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Applications of augmented reality-based natural interactive learning in magnetic field instruction

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ABSTRACT

Educators must address several challenges inherent to the instruction of scientific disciplines such as physics – expensive or insufficient laboratory equipment, equipment error, difficulty in simulating certain experimental conditions. Augmented reality (AR) can be a promising approach to address these challenges. In this paper, we discuss the design and implementation of an AR and motion-sensing learning technology that teaches magnetic fields in a junior high school physics course. The purpose of this study is to explore the effects of using natural interaction on students' physics learning and deep understanding compared to traditional learning tools. The 38 eighth graders who participated in this study were assigned to either an experimental group or a control group. Analysis of the results shows that the AR-based motion-sensing software can improve students' learning attitude and learning outcome. This study provides a case for the application of AR technology in secondary physics education.

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Introduction

The emergence of advanced technologies leads to new ideas and innovative practices, such as the integration of interactive media into education. In physics education, computer-simulated experiments are often used to present phenomena that are difficult to observe in reality. For example, magnetic fields are common phenomena in daily life. However, the invisibility of magnetic repulsion and attraction can lead to confusion and increased difficulty in teaching the topic. Physics educators must address how to teach intangible objects and processes in a sensory way.

The traditional demonstration of magnetism is to examine iron scraps simulating the distribution of a magnetic field. In most classes, teachers demonstrate and students watch, and teaching is challenging because of insufficient or expensive equipment, inconvenient operation (for example, iron scraps are easily absorbed onto the magnets and the residue is swept after the experiment), and so on. In other cases, virtual experiments are controlled interactively by means of a mouse, keyboard, touch screen, wearable devices, or other handheld devices. Although there are many Flash-based multimedia magnetic field experiments for simulation in teaching, the experience can be limiting and unnatural. A large gap remains between the information input mode and the real experimental conditions during the experiments. This requires an adaptive process to help students understand these experiments.

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Augmented reality

In recent years, Augmented Reality (AR) technology, an extension of Virtual Reality (VR), has been increasingly used in the field of education (Wu, Lee, Chang, & Liang, 2013). The presentation of AR, which is based on real-world scenes and enhanced by virtual data, provides a more intuitive and natural way to teach and interact with information, and creates a powerful space for exploration. Generally, VR/AR is most applicable in the following two instructional situations: (1) when the phenomenon cannot be simulated in reality (e.g. if it is too small or too large), such as the solar system in "the book of the futures" (Cai, Wang, Gao, & Yu, 2012); or (2) when real experiments are dangerous or have practical concerns (Cai, Chiang, & Wang, 2013; Cai, Wang, & Chiang, 2014; Chang, Wu, & Hsu, 2013). Cai et al. (2013) used a virtual lit candle in a real classroom for the convex imaging experiment to avoid the risk of fire. Chang, Wu, et al. (2013) designed an experiment to examine students' learning behaviors under the nuclear radiation pollution environment near the 1st Fukushima Daiichi Nuclear Power Plant in Japan after a 3.11 earthquake. Cai et al. (2014) targeted "the composition of substances" segment of junior high school chemistry classes and, furthermore, involved the design and development of a set of inquiry-based AR learning tools. They concluded that the AR tool has a significant supplemental learning effect as a computer-assisted learning tool and is more effective for low-achieving students than high-achieving ones. Students generally have positive attitudes toward AR tools and students' learning attitudes are positively correlated with their evaluation of the software. Despite evidences that demonstrate AR's benefits in the classroom, the use of AR technology alone cannot solve the natural interaction problem in education. This is because, in order to trigger a computer response by the optical capturing of markers in an AR application, learners need to map the interactive operation to the intermediary medium. For example, in the convex imaging experiment proposed in Cai et al. (2013), learners need to (1) operate 2D-code cards to change the object distance and the distance between the object and the lens; and (2) imagine that the 2D-code cards are the experimental facilities. The learning effects could have been compromised due to the increased cognitive load caused by the information migration. The experiment may be more interesting if the virtual object that is difficult to achieve in reality was merged into a real scenario with AR and the learners' interactive operational behavior was the same as the real experimental condition. The latter is the human–computer interaction technology that is representative of a motion–sensing interaction.

Natural interaction technology

In recent years, free motion-sensing interactive technologies that can replace a keyboard and mouse have impacted educational practices in significant ways (Johnson et al., 2013; Johnson, Adams, & Cummins, 2012; Johnson, Adams, Estrada, & Freeman, 2014, 2015; Johnson, Levine, Smith, & Stone, 2010; Johnson, Smith, Willis, Levine, & Haywood, 2011). Stemming from games, this motion-sensing technology enables users to operate and control games through gestures and body motion. Utilizing this technology usually requires a proper hardware and software package. Three cases have shown the potential of AR-based natural interaction technology in the educational field.

In November 2010, Microsoft Corporation released a motion-sensing device called Kinect, which contributed to a wave of motion-sensing device applications. Researchers at the Vienna University of Technology had demonstrated the application of AR technology in teaching mechanics (Kaufmann & Meyer, 2008). It used a physics engine to develop computer games, simulating experiments in the field of mechanics in real time. The students actively created their own experiments and studied them in a 3D virtual world. Before, during, and after the experiment, the system provided a variety of tools to help students analyze the force, mass, motion paths, and other physical quantities of the target object. However, the system required expensive helmets, stereoscopic glasses, and other equipment. Researchers from Arizona State University developed a multimedia art learning environment in mixed-reality called SMALLab (Johnson-Glenberg, Birchfield, Savvides, & Megowan-

Romanowicz, 2011), which allowed students to learn through the body's 3D motion and hand gestures in a PC-simulated collaborative multimedia space. They designed a series of collaborative learning solutions based on the environment mentioned above under the guidance of a community team composed of professional K-12 teachers, students, media researchers, and artists. This simulative teaching environment was created by combining motion-sensing and AR techniques. However, the environment requires a separate space and sophisticated equipment. Chang, Chou, Wang, and Chen (2013) developed Kinempt (kinect-based vocational task prompting system), which allowed individuals with cognitive impairments to accomplish task objectives independently through prompted steps. The evaluation found that the system, combined with specific operating strategies, can effectively enable individuals with cognitive impairments to obtain job skills.

AR-based natural interaction technology has also been applied in teaching magnetism. Buchau, Rucker, Wössner, and Becker (2009) developed an AR simulation for teaching magnetism. In the simulation, a previously calculated magnetic field is applied, but it is static with invisible real-time effects and two-magnet models are absent. Mannus, Rubel, Wagner, Bingel, and Hinkenjann (2011) taught basic magnetic concepts with two handheld devices and AR techniques, which demonstrated that the experiment improved the students' understanding of magnetic fields. Matsutomo, Miyauchi, Noguchi, and Yamashita (2012) simulated the magnetic induction line and AR images presented in real time and designed a dependent magnetic model and magnet-current model based on the teaching application. One year later, Matsutomo, Mitsufuji, Hiasa, and Noguchi (2013) further refined the model, moving and plotting the distribution of the magnetic induction line on a monitor, by using a specially prepared bar-like fake magnet. Ibáñez, Di Serio, Villarán, and Kloos (2014) found that the AR application can effectively improve students' understanding of electromagnetic concepts and phenomena. They also determined that, compared to web-based application, AR-based application enables students to have higher-level experiences.

As can be observed, an AR-based simulation has more advantages than the rigid mouse-controlled form. This conforms to the AR operational advantages generalized by Carmichael, Biddle and Mould (2012) from cognitive theory, including the use of reality, virtual flexibility, invisible interface, and spatial awareness. From the perspective of virtual flexibility, this will create a wider space to liberate users from the use of a mouse and a keyboard. Carmichael et al. (2012) believed that multiple advantages can be utilized to enhance the AR system efficiency (the better a learning system is designed, the better AR works as an interface). Vogt and Shingles (2013) experimentally demonstrated that the AR technology can be independently applied and used by users without specialized knowledge. In the virtual simulation learning context, the presentation effect of abstract objects is subject to the level of students' prior knowledge and the difficulty of the learning content. With sufficient prior knowledge, whether we use abstract objects in teaching causes no impact on learning; this suggests that the influence of a technological innovation must be closely correlated with the students' prior knowledge. This also leads to the question of what influence an AR-based natural interface learning environment has for students with different levels of prior knowledge. Does it affect students' in-depth cognition? How can we evaluate the effect of AR technology on learning? In this study, we use AR and natural interaction technology in a class that teaches magnetic fields to explore the influence of an AR natural interactive environment on learners' attitude and learning outcomes.

Natural interactive learning environment system

System overview

The system integrates AR with natural interaction technology. The development of the system can be divided into three phases: modeling of magnetic induction line, motion-sensing, and compositing rendering, as shown in Figure 1. We build a magnet and magnetic induction line model based on Biot-Savart Law using 3D modeling tool *3DS Max* and graphics engine *Java 3D*. Then, we plant the

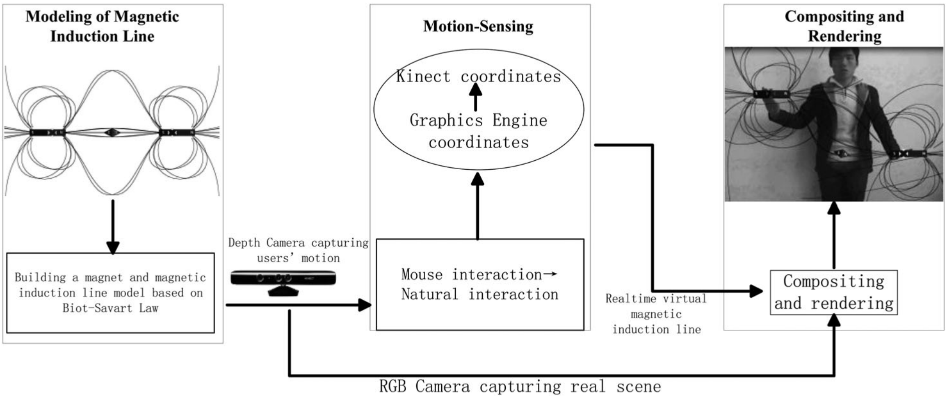

Figure 1. System overview.

model into a Kinect environment and adjust the coordinate system and the interactive mode between users and the model. With the help of the built-in RGB camera of Kinect, the system can render real-time virtual models and the real scene to present a mixed interactive environment. The depth camera also helps to return the distance between users and the Kinect device, so we can control the rotation of the virtual model by changing the relative distance.

System interface and user operation

Because this system emphasizes natural interaction, there is a borderless full-screen interface after the program starts. At first, users will see the real picture captured by the Kinect RGB camera. Then users wave their hands to trigger the virtual magnet model and the simulated magnetic field, which are displayed in two forms: magnetic induction line and small magnetic pins.

The system includes four parts: a magnetic induction line model 1 with a magnet and small magnetic pins (Figure 2(a)), a magnetic induction line model 2 with a magnet and magnetic pins (Figure 2(b)), an S-N model with two magnets and a small magnetic pin (Figure 2(c)), and an N-N model with two magnets and small magnetic pins (Figure 2(d)), as shown in Figure 2.

Method

Participants

In this experiment, the sample consists of 42 students in grade 8 at a junior high school. Prior to the experiment, students in the sample were randomly divided into two groups: Groups A (control group) and B (experimental group). Each group was divided into five subgroups with four students in each subgroup. The two groups were not systematically different with respect to achievements in physics

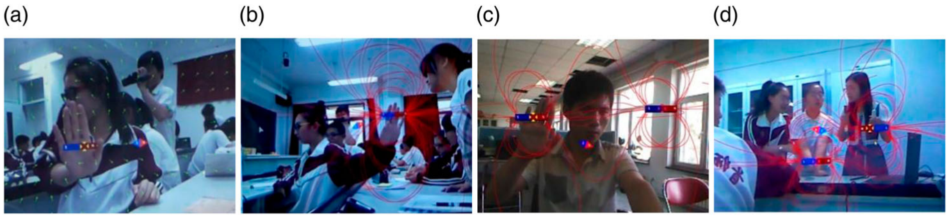

Figure 2. Magnetic induction line model.

according to the independent sample *t*-test on the last mid-term physics exam. Four students, No.S5, S15, S19, S41, who did not attend the post-test, were excluded from the experiment.

Research design

Quasi-experimental study

A quasi-experimental study refers to a method by which the experiment is performed in a more naturally occurring way with the original population and without a random arrangement of the study objects (e.g. classrooms) (Thompson & Panacek, 2006). We used a quasi-experimental design consisting of a pre-test, a post-test, and a delayed post-test, as shown in Table 1. ("O" means "measurement," the subscript means the sequence of measurements, and "X" means "experimental treatment.)"

In this experiment, there was only one experimental variable, namely, the teaching method. In the control group, the traditional teaching method and models were used to explain the knowledge of magnetic induction lines. In the experimental group, the AR-based motion-sensing program was used by the students to explore and acquire the knowledge of magnetic induction lines. In both the control and experimental groups, the instructor was the same. During the experiment, we conducted three tests: before, immediately after, and one week after the lessons.

Instructional design for experimental and control groups

Both groups performed team-based inquiry learning covering the same learning objectives. The learning objectives were derived from widely used textbooks and confirmed by three experts from the physics teaching team in the junior school. The teaching program was based on the original teaching design of the teachers in the junior school. The overall experimental conditions were adjusted and finalized.

The learning time for both groups was the same, about one hour. However, before class, five teams in Group B had 30 minutes each to experience the equipment and learn its basic operation. The preliminary experience was a previously developed brick-fighting AR motion-sensing game irrelevant to the curriculum. It aimed to reduce the side effects of a new AR motion-sensing operation on learning.

The first 10 minutes of the lesson for both groups was similar based on the teaching plan. Beginning with existing knowledge about magnetism in the elementary school, the teacher introduced the concept of a magnetic field and gradually built inquiry learning architecture for the students. Prior to the inquiry learning process, the students already had a basic understanding of magnetic fields as invisible and intangible, but as having an objective existence based in matter.

The inquiry learning highlighted the rule of the magnetic field and the magnetic lines. Four tests were set, that is, the direction of the magnetic field, the nature and direction of the magnetic induction line, the characteristics of the magnetic induction line and the magnetic induction line inside the magnet, and the magnetic field around two magnets. Five subgroups in Group A were provided with two bar-like magnets, some small magnetic pins, and white papers; while five subgroups in Group B were provided with a Kinect device and two magnets.

To ensure the participation and collaboration quality in each subgroup, each student was assigned a role with specific tasks during the inquiry process (i.e. commander, operator, recorder, or reporter). The commander was responsible for directing the operator to operate the instrument and device and coordinate the task division; the recorder had to complete the test report and record the findings and conclusion on the report sheet as required; and the reporter had to report the inquiry process and results to the class after the experiment (a group can either volunteer to present or it can be

Table 1. Pre- and post-tests and delayed test design.

Group/test	Pre	Variable	Post	Delayed
Group A (Control)	O_1	– (Traditional teaching method)	O_2	O_3
Group B (Experimental)	O_1	X (motion-sensing teaching software-based teaching method)	O_2	O_3

picked by the teacher.). The roles were designed to trigger students' active hands-on experimentation, thinking, digestion of content, collaboration, and teamwork. After the end of the experiment, the teacher summarized the learning objectives and experimental process to ensure that each student built up the correct concept in addition to the teams' summaries. In addition, each subgroup had an undergraduate assistant to cope with unexpected conditions related to the software and hardware.

Because of the use of different experimental equipment, the two lessons of Groups A and B had dissimilar sequences during the inquiry process, but the contents were generally kept consistent. For example, students in Group A recorded the direction of the magnetic field on paper with small magnetic pins and magnets and drew the shape of magnetic induction lines by connecting the points; students in Group B determined the direction of a magnetic field presented by magnetic induction lines through repeated experiments in the AR environment. Examples of the inquiry scenario of both groups are shown in Figure 3.

Questionnaires and interviews

We made questionnaires to evaluate the students' satisfaction and acceptance level with the AR-based motion-sensing teaching method. Additionally, we explored whether the students would talk about their feelings about the teaching method as well as comment on the AR-based motion-sensing program in the experimental operation. Several students would be randomly selected to have a 30-minute interview after the lesson.

Research tools

Magnetic knowledge quiz

Three tests were given during the study. The physics knowledge quiz used in all tests was the same except for the sequence of questions in the pre- and post-tests. We analyzed the learning objectives required in the magnetic induction lines chapter and sorted out the knowledge logistics of magnetic induction lines and the corresponding learning objectives in advance. During an interview with the teachers, we shared our analysis results, discussed these results with them, adjusted the analytic results, finalized the learning objectives to be included, and confirmed the emphasis and difficulties in the lesson according to the teachers. Then, we designed the test questions on magnetism with the purpose of examining the learning objectives generalized from the preliminary analysis. The final quiz included two types of questions: graphics and judgment. For example, one of the judgment questions is about the concept of magnetic induction lines: *Magnetic induction lines are all curves with arrows, and they cannot be straight lines.* One of the graphic questions is about comprehensive application: *Mark the names of magnet poles, and draw the magnetic induction lines in* Figure 4.

Furthermore, we consulted with three physics teachers to determine the learning objectives to be investigated throughout the experiment. Additionally, we randomly selected four junior students to

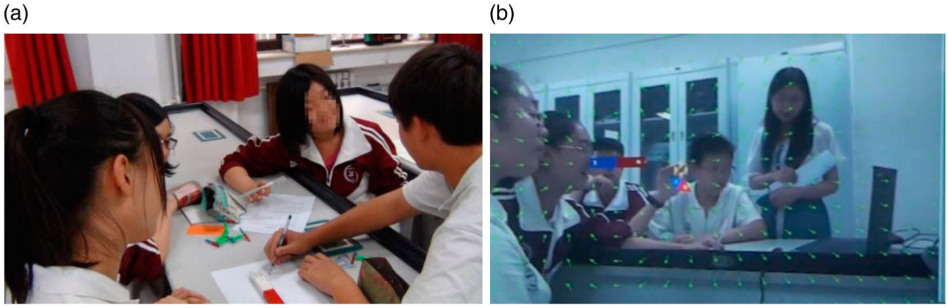

Figure 3. Both groups in exploration.

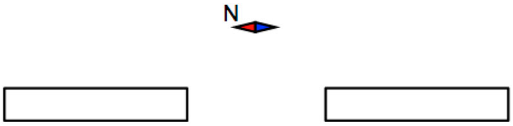

Figure 4. Example of graphic questions.

ensure that they could accurately understand the questions without any ambiguity to guarantee the reliability and validity of the quiz. The sequence of questions in the quiz was changed in the pre- and post-tests. This was done to avoid the phenomenon of students answering the quiz without hesitation and by memory. In the third test (the delayed test), we used the same quiz. To sum up, the quiz was made by a junior high school physics teacher and further examined by a group of physics education experts, including three junior high school physics teachers and two professors specializing in science education in order to guarantee the reliability and validity.

Attitude questionnaire

The attitude questionnaire model used in the test was modified based on the questionnaire proposed in Chen and Tsai (2012), Chu, Hwang, and Tsai (2010), Chu, Hwang, Tsai, and Tseng (2010). It was used to evaluate the students' satisfaction and acceptance level with the AR-based motion-sensing teaching method. After the lesson with the experimental group, all of the students in the experimental group completed the questionnaire. The students in the control group did not answer the five-point Likert-scale questionnaire. It consisted of 25 questions, including 4 parts: learning attitude (1–4 questions), satisfaction (5–11 questions), attitude toward the motion-sensing technology and AR-based program in learning (12–14, 19–22 questions), and evaluation of the experience and of the design of the procedural operation (15–18, 23–25 questions). 14 out of 20 questionnaires were completed. The instrument had a coefficient of internal consistency (Cronbach's alpha) of 0.94. The experimental data were analyzed using SPSS 20.0. Cronbach's Alpha coefficient for the questionnaire was 0.953, suggesting that the questionnaire is reliable.

Research findings

Quantitative analysis

Overall analysis of test results

The average scores of both groups A and B before, after, and one week after the experiment are shown in Figure 5.

As observed from the test score, the average scores of Group B were higher than those of Group A in the tests immediately after and one week after the experiment, when the prior scores of both groups were not significantly different. In addition, the average score of Group B one week after the experiment was much higher than group A, suggesting that the inquiry experiment in the AR-

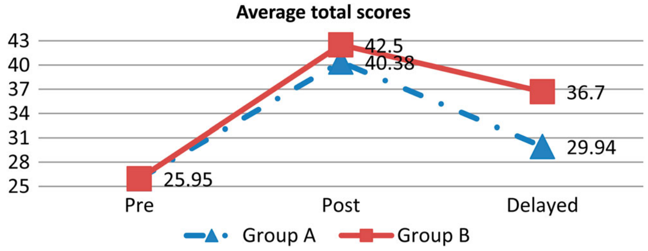

Figure 5. The average scores in both groups A and B before, after, and one week after the experiment.

based environment with the motion-sensing devices had a positive influence on students' learning and was able to maintain that influence for a longer time. There was no significant difference between the control and cxperimental groups in the pre-test, post-test, and delayed test ($p < .05$).

Stepwise analysis of test results: graphics

The graphics in the test can intuitively reflect students' understanding of magnetic field and magnetic induction lines. In the 3 tests, the average scores of the graphic part in Groups A and B are shown in Figure 6.

Figure 6 indicates the scores of Group B were higher than those of Group A. Additionally, while evaluating the test sheets, we found that students in Group B were more active than those in Group A. Prior to the experiment, there were 12 and 16 students from groups A and B, respectively, who participated in the quiz (answering all of the questions). The statistical results from the two tests after class are shown in Table 2; all unfinished quiz sheets were excluded from the results. After class, students' participation in graphic questions was significantly different between the two groups. The participation rate of students in Group B was higher than those of Group A.

Irrespective of score or participation, students in Group B performed better than those in Group A on graphics questions, suggesting that the seamless environment of AR and motion-sensing technology is conducive to student understanding of magnetic fields and magnetic induction lines.

Stepwise analysis of the test results: judgment

The judgment questions in the quiz were used to investigate whether the students mastered and understood the concepts. We found that students could grasp the concepts only when the observed phenomena were summarized as laws in the experiment. The average scores for judgment questions in the 3 tests for both Groups A and B are shown in Figure 7.

The score trend of both groups is different from that in the overall and graphic parts. Group B was lower than Group A in test scores for the judgment questions in the 3 tests, and the gap between the test scores during the experiments widened. This suggests that our program was not significantly helpful in helping the students understand the laws, compared to the intuitive recognition of the magnetic field and the magnetic induction line. However, we found that both groups behaved consistently in the judgment questions one week after the experiment, and the gap between the two groups was the smallest in the 3 tests. This suggests that Group B was better than Group A in maintaining the knowledge for a longer time.

Stepwise analysis of test scores: mastery of knowledge

Judgment questions were analyzed and the results are shown in Table 3. Students had the most difficulty with Questions 2, 7, and 9. Questions 2 and 9 were concepts and laws that could not be observed in the experiments. As for conceptual questions (Questions 3 and 5), the students frequently gave incorrect answers, suggesting that the students poorly mastered the phenomena

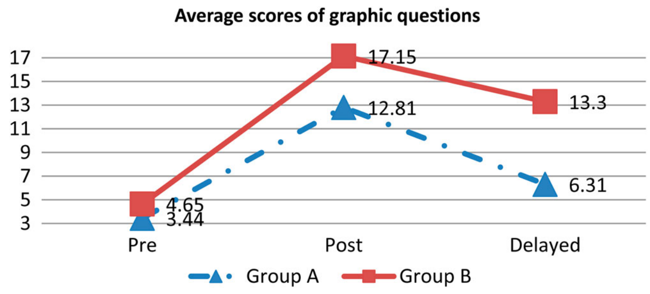

Figure 6. Average scores of graphic questions in Groups A and B before, after, and one week after the experiment.

Table 2. Participants answering all of the questions of Groups A and B in graphic questions in the pre- and post-tests and the delayed test.

	Pre		Post		Delayed[a]	
Graphic questions	*N*	Percent	*N*	Percent	*N*	Percent
A	12	75.00	5	31.25	6	37.50
B	16	80.00	14	70.00	17	85.00

[a] One week after Experiment

that were not observable. Question 7 was about N and S poles. The answers were generally correct during the experiments after class; however, after one week, the students did not retain much knowledge. Additionally, on Question 1 in the graphic part, no student could plot the tangent line accurately on the three tests. It is difficult for students to understand this concept in class, so more time may need to be allocated to teach this concept.

Comparing the data of Groups A and B, we found a larger difference in Questions 3 and 6, which was especially significant after the experiment, as shown in Figures 8 and 9.

Question 3: The magnetic field is not real, but assembled for studies.

Question 6: the magnetic induction line is plotted to depict the magnetic field imaginarily and does not objectively exist.

Both questions were related to the magnetic field. Group A's scores on Question 3 were better than Group B, but the results for Question 6 were the opposite. Group B may have confused two concepts when the students observed the magnetic induction lines and explored the nature of the magnetic field in class. This checkpoint is marked as a difficult point, and it requires more adequate instruction on the difference between the concepts by the teacher.

Attitude questionnaire analysis

Fourteen students of the experimental group scored high in the attitude questionnaire, suggesting that students were actively learning physics. The result is shown in Table 4. The attitude questionnaire clarifies several factors.

In questions regarding experience and satisfaction, the students' scores increased and they showed an interest in further experiencing the inquiry learning process with AR-based motion-sensing technology as shown in Table 5.

The average score was 4.67 in this part, showing that the students actively applaud the inquiry learning process with the AR-based motion-sensing environment. Notably, the students were strongly interested in and willing to learn with AR-based motion-sensing technology. This suggests that the students liked the new curriculum and the technology used. The inquiry learning process with the AR-based motion-sensing software stimulated the enthusiasm and interest of the students.

In questions on learning attitude with the AR-based motion-sensing program, students' answers are shown in Table 6.

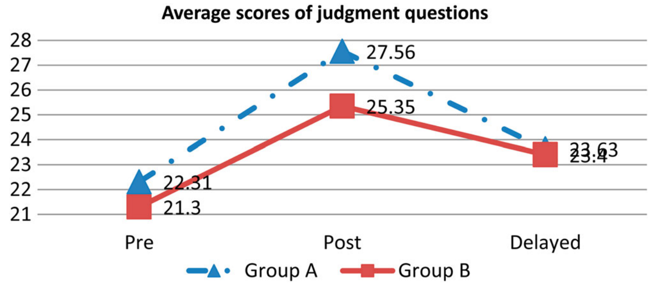

Figure 7. Average scores of judgment questions in Groups A and B before, after, and one week after the experiment.

Table 3. Answers of Groups A and B in judgment questions before, after, and one week after the experiment (after the invalid samples are eliminated).

Questions percentage (%)		1	2	3	4	5	6	7	8	9	10	11	12
Pre-test	Group A	100	37.5	75	75	50	68.75	50	50	18.8	100	43.8	75
	Group B	90	35	75	70	60	60	45	65	25	80	45	60
Post-test	Group A	100	37.5	100	68.8	56.3	81.3	93.8	62.5	68.8	87.5	75	87.5
	Group B	95	35	85	65	70	90	75	55	50	80	80	65
Delayed Post-test	Group A	100	31.3	87.5	68.8	75	81.3	43.8	37.5	31.3	93.8	62.5	75
	Group B	100	30	55	70	65	95	45	70	25	85	65	70

Based on the responses to Q15, Q16, and Q18, the students could rapidly get started after knowing the operation method, although they gave lower scores for the operability and reading of the software. This suggested that the current operation did not add barriers to the use of the software. However, to attain better user experience, the software must be improved. Based on the responses to Q23, Q24, and Q25, the students confirmed the authenticity of the software, although they gave lower scores to the software package than we expected. This suggested that the software's core functionality reached its anticipated goals.

On the whole, students' responses to the attitude questionnaire were positive and showed that they were excited and optimistic about the new technology and software. The questions that had the highest scores were students' interest in physics, inquiry learning, and AR-based motion-sensing technology; lower scores occurred on the interface design, such as the software color and layout. This suggested that the software resulted in the anticipated effect on the experimental group (group B). Issues raised by the feedback were consistent with our expectations and will be further resolved and improved.

Students' perspective on AR-based natural interaction learning

After the lesson of the experimental group, we randomly selected four students (numbered as S1, S2, S3, and S4) for interviews. From the interviews with students, we can draw the following conclusions:

(1) Most of students felt that the lesson was very novel and interesting.

Compared to the control group, we added the AR-based motion-sensing program in the experimental group and the students worked on their own. The students had not observed the AR-based motion-sensing program before. Some students had heard of the technology, but they had not applied it in the classroom. Therefore, for the students, the method was very novel and interesting. They thought it was "very novel because of augmented reality in a way that hasn't been done before"; "I felt the lesson was very uniquely designed"; "I have not used the motion sensing

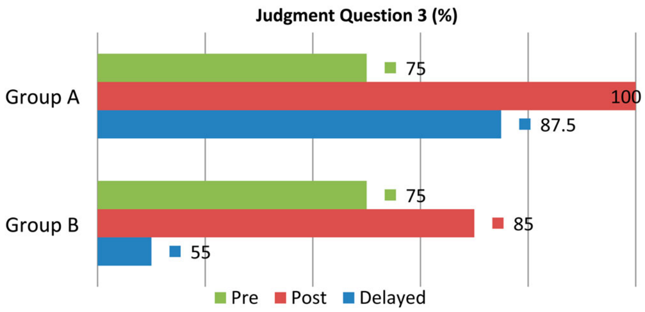

Figure 8. Answers of Groups A and B to Judgment Question 3 before, after, and one week after the experiment (after the invalid samples are eliminated).

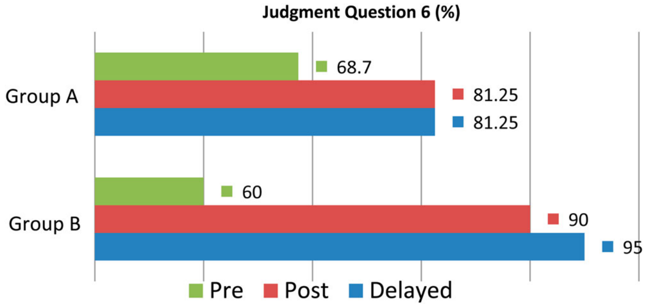

Figure 9. Answers of Groups A and B to Judgment Question 6 before, after, and one week after the experiment (after eliminating invalid samples).

Table 4. The Mean and SD of learning attitudes.

Learning attitudes	Mean	SD
Q1: I feel learning magnetic field content is meaningful and worthy	4.57	.65
Q2: I feel learning and observing more physics content is important	4.86	.36
Q3: I will actively seek solutions (from the teacher, classmate, network, book) in case of issues during physics study	4.57	.51
Q4: I feel learning physics is important for everybody	4.43	.76

Table 5. The Mean and SD of feelings about the lesson.

feeling of the lesson	Mean	SD
Q5: Learning through AR-based motion-sensing software is more interesting than previous learning methods	4.79	.58
Q6: Inquiry learning helps me discover new problems	4.86	.36
Q7: I like learning physics with AR-based motion-sensing software	4.57	.76
Q8: I like learning physics in an explorative way	4.79	.43
Q9: I hope to learn with and use AR-based motion-sensing software in other disciplines, such as chemistry and biology.	4.71	.61
Q10: If permitted, I hope to learn physics with similar AR-based motion-sensing software	4.64	.84
Q11: I will recommend this AR-based motion-sensing software to my classmates and friends	4.36	.93

Table 6. The Mean and SD of attitudes toward the AR-based motion-sensing program.

Attitude toward the AR-based motion-sensing program	Mean	SD
Q12: I feel the AR-based motion-sensing program presents richer content	4.57	.76
Q13: I feel the inquiry AR-based tool is helpful for leaning new physics knowledge	4.57	.76
Q14: AR-based motion-sensing software is more effective than other learning software used before	4.43	.76
Q19: The explorative content of the AR-based motion-sensing program is highly relevant to the course content (magnetic field). I want to use it.	4.36	.63
Q20: The AR-based motion-sensing software enables me to learn at my own pace and collaborate with my partners.	4.50	.65
Q21: With AR-based motion-sensing software, I can grasp important knowledge points better and understand what I wouldn't understand otherwise.	4.29	.73
Q22: The AR-based motion-sensing program gives me a larger space to think and reflect and enables me to resolve problems more easily	4.36	.84

technological software before, but have played games, and I felt it was novel in learning"; "The lesson and what was learnt together with everybody were very new. If the method is used in class, it will be of interest to students". Additionally, compared to the traditional inquiry teaching method, the experimental course in a problem-based explorative mode is welcomed and affirmed by the students. To sum up, students were impressed by the AR and motion-sensing technology display and experiments because the AR and motion-sensing technology applications attracted their attention.

(2) The course result of the experimental group is satisfactory

With interviews, we found that the interviewed students expressed that they understood the knowledge system of magnetic induction lines and even affirmed that they have grasped all of the learning objectives. They believed: "the lab facilities used in the experiments can be reduced and found again in the virtual world, and then help us grasp, understand better, and then master the knowledge";

> I felt it was playable, students who love it would get interested in it, and then grasp the knowledge better. This method is new. If the method is applied in class, students' enthusiasm will be stimulated. And further the instructor teaches very well, the PPT was designed well

"I have grasped 90% of the above". These expressions showed that the students started to acquire knowledge of magnetic induction lines. Therefore, we are convinced that the teaching method using AR-based motion-sensing software can result in a positive teaching outcome.

Discussion and conclusion

In conclusion, the experimental results showed that the AR-based motion-sensing teaching software used in experimental teaching can help students understand magnetic fields and the magnetic induction lines more intuitively, deepening their mastery of difficult but key learning objectives, and help them memorize the content for a longer period of time; however it is not prominent in helping students move from learning objectives to laws. Additionally, the experimental results showed that the AR-based motion-sensing teaching software can greatly trigger students' learning motivation and interest, encouraging students to learn more actively and extensively.

Specifically, the graphic questions can reflect students' imaginary intuitive knowledge of magnetic fields and magnetic induction lines. Although both groups behaved consistently in the graphic questions and the overall quiz, the students in the experimental group were better than in the control group. Based on the completion of questions, the students in the experimental group were inclined to answer all of the questions. This suggested that the AR-based motion-sensing technology software can help students understand the magnetic field and magnetic induction lines intuitively and engage their interests as well. In other words, AR and motion-sensing technology is conducive to the intuitive imaginary cognition of magnetic field and the magnetic induction lines for students.

The judgment questions were mainly used to investigate the mastery and understanding of concepts. Students learn better when they deeply understand the observed phenomena and interpret them as laws via an experiment. Before, immediately after, and one week after the experiment, students in the experimental group received lower scores in the judgment questions than students in the control group; the gap reached the maximum value immediately after the experiment and was not significant one week after the experiment. This suggested that the AR-based motion-sensing software was insignificant in helping students move from concepts into laws, but the experimental group was better than the control group in persistence and long-term mastery of knowledge. These findings confirm the results of prior studies (Ibáñez et al., 2014; Mannus et al., 2011).

The results of the attitude questionnaire reflect the effect of the AR-based motion-sensing teaching software on learning motivation and interest among students in the experimental group. In the whole attitude questionnaire, students in the experimental group gave positive feedback with active attitudes toward new technology and software. The highest score in the questionnaire appeared in students' interests in physics, inquiry learning, AR-based technology, and motion-sensing software; the lower scores were related to the interface design, such as software color and layout, and so on.

Limitations

Firstly, because the AR-based Kinect device is new to students, there is an adjustment required due to its novelty. If we do not provide the proper guidance, the final teaching evaluation results will be affected by their unfamiliarity with the equipment and the environment. We arranged assistants for the experimental group to cope with the technical issues, such as building the environment, explaining the operation procedure, answering students' questions about the equipment and the environment. Even though the assistants did not provide instruction, it is possible that their involvement affected the teaching evaluation results in the experimental group.

Secondly, the system was not always stable. The AR technology itself overlaps and interacts with the virtual objects when capturing the real surroundings. This places a higher demand on the PC's functionality. Moreover, identifying and converting the optically captured motion and gesture into instructional information put extra burdens on the PC's performance. For example, the system sometimes made sudden pauses during the application. The students reported afterwards that the not-so-friendly user interface negatively affected their learning experience. It would be more conducive to learning if the stability of the AR-based motion-sensing software could have been improved.

Disclosure statement

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