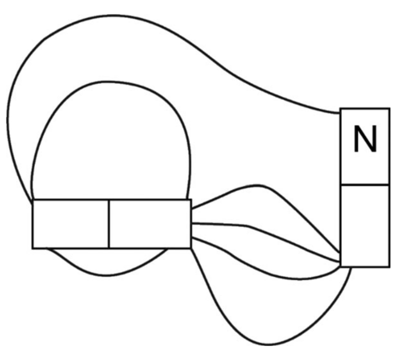

Figure 3. Graphic item.

As for the reliability of the test, due to the relatively few items, the Spearman-Brown prophecy formula was thus utilized to measure it (Kelley, 1925). The r_{kk} value for the prior knowledge, retention, and transfer test were 0.76, 0.81, and 0.75, respectively, indicating the acceptable reliability of the test (LeBreton & Senter, 2008).

3.4.2. Questionnaire

The questionnaire used in this study contained a PA scale (before treatment), a motivation scale, and an attitude scale (after treatment).

Physics anxiety scale., the condensed 16-item version Physics Anxiety Rating Scale (PARS) developed by Sahin (2014) was administrated in our study to measure students' PA (refer to part A of Appendix). Items of the scale are all in a five-point Likert rating in which numerical values ranged from "strongly disagree (1)" to "strongly agree (5)." The Cronbach's alpha was used to examine the internal consistency of the scale, and high reliability was found with an alpha value of 0.863.

Motivation scale. The Instructional Materials Motivation Survey (IMMS) designed by (Keller, 2010) based on his proposed ARCS motivation model (Keller, 1987) was modified to measure learners' level of motivation through 4 dimensions: attention, relevance, confidence, and satisfaction (refer to part B of Appendix). The scale has been widely used to measure students' motivation in educational settings, particularly in simulation-based instruction (e.g. Chen, 2019; Di Serio et al., 2013; Makransky et al., 2019). In this study, the revised scale consists of 20 items with five questions for each dimension, and all items are in a 5-point Likert rating. The scale has a high internal consistency in each category: attention ($\alpha = 0.89$), relevance ($\alpha = 0.85$), confidence ($\alpha = 0.90$), satisfaction ($\alpha = 0.87$).

Attitude scale. To explore students' perception of the proposed AR learning tool, we used the scale based on the measures of Cai et al. (2017), which is modified by the scale of (Chu et al., 2010). The scale consists of 5 items and was only administered to the students who used the AR learning tool. Each item was rated on a 5-point Likert scale. The Cronbach alpha of the attitude scale is 0.823, implying the high reliability of the test.

4. Results

As described above, we conducted a prior knowledge test and PA test among students before treatment. To classify students into low physics anxiety (LPA) and high physics anxiety (HPA), a k-means clustering analysis ($k = 2$), followed by Cai et al. (2019)'s grouping method, was conducted among all participants ($N = 96$) in our study. According to the clustering results, 45 students showed HPA (AR group: $N = 24$, Non-AR group: $N = 21$), and the remaining 51 students showed LPA (AR group: $N = 24$, Non-AR group: $N = 27$). To ensure the results accurately discriminate students with different PA levels, we conducted a single sample t-test to determine if a statistically significant difference existed among the two PA groups and the overall population mean. Results showed that both students with high (Mean = 2.98., SD = 0.35) and low anxiety (Mean = 2.02, SD = 0.38) were significantly different from the overall mean (Mean = 2.468, SD = 0.61). Specifically, students with HPA showed significantly higher anxiety scores than the overall group ($t = 9.764$, $p < 0.001$), while those with LPA were significantly lower than the overall group ($t = -8.495$, $p < 0.001$). Therefore, the clustering results can accurately differentiate students with LPA or HPA from the total population, and participants were assigned into four conditions: (1) AR & LPA; (2) AR & HPA; (3) Non-AR & LPA; (4) Non-AR & HPA.

4.1. Learning performance

In this study, the student's learning performance was reflected by the score of two aspects: retention test and transfer test. The descriptive statistics results are shown in Table 1. A two-way analysis of covariance (ANCOVA) was conducted on the post-test (i.e. retention test and transfer test) scores

Table 1. Descriptive statistics of students' learning performance results.

Groups	*N*	Prior knowledge		Retention		Transfer	
		Mean	SD	Mean	SD	Mean	SD
AR							
HPA	24	13.33	4.11	23.58	1.67	9.08	1.86
LPA	24	16.75	1.84	23.33	1.52	9.58	1.67
Non-AR							
HPA	21	13.52	4.19	20.29	2.12	7.14	2.15
LPA	27	15.63	1.92	21.93	2.11	7.11	2.10

by using prior knowledge test scores as covariates, following the guidance of Tabachnick and Fidell (2012). The detailed results were reported as follows.

4.1.1. Retention

After verifying the homogeneity of regression was not violated ($F = 0.196$, $p > 0.05$), we conducted a two-way ANCOVA on the retention results of the magnetism knowledge test. As shown in Table 2, a significant interaction effect was observed between PA level and experimental condition (F (1, 91) = 5.845, $p < 0.05$, $\eta^2 = 0.06$). Thus, it is sensible to perform a simple main effect analysis to further investigate the effects of the experimental condition and PA on students' learning retention.

As for the effects of PA level on retention results of students in different experimental conditions (see Table 3), it was found both HPA (F (1, 91) = 34.24, $p < 0.001$, $\eta^2 = 0.273$) and LPA (F (1, 91) = 7.07, $p < 0.01$, $\eta^2 = 0.072$) learners treated by MagAR performed significantly better than those who used the non-AR experimental materials. Regarding the effects of the experimental condition on students with different physics anxiety, a significant effect was only found on the Non-AR group learners (F (1, 91) = 8.667, $p < 0.01$, $\eta^2 = 0.087$), while the HPA students and the LPA students in the AR group showed similar results as regards to learning retention (F (1, 91) = 0.139, $p = 0.71$).

4.1.2. Transfer

To explore the differences of transfer results among students in different conditions, we conducted a two-way ANCOVA analysis by using prior knowledge scores as covariate, physics anxiety (HPA/LPA) and experimental condition (AR/Non-AR) as independent variables. The F-test results for the product terms of experimental conditions, PA levels, and prior knowledge scores did not violate the homogeneity-of-slopes assumption ($F = 0.118$, $p > 0.05$), indicating it is sensible to perform the ANCOVA test.

Table 4 shows the results of two-way ANCOVA, no significant effects were found both for PA level (F (1, 91) = 0.540, $p = 0.464$) and the interaction between PA level and experimental condition (F (1, 91) = 0.128, $p = 0.721$). To this end, we subsequently investigated the main effect of experimental conditions on transfer test results, and a significant effect was discovered between students who learned with the two different experimental materials (F (1, 91) = 30.532, $p < 0.001$, $\eta^2 = 0.251$). Specifically, students who were treated with AR learning tool (Adjusted mean = 9.30, SE = 0.27) achieved a significantly higher score than those with Non-AR materials (Adjusted mean = 7.19, SE = 0.27), as is shown in Table 5.

Table 2. The two-way ANCOVA result of the learning retention.

Variables	SS	df	MS	*F*	η^2
Covariance	0.080	1	0.080	0.022	0.000
Experimental condition	131.525	1	131.525	37.029***	0.289
PA level	10.326	1	10.326	2.907	0.031
Experimental condition * PA level	20.762	1	20.762	5.845*	0.060
Error	323.224	91	3.552		

Note: * $p < .05$; *** $p < .001$.

Table 3. Simple main effects analysis results of experimental condition and PA level on learning retention.

Sources	SS	df	MS	*F*	η^2	Comparison
PA level						
HPA	121.61	1	121.61	34.24***	0.273	AR > Non-AR
LPA	25.11	1	25.11	7.07**	0.072	AR > Non-AR
Error	323.22	91, 91	3.55			
Experimental condition						
AR	0.50	1	0.50	0.139	0.002	
Non-AR	30.78	1	30.78	8.667**	0.087	LPA > HPA
Error	323.22	91, 91	3.55			

Note: ** $p < .01$, *** $p < .001$.

4.2. Learning motivation

To compare the differences in students' learning motivation under different conditions, we performed a two-way MANOVA by using the PA level and experimental condition as independent variables, four dimensions of motivation (i.e. attention, relevance, confidence, and satisfaction) as dependent variables. The descriptive statistics are shown in Table 6.

Before examining the effect of each independent variable on the dependent variables, we first tested the MANOVA hypothesis. It was found the motivation scores were all normally distributed, and the Levene's test for equality of error variances were not significant for all four variables (Attention: $p = 0.072$, Relevance: $p = 0.062$, Confidence: $p = 0.438$, Satisfaction: $p = 0.665$). Furthermore, the Box's test of equality of covariance matrix was not significant (F (30, 21900.83) = 1.51, $p = 0.036 >$ 0.001). As such, it is sensible to perform the MANOVA test.

According to the results of MANOVA analysis, a significant interaction effect was found between experimental condition and PA level (Pillais' Trace = 0.111, F (4, 89) = 2.777, $p = 0.032$, $\eta^2 = 0.111$). Specifically, all four dependent variables were influenced by the significant interaction (Attention: F (1, 92) = 6.839, $p = 0.010$, $\eta^2 = 0.069$; Relevance: F (1, 92) = 5.066, $p = 0.027$, $\eta^2 = 0.052$; Confidence: F (1, 92) = 7.089, $p = 0.009$, $\eta^2 = 0.072$; Satisfaction: F (1, 92) = 11.384, $p = 0.001$, $\eta^2 = 0.110$) between the two sources. To this end, a simple main effect test was then performed. The results are shown in Table 7.

As for the effects of different experimental conditions on learning motivation of students with different PA, the HPA students presented significant lower motivation than LPA students on all the four subscales of IMMS (Attention: F (1, 92) = 7.427, $p < 0.01$, $\eta^2 = 0.075$; Relevance: F (1, 92) = 6.879, $p < 0.05$, $\eta^2 = 0.07$; Confidence: F (1, 92) = 11.955, $p < 0.001$, $\eta^2 = 0.115$; Satisfaction: F (1, 92) = 11.902, $p < 0.001$, $\eta^2 = 0.115$) when experimented with traditional learning materials, while learners in AR condition showed similar but higher motivation regardless of their PA level.

Regarding the moderation effects of learners' PA level on their learning motivation when treated with different experimental tools. In the HPA group, the AR learners had significantly higher attention (F (1, 92) = 15.648, $p < 0.001$, $\eta^2 = 0.145$), confidence (F (1, 92) = 9.430, $p < 0.01$, $\eta^2 = 0.093$), and satisfaction (F (1, 92) = 11.072, $p < 0.001$, $\eta^2 = 0.107$) than non-AR learners, while there was no significant difference found in the results of perceived relevance between these learners. Moreover, the students with LPA all perceived similar but high results of motivation whether treated by AR or non-AR materials.

Table 4. The two-way ANCOVA result of the learning transfer.

Variables	SS	df	MS	*F*	η^2
Covariance	35.15	1	35.15	10.130**	0.100
Experimental condition	105.94	1	105.94	30.532***	0.251
PA level	1.872	1	1.872	0.540	0.006
Experimental condition * PA level	0.445	1	0.445	0.128	0.001
Error	315.755	91	3.470		

Note: *** $p < .001$.

Table 5. Main effects of experimental condition on transfer test.

Experimental condition	N	Mean	SD	*Adjusted mean*	*SE*	*F*	η^2
AR	48	9.33	1.56	9.30	0.27	30.532***	0.251
Non-AR	48	7.13	2.10	7.19	0.27		

Note: *** $p < .001$.

4.3. Students' attitudes toward the AR learning tool

Table 8 shows the descriptive statistics of students' attitudes toward the AR-based experimental tool according to their PA level. The independent sample t-test was then conducted to investigate the differences in attitudes between high-anxiety and low-anxiety learners. The results revealed that although all the high-anxiety students showed a lower level of attitude than those with LPA, no significant differences were found between them. Specifically, the students with LPA all hold highly positive attitudes (over 4 points) towards the AR learning tool. For the HPA students, Q1, Q3, Q4, and Q5 achieved a relatively high score (over 3.9), implying this tool contains the contents which are related to the magnetism knowledge and helpful for their learning. With regard to Q2, the relatively low results (Mean = 3.79, SD = 0.78) indicated that most high-anxiety students think this is useful to them.

5. Discussion

While studies showed the positive effect of AR on learning performance and motivation (Chang et al., 2019; Lai et al., 2019; Sırakaya & Alsancak Sırakaya, 2020), few of them focused on the individual emotional attributes such as learning anxiety. Concentrating on the physics discipline, this study explored how different experimental conditions (AR & Non-AR) influenced the learning performance and motivation of students with different levels of LA (low & high). Besides, students' attitudes towards AR application were also examined. The findings are discussed below.

As for the learning performance (RQ1), we examined both learning retention and transfer. In general, the study found that students in the AR group significantly performed better than those treated by traditional materials both on knowledge retention and transfer, no matter how anxious they were about physics. This finding confirmed the positive educational efficacy of AR on learning gains and was in line with some former work (e.g. Cai et al., 2021; Dehghani et al., 2020; Singh et al., 2019). The AR can help students internalize abstract and complicated concepts by visualizing them and providing a natural interaction with the virtual-real mixed environment (Azuma, 1997; Dehghani et al., 2020), thereby improving the learning gains. Besides, AR can effectively promote knowledge transfer on magnetism than traditional material; this also collaborated the study of Cai et al. (2021), which depicts that AR virtual experiments can lead students to concentrate on high-level conception. Moreover, in the traditional group, students with LPA outperformed those in the HPA condition in terms of retention knowledge, while the counterpart in the AR group showed similar results. This finding implied that PA had a negative impact on learning retention if learners were not given an effective intervention. This finding echoes some previous studies (e.g. Sahin, 2014; Sahin et al.,

Table 6. Descriptive statistics of motivation results.

	Attention		Relevance		Confidence		Satisfaction	
Groups	Mean	SD	Mean	SD	Mean	SD	Mean	SD
AR								
HPA	4.28	0.47	4.01	0.48	4.00	0.60	4.18	0.52
LPA	4.13	0.45	3.93	0.38	3.95	0.52	3.97	0.48
Non-AR								
HPA	3.65	0.52	3.77	0.57	3.46	0.56	3.63	0.55
LPA	4.07	0.67	4.17	0.62	4.05	0.65	4.18	0.62

Table 7. Simple main effect results of experimental condition and PA level on learning motivation.

Dependent Variable	Sources	*F*	η^2	Comparison
Attention	Experimental condition			
	AR	0.933	0.010	
	Non-AR	7.427**	0.075	HPA < LPA
	PA level			
	HPA	15.648***	0.145	AR > Non-AR
	LPA	0.154	0.002	
Relevance	Experimental condition			
	AR	0.305	0.003	
	Non-AR	6.879*	0.070	HPA < LPA
	PA level			
	HPA	2.30	0.024	
	LPA	2.799	0.030	
Confidence	Experimental condition			
	AR	0.087	0.001	
	Non-AR	11.955***	0.115	HPA < LPA
	PA level			
	HPA	9.430**	0.093	AR > Non-AR
	LPA	0.383	0.004	
Satisfaction	Experimental condition			
	AR	1.724	0.018	
	Non-AR	11.902***	0.115	HPA < LPA
	PA level			
	HPA	11.072***	0.107	AR > Non-AR
	LPA	1.919	0.02	

Note: *$p < .05$, **$p < .01$, ***$p < .001$.

2015). The cause for this may stem from the inconvenient operation of physical magnetic learning materials (Cai et al., 2017); specifically, through teacher's observation, some students got troubles in traditional lab work. For example, due to inappropriate operation, the iron filings were attracted to the magnet, thereby hindering their knowledge acquisition.

To answer the RQ2, four dimensions (i.e. attention, relevance, confidence, and satisfaction) of Keller (1987)'s ARCS motivation model were examined. Similar to the result on learning performance, the negative relation between anxiety and motivation in Non-AR condition also emerged in current work. This finding reaffirmed the view that higher anxiety yields lower motivation if not controlled well (Liu, 2012). Besides, LPA and HPA students in the AR group presented similar motivation, which may indicate that AR can moderate the negative impact of anxiety on learning motivation by enabling students to observe and manipulate the learning materials along with the corresponding information. Since the real magnets were served as AR markers, students could learn this topic by observing the real-time changing magnetic induction line generated by the interaction congruent to the real-world operation. This embodied visual and haptic AR experience would further promote students learning motivation (Lindgren et al., 2016). Moreover, although the positive effect of AR on LA was not significant like Chen (2019)'s work on maths discipline, the non-significant

Table 8. Descriptive statistics of students' attitudes toward the AR-based experimental tool and the *t*-test results.

Attitude toward the AR-based experimental tool	PA	Mean	SD	*t*
Q1. I feel the AR-based learning tool is helpful for learning new physics knowledge.	HPA	3.96	0.62	−1.850
	LPA	4.29	0.62	
Q2. The AR-based learning tool is more effective than other learning software I used before.	HPA	3.79	0.78	−0.840
	LPA	4.00	0.93	
Q3. The content of the AR-based experimental tool is highly relevant to the course content (magnetism). I want to use it.	HPA	4.21	0.78	−1.003
	LPA	4.42	0.65	
Q4. The AR-based experimental tool enables me to learn at my own pace and collaborate with my partners.	HPA	4.00	0.59	−0.225
	LPA	4.04	0.69	
Q5. The AR-based experimental tool gives me a larger space to think and reflect and enables me to resolve problems more easily.	HPA	3.96	0.62	−0.644
	LPA	4.08	0.72	

but high results (>3.9) also shed light on the AR benefits on motivation and echoed with some previous studies (e.g. Chang et al., 2019; Lai et al., 2019; Sırakaya & Alsancak Sırakaya, 2020).

In addition, the HPA students in the AR group had higher perceptions of attention, confidence, and satisfaction than the Non-AR counterpart. This result implies that AR can significantly increase HPA students' curiosity about learning materials, help them believe they would control their learning pace, and be satisfied with the learning process (Keller, 2010). An interesting finding has emerged on relevance, that is, regardless of how anxious they were, students all presented similar but high results on relevance concerning both experimental materials, which means the physical and AR manipulative all conveyed the knowledge by the way that relevant to their lives and learning goals (Keller, 2010). One possible reason for this is that both conditions used the real magnets to manipulate the experiment, in which they could perform more meaningful motions that congruent to the learning goal.

Furthermore, with regard to the attitude (RQ3), we found both HPA and LPA students hold a positive attitude on the AR experimental tool, which confirmed the usability of the MagAR on magnetism learning. This finding aligns with the review of Sırakaya and Alsancak Sırakaya (2020), which indicated that AR could help develop students' positive attitudes. Besides, the high rating of Q3 corroborates the finding on the relevance dimension of motivation wherein students all reported high results no matter how anxious they were.

6. Conclusions

This study tried to compare the impact of experimental conditions and PA level on students' learning performance, motivation, and attitudes towards AR materials. The MagAR was proposed based on Keller's ARCS model (Keller, 2010) to support magnetism learning of junior high school students. From empirical results, the following conclusions can be drawn: First, AR can significantly improve students' retention and transfer knowledge no matter what LA students present. Moreover, although the traditional material can improve LPA students' retention knowledge, this effect disappeared in the transfer condition, which ulteriorly highlights the AR's exclusive benefits on learning transfer. Second, except for the relevance dimension, HPA students in the AR group perceived higher motivation than students in the Non-AR group. Meanwhile, both HPA and LPA students treated by AR presented similar but high motivation, which signified the AR benefits motivation, especially on HPA students. Third, regardless of how anxious they were, students all held positive attitudes on AR experimental tool. Furthermore, we found that learning anxiety was negatively related to learning performance and motivation in traditional condition, echoing with previous studies (Liu, 2012; Sahin et al., 2015).

Some implications can be highlighted based on our findings. As for the positive effect of AR on learning performance, motivation, and attitudes, we argue that AR can be served as an effective tool to facilitate students' lab work, especially for abstract concepts. Considering AR can display the measuring data on the physical experimental instruments, thereby reducing cognitive load and promoting learning performance (Thees et al., 2020), more research was recommended to focus on promoting laboratory experience. Regarding the finding that AR can better foster knowledge transfer and present a distinct advantage in motivating HPA students. More research that focused on the high-level knowledge representation and certain portraits of students with HPA (e.g. cognitive style) is suggested to be implemented to provide a suitable AR manipulative to arouse students' interest and promote their learning performance. Moreover, in terms of the interaction effect between experimental conditions and LA level on learning retention and motivation, it is suggested that we cannot simply compare different experimental conditions without considering the role of some emotional factors such as anxiety.

Some limitations of the study need to be mentioned. On one hand, the learning anxiety in our study was only served as a trait of students and collected before treatment; the "state anxiety," which may fluctuate over time, is also a critical attribute of students but ignored in the present study (Spielberger et al., 1983). If we can measure the changes in anxiety at different phases of lessons, there may be more interesting findings. On the other hand, we only investigated the impact of LA on experimental learning; some possible anxiety-related factors (e.g. gender, autonomy) that emerged from other studies (Chen & Hwang, 2020; Sahin, 2014) were not considered in the current study. In future work, more effort can be made to understand and reduce anxiety as well as the negative impacts it may cause. What is more, more empirical attempts are needed to evaluate whether the findings of the current study can be replicated to different subjects and educational levels.

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