

Using the Augmented Reality 3D Technique for a Convex Imaging Experiment in a Physics Course*

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Augmented Reality (AR) provides new possibilities for simulating teaching environments, experiencing teaching processes and promoting teaching interaction through certain teaching approaches, including virtual-real blended, real-time interactive or three-dimensional immersive. This paper first briefly introduces the present research status of implementing AR in education and then illustrates the 3D AR learning environment and the long-distance augmented video system. Furthermore, we explain a specific case in which the convex lens image-forming experiment was adopted as the material and we conducted an interactive and integrated image-forming experiment using AR technology to improve teaching. The case study was mainly to investigate the learning attitudes of the experimental group students by using AR instructional applications and to compare the difference in the learning achievements of eighth graders with the convex lens image-forming experiment in two learning environments. The mean scores of the experimental group increased more significantly than the mean scores of the control group; however, there appeared to be no significant difference in the mean scores between the two groups in post-tests. In addition, most students were found to have positive attitudes towards using AR for their learning in physics courses: they believe that AR instructional applications hold their attention and increase their learning motivation in physics courses. The results show that this learning environment that blends reality with virtuality will greatly stimulate the learning interests of students and promote their level of activity, suggesting significant potential for this learning application in practice.

Keywords: applications in subject areas; interactive learning environments; improving classroom teaching; augmented reality

1. Introduction

Augmented Reality (AR) is an extension of Virtual Reality (VR) technology. AR and VR were created nearly simultaneously. As early as 1968, the first Helmet Mounted Display (HMD) devised by Sutherland, a pioneer in graphics, was transparent rather than immersive, making it useful as an AR tool. During the next 20 years, there were no significant developments in AR technology due to the limitations of hardware and the lack of research in graphic design. Caudell and David and their colleagues from Boeing Company coined the term “Augmented Reality” in the auxiliary distribution system they designed [1]. Although there is no general consensus on the definition of AR yet, it is commonly agreed that AR is the technology integrating 2D or 3D virtual information generated by a computer into authentic contexts around the user with the assistance of 3D-graphics technology, human-computer interaction techniques, various

sensing technologies, computer vision techniques and multi-media techniques.

At present, the applications of AR are mainly divided into two types. One type is based on image recognition. First, cameras detect objects or specially designed markers in the real world, and then the images are processed and analyzed. Then projects 2D or 3D information onto these objects or markers in real time. The other type of AR application is based on sensors. In this case, it is not necessary to detect specific objects to determine the position where virtual information will be presented. Instead, GPS (Global Positioning System) and other sensors (such as gravity accelerators and compasses) are used to conduct an overall analysis; then, the corresponding data are projected onto the current scene. We will focus on the first type of AR in this study.

The significance of AR in education rests with providing a self-oriented space for exploration for learners in the interaction mode closest to real life,

which is especially inspiring and helpful for abstract knowledge. AR aims to improve the performance of users and promote their perception of the world. Models in the AR environment can be quickly constructed, operated upon and rotated. An ideal AR system can integrate users into virtual information seamlessly and enable users to have real-time interactions with 3D objects in the virtual world through natural operations. This feature makes it possible for users to observe objects in the real world that are inaccessible to human beings or in the micro world that only exist in our imagination. Users can analyze these objects from every conceivable angle to explore the essence and principles of the world.

2. Related work

From the perspective of theoretical research, although virtual learning environment based on AR technology is new, some of its characteristics coincide with ideas in education theories. For instance, “behaviorism” holds that learning is the result of associations formed between stimuli and responses. In an AR-based learning environment, users interact with the environment and receive feedback immediately, according to which they can decide what to do next, thereby forming a connection between their responses and knowledge. Second, an AR-based learning environment provides users with plenty of model constructing tools and various scenarios, all of which are designed to be easily used by the learner. Learners can construct the objective world and gradually improve their recognition structures in this autonomous learning environment, which satisfies both Piaget’s assumption and practice of “bring laboratories into classes” and the argument of constructivism that “learning is embedded in authentic social experiences”.

There are two categories of research on the integration of AR into education: games and e-learning. The former category classifies games according to the technologies adopted. Because 3D graphics games represent the highest level of contemporary computer games, we refer to these games as 3D virtual worlds or 3D virtual environments when examining their use in teaching. However, Clougherty proposed dividing e-learning into three steps [2]. The first step is learning with a Learning Management System, e.g., the Moodle platform. The second step is learning in a social web-based environment, e.g., blogs, wikis, and other Web 2.0 platforms. The third step is learning in a 3D virtual space, e.g., Second Life or Sloodle, to which AR-based learning belongs.

Currently, studies on AR have shifted from the algorithm itself to its application in specific fields.

Some scholars have attempted to study AR applications in an educational context. Billingham, Kato and Pouprev designed an interface called Magic Book based on AR technology [3]. The contents in the book are converted into animations, which are then superimposed on the book. People can turn the pages of the book, look at the pictures and read the text without any additional technology. However, if they look at the book through an AR display, they can see 3D virtual models emerging from the pages. The models appear to be attached to the real page, and thus users can see the AR scene from any perspective simply by moving themselves or the book. Users can change the virtual models simply by turning the page, and when they see a scene they particularly like, they can fly into the page and experience it as an immersive virtual environment.

Kaufmann and Schmalstieg envisioned cooperative teacher-student interactions with AR technology and confirmed through their experiments that observing 3D objects in their textbooks and interacting with them helps students to improve their spatial abilities [4]. The system offers a basic set of functions for the construction of primitives such as points, lines, planes, and other simple elements, as well as Boolean operations. Thus, teachers can easily explain the transformations of geometric figures and the relations among them in space. Meanwhile, students will have a better understanding of otherwise confusing spatial concepts in this environment through a blend of reality and virtuality. However, this system merely presents simple images, and the facilities required are complex, making this approach operationally inconvenient.

Su applied AR to support children in learning phonetic notation symbols with the aim of perceiving whether children can acquire effective learning outcomes with the assistance of media through educational games [5]. He compiled a series of textbooks on phonetic notation symbols, constructed responding virtual animal images according to the pronunciation of each phonetic notation symbol and asked the children to pick the correct sign to receive expected feedback. The simple operation and virtual image interactions strengthened the children’s interests and impressions of Chinese phonetic notation effectively, leaving a deeper impression of Chinese phonetic notation on them.

Dünser and Horneker took fables as materials and added 3D roles, sounds and interactive tools to observe how children aged between 5 and 7 communicate and cooperate in learning in an AR-based learning environment [6]. The children used AR tools with signs on them to read stories and complete the tasks. The experiment indicated that children had a higher level of concentration in an AR-based learning environment and that they were

more willing to make attempts to fulfill the tasks. Furthermore, they designed another AR-jam book for 7-year-old children to explore how the knowledge and skills children possess in real life influence their success or failure in this new interaction mode [7]. The conclusion suggests that the style that best approximates physical interaction can lead to better-diversified interactions. For instance, when children move or reverse the signs, similar movements of the responding objects in the AR scene will be generated, which can greatly stimulate children's curiosity.

Liu, Cheok, Mei-Ling, and Theng devised an AR-based experimental teaching system on the solar system [8]. The system provides 9 cards with different markers on them to represent the different planets. During the learning process, questions are put forward, and students respond to them by placing the correct card at a designated position. Compared with previous simulation tests that merely offer literal options, AR stands out not only because of its 3D virtual advantage but also because of its simplicity in operation, which can engage learners and improve their performance.

Lee and Lee designed a mathematical game for students in kindergarten and primary school to help them with the operation of addition [9]. Children easily tire of traditional board games. However, the board supported by AR, which provides children with a 3D view and continuously changing contents, sustains their interest in learning to enjoy this visually interactive game composed of various elements.

Researchers from the Vienna University of Technology presented an AR application in mechanics education [10]. It utilizes a recent physics engine developed for the PC gaming market to simulate physics experiments on mechanics in real life. Students are able to build their own experiments actively and study them in a three-dimensional virtual world. A variety of tools are provided by the system to analyze the forces, the mass, the paths and the other properties of the objects during different periods of the experiments. Nevertheless, the system requires expensive facilities, such as helmets and anaglyph spectacles.

Priestnall illustrated a methodology to implement AR in education [11]. It utilizes aerial photography, Digital Surface Models (DSM) and geology data for three-dimensional contouring, thereby recreating the glacial history of the region and converting abstract concepts into solid visual imagery.

Researchers from Arizona State University developed an innovative learning environment—Situating Multimedia Arts Learning Laboratory (SMALLab) [12]. It allows the learner to study

movements and gestures in space while interacting with dynamic visual and sonic media. With the guidance of a community group consisting of professional K-12 teachers, students, media researchers and artists, the researchers proposed a series of collaborative study plans based on this environment. Likewise, this environment requires independent space and sophisticated installations.

Martín-Gutiérrez, Saorín, and Contero presented an application of AR to improve spatial abilities for engineering students [13]. An augmented book called AR-Dehaes was designed to provide 3D virtual models that help students perform virtual tasks to improve their spatial abilities during a short remedial course. A validation study with 24 Mechanical Engineering freshmen showed that the training had a measurable, positive impact on the students' spatial ability.

El Sayed, Zayed, and Sharawy designed an application of AR in education, the AR Student Card (ARSC), and examined learning outcomes with both online and offline versions [14]. In the online version, students are able to interact with teachers or learning materials through keyboards or signs on the cards, e.g., making inquiries. In the offline version, the operations of students, such as answering questions, doing exercises, and searching for resources, are traced and analyzed for the teachers' reference. Their research suggests that ARSC will lower educational costs without compromising outcomes. Furthermore, students maintain great interest throughout their use of the system: 89% of the students were satisfied with the effect of the ARSC, and more than 87% agreed that such a system is needed in education.

The New Media Consortium (NMC) is a famous international not-for-profit consortium composed of more than 250 colleges, universities, museums, corporations, and other learning-focused organizations dedicated to the exploration and use of new media and technologies. The Consortium listed AR as one of the six most emerging technologies and practices with the greatest potential in its Horizon Report from 2010 to 2012, predicting that it is likely to enter mainstream use on campuses within 2–3 years [15–17]. Furthermore, the transmission from “simple Augmented Reality” in the 2010 edition to “Augmented Reality” in the 2011 and 2012 edition demonstrates that this technology is maturing rapidly.

3. Material and methods

In this study, we aimed to create the necessary learning context with AR technology by supplying learners with vivid real-time demos. In our system, an interactive AR video is transmitted via the

Internet, and learners are able to interact seamlessly with three-dimensional models in the real-virtual integration environment through a device with a camera, which addresses the deficiency of the traditional video system in distance education.

3.1 Local AR system

The system displays the real scene captured by the camera as the bottom layer. According to the calibration parameters of the internal and external cameras and the real three-dimensional position of a particular sign created in advance with a three-dimensional algorithm in authentic space, the system can determine the virtual three-dimensional model from the model library. Then, the camera projection matrix of the model is projected onto the plane of the camera using the marked three-dimensional position. In the end, the system synthesizes the image of the virtual three-dimensional model on the projection plane and the real space image on the projection plane to export the compound picture combined with virtual reality and actual reality. The manufacture procedure is shown in Fig. 1.

3.2 Remote AR video

The video in the classroom environment transfers knowledge to learners from auditory and visual stimuli over the Internet, which addresses the deficiency of traditional, static web-based courses in distance education. However, due to the shortage of interactions between students and the learning content in the current remote video system, it is difficult to transfer abstract knowledge or experimental phenomena in the real environment to students. Therefore, there are some limitations in the current remote video learning system. We proposed a one-to-many remote video learning

system based on AR technology, with which teachers can transmit educational content to remote students. The system shields the complexity of AR technology; it only requires a desktop and a laptop or a mobile device with a camera connected to the network. The experiment shows the novel remote video system supports learners in knowledge construction.

3.3 A case study: convex lens instruction

3.3.1 Instructional analysis

After interviewing some middle school science teachers, we found that the convex lens image-forming experiment is a complicated learning unit for junior high school students. The science teachers proposed four instructional problems as follows. Students (1) are not able to understand the basic physics concepts, such as object distance, image distance and focal distance, in physics classes. (2) Students do not understand certain vague concepts, including the nature of image-forming and the relationship between the object distance and image distance. (3) Students cannot analyze abstract concepts and dynamic problems, such as what will happen as you move the object closer to the lens from far away. (4) Students cannot fully understand the significance of the experiment and always fail to operate image-forming experiments. To overcome these learning obstacles, researchers attempted to use AR teaching tools in a convex lens image-forming experiment.

3.3.2 Participants

Two classes of eighth-grade students from Nankai Foreign Language Middle School in Tianjin City, China, participated in this study. The experimental group consisted of 24 students (female: 16; male: 8),

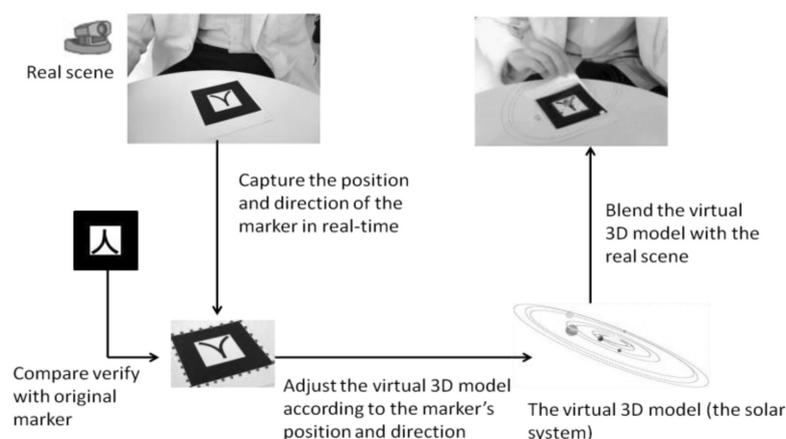


Fig. 1. The production process of a mixed scene.

using AR tools as a supplemental instructional activity; the control group consisted of 26 students (female: 14; male: 12) proceeding with their traditional instruction. The selection process of the two classes was based on the students' previous academic achievements. The two classes were selected to be equal to some degree.

3.3.3 AR tool application

Convex-imaging augmented reality teaching aids can directly simulate convex imaging experiments by using three different markers to substitute for the candle, the convex lens and the fluorescent screen, as shown in Fig. 2.

The 3D model of the convex lens and a straight line parallel to the axis, which is used to mark the focal length and twice focal length, is displayed on the screen when the camera captures the convex marker, as shown in Fig. 3.

By placing the candle marker and the screen marker on each side of the convex marker, respectively, the screen will automatically present the relevant objective image based on the position of the distance from the candle to the convex lens, as shown in Fig. 4. If the distance between the candle and the convex is adjusted, the image on the screen is also changed correspondingly according to the convex imaging rule.

Let the object distance be u , the image distance be

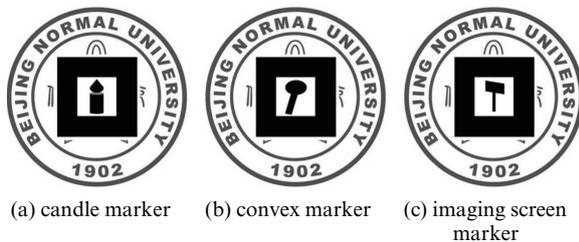


Fig. 2. Convex imaging markers.

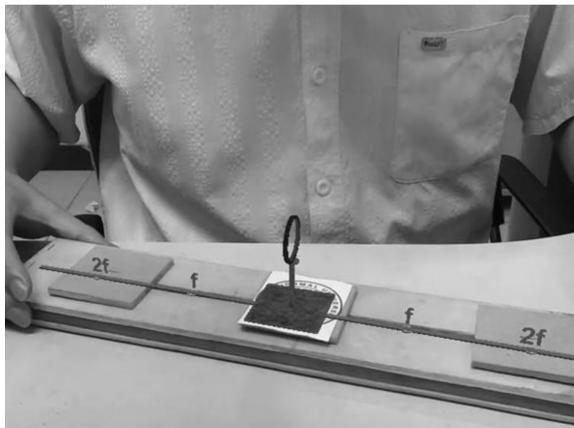


Fig. 3. The virtual convex is blended into the real scene.

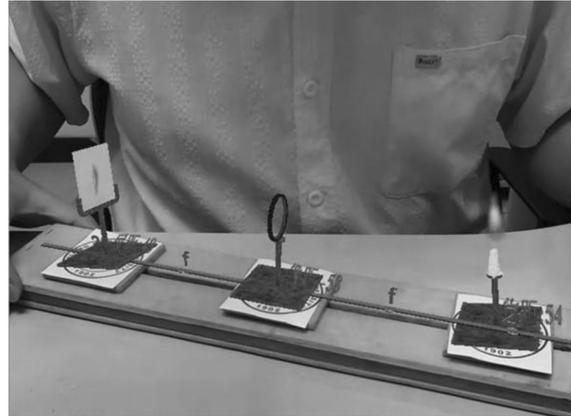


Fig. 4. AR simulation convex imaging experiment.

v , and the focal length be f . When $u < f$, according to the formula for convex imaging

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f},$$

a virtual image is observed. The relationship between the image distances v and u is as shown in Table 1 and Fig. 5.

According to Table 1 and Fig. 5, when the object moves closer to one focal length, the virtual image moves quickly towards infinity. Otherwise, when u is at half of the focal length, v slows. Fig. 5 shows the relationship between the object distance and the image distance. As the range within which the camera can take pictures is limited, when u is between one focal length and half of the focal

Table 1. The relationship between the image distance (v) and the object distance (u) when $u < f$

u	v
$5/6 f$	$-5 f$
$1/2 f$	$-f$
$1/3 f$	$-1/2 f$
$1/4 f$	$-1/3 f$

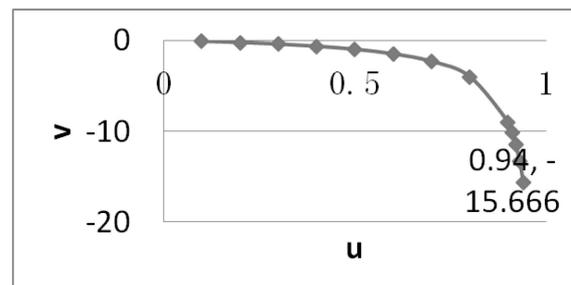


Fig. 5. The relationship between the object distance (u) and the image distance (v).



Fig. 6. Students enhancing the convex imaging experiments.

length, the camera cannot obtain a full picture. When u is between half of the focal length and zero, v does not change significantly. To obtain a clear process of showing virtual images, v must be specially implemented.

After the teacher displays and instructs the students on how to use the AR tools, students from the experimental group practice and learn these concepts of convex imaging with AR. However, the students from the control group learn according to the traditional instructional method. Fig. 6 shows students enhancing the convex imaging experiment.

3.3.4 Research design

This study incorporated a quasi-experimental design consisting of a questionnaire survey to collect the learning achievements after the convex lens image-forming experiment and the attitudes of the students towards using AR tools to learn. The two classes experienced the instructional processes for the convex lens unit shown in Table 2. This study followed a pre-post test with an additional post-test quantitative measure in the experimental group. The research aims of this study were as follows: (1) to compare the physics learning achieved between the experimental and control groups and (2) to explore the feelings of the students about using the AR tools to learn after they experienced them.

3.3.5 Instruments and analysis

We used two types of instruments in this case study, including the learning achievement instru-

ment and the AR learning attitudes questionnaire. The learning achievement instrument was a paper and pencil test that was related to images formed by a convex lens. The instrument was examined and revised by science experts, middle science teachers, and instructional designers. The assessment content related to each instructional objective was selected for the instrument. Each student from the control group and experimental group completed a pre-post test on the learning-achievement instrument. The results were analyzed through descriptive statistics and an independent t-test to compare the mean scores of the pre-post experimental tests. In addition, students from the experimental group were asked to complete the questionnaire at the end of the unit of instruction. The questionnaire mainly explored the students' attitude towards learning using the AR instructional activities. The questionnaire aimed to capture the attitudes of the students towards physics in both in-class learning experiences and in the instructional application of AR tools. The content validity of the attitude instrument was developed by a faculty from Beijing Normal University who had educational technology expertise in the development of attitude instruments. The questionnaire utilized a 5-point Likert scale ranging from the level of "strongly agree" to "strongly disagree." The instrument had a coefficient of internal consistency (Cronbach's alpha) of 0.94. The statistical analysis was conducted using SPSS software.

Table 2. Instructional processes for the convex lens unit between the experimental and control groups

Group	Instructional procedures		
	Traditional classroom	Treatment	Physic experimental classroom
Experimental group (n = 24)	Traditional lecture	AR instructional applications	Hand-on experiments
Control group (n = 26)	Traditional lecture		Hand-on experiments

4. Findings and discussion

4.1 Students' learning achievements

The main purpose of this case study was to explore the learning achievements and learning attitudes of eighth graders for the convex lens experiment with the instructional application of AR. The study employed SPSS to analyze the learning achievement scores of both groups. The means and standard deviations in pre-tests and post-tests of the learning evaluation for both the experimental and control groups are presented in Table 3. The results revealed that the mean score indicated by the experimental group ($M = 80.42$) increased more than that indicated by the control group ($M = 78.69$) in the post-test. To understand whether there is a significant

Table 3. Students' pre- and post-test scores in the experimental and control group

Group	N	Pre-test		Post-test	
		Mean	SD	Mean	SD
Experimental	24	67.42	19.19	80.42	15.46
Control	26	67.65	15.84	78.69	13.94

Table 4. Independent t-tests

score	Equal variances assumed	Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
	Equal variances assumed	1.768	0.233	0.415	48	0.680	1.72436	4.15691	-6.63368	10.08239
	Equal variances not assumed			0.413	46.420	0.681	1.72436	4.17448	-6.67638	10.12510

Table 5. Survey results of students' learning attitudes (N = 24)

Factors	Questions	Mean	SD
Physics In-class learning experiences.	1. I am afraid to take physics courses.	4.43	0.94
	2. When I'm in a physics course, I always look forward to the end of the course.	4.37	0.93
	3. I am interested in some physical phenomena in our daily life, and I hope to make inquiries.	4.50	0.86
	4. I like to do physics experiments.	4.63	0.72
	5. It's easy to summarize the results of physics experiments.	3.87	0.97
AR instructional applications in physics courses attract my attention and stimulate my curiosity, and I want to explore physics more deeply.	6. AR tool instructional applications	4.47	0.82
	7. AR instructional applications are very difficult to understand and are not easy to operate.	3.83	0.95
	8. I can fully comprehend the meaning of AR instructional experiments.	4.00	0.98
	9. I concentrate on doing experiments when I use the AR instructional tools.	4.20	1.06
	10. AR instructional methods facilitate my understanding of physical phenomena and concepts.	4.23	1.07
	11. The AR instructional method could increase my motivation to learn in the physics course.	4.27	0.87
	12. I strongly prefer learning physics by AR instructional tools.	4.40	9.86
	13. I am very impressed with AR instructional display and experiments.	4.27	1.01
	14. AR instructional tools can help me memorize the results of physics experiments.	4.30	1.02
	15. AR instructional method has helped me to link knowledge with physics experiments.	4.13	1.01

difference between the experimental and control groups in the post-test scores, independent t-tests were conducted (Table 4). Although the post-test scores of the experimental group were higher than those of the control group, the pre-post tests for both groups also demonstrated that the treatment in the experimental group was not significantly different from that in the control group.

4.2 The result of students' learning attitudes

The researchers analyzed the questionnaire questions by dividing them into two main sections: (1) in-class physics learning experiences and (2) AR tool instructional applications. The results of each section are delivered in Table 5, and the findings are as follows. The experimental group of students completed and returned the surveys with Likert 5-point scale questions designed to assess their learning attitudes and perceptions about physics courses and the AR learning environment.

4.2.1 Physics in-class learning experiences

Among the question items, only the index of question 5 ("It's easy to summarize the results of physics

experiments”) ($M = 3.87$) is lower than average. This finding implies that most students think it is difficult to summarize the results of physics experiments. In addition, we obtained an interesting result that, although students are afraid to take physics courses, they are interested in some of the physical phenomena in their daily life, especially when performing physics experiments. Based on these results, the researchers reasoned that most students like to make inquiries and try new activities, including doing experiments by themselves. Therefore, teachers should try innovative instructional methods and design more-realistic physics questions that reflect everyday situations in physics courses to emphasize students’ self-oriented learning and to increase their motivation.

4.2.2 AR tool instructional applications

According to the results of the questionnaire survey about the AR tool’s instructional application, most students displayed positive attitudes towards using AR to learn in physics courses. The index of students’ acceptance fell in the middle range ($M = 4.26$) from 3.83 to 4.47. Questions 6 (“AR instructional applications in physics courses attract my attention and stimulate my curiosity, and I want to explore physics more deeply”) had the highest mean score ($M = 4.47$), but other question items also possessed mean scores that were higher than average, such as Question 11 (“The AR instructional method could increase my motivation to learn in the physics course”) ($M = 4.27$), Question 12 (“I strongly prefer learning physics by AR instructional tools”) ($M = 4.40$), Question 13 (“I am very impressed with the AR instructional display and experiments”) ($M = 4.27$), and Question 14 (“AR instructional tools can help me memorize the results of physics experiments”) ($M = 4.30$). Thus, we observed that students not only preferred learning physics with AR tools but also were impressed by the instructional display and experiments using AR because AR instructional applications attracted their attention, helped them memorize the results of experiments and increased their learning motivation.

4.3 Discussion

In this study, researchers developed innovative AR tools and highlighted their effects compared with using current techniques.

The convex lens image-forming experiment realized in this paper overcomes the shortcomings of experiments with real objects—for example, complex equipment and high costs—and the shortcomings of purely virtual experiments—for example, weak sound-surround ambiance and inferior manifestation effects—instead providing an interactive

experimental experience in a mixture of reality and virtuality. The experiment only required a computer and an ordinary webcam. The process was very simple and environmentally friendly, required unsophisticated facilities and was easy to operate. During an experiment, all of the data were displayed on the screen in real time, allowing every student in large classrooms to view the entire process. After the experiment in Tianjin Foreign Language Middle School, some students contacted us to further discuss problems related to the experiment through email and other instant messaging tools. We continuously responded to them with the long-distance augmented video system in a process that continued.

One interesting aspect that arose in this pilot project was the comparison between pure virtual experiments and AR-based experiments. In a pure virtual experiment, users usually feel that they are strictly separated from the virtual experimentation environment: e.g., “I’m in the real scene while what I observe is entirely fictitious”. On the other hand, in an AR-based experiment, as the virtual objects (such as the candle, the convex lens, the screen and the illustrating characters) blend with real backgrounds, users can see themselves in the projection and are able to operate virtual objects in a natural interactive method. These characteristics can never be realized in a pure virtual experiment that only responds to operations on the mouse or keyboard. As a result, students prefer this AR-based experiment.

Regarding AR instructional applications, this case study was mainly designed to investigate the conceptual understanding of eighth-graders with respect to convex lens image-forming experiments and learning attitudes towards AR and traditional instructional environments. Analysis of the students’ learning achievements determined that there was no significant difference between the experimental and control groups. Thus, the case study led to no direct evidence that AR tools promote learning effects, which is in agreement with prior study findings [8]. However, the teachers found that AR tools help low-achieving students make greater progress than high-achieving students. Therefore, the researchers believe that AR tools may have positive instructional outcomes for low-achieving students.

In addition, the results of the questionnaire investigation showed that students do not like taking physics courses, based on their prior learning experiences. After conducting the case study for one month, most students in the experimental group had positive attitudes and feedback towards using AR tool for their learning. They were impressed by the AR instructional display and experiments because

the AR instructional applications attracted their attention, helped them to memorize the results of experiments and increased their learning motivation. These findings confirm the results of prior studies [5, 7, 9, 14].

4.4 Limitations of study

Although AR-based experiments provide students with pleasant experiences that differ from those of previous traditional experiments because they were based on image recognition technology, the virtual objects formed under weak light conditions may twinkle at times. Furthermore, the performance of our long-distance augmented video system was far from satisfactory. We are making efforts to enhance the recognition accuracy of this experimental AR system and to improve the steadiness of the long-distance connection.

The study results were based on an analysis of pre-post learning achievements that did not investigate changes in the students' understanding of physics concepts; thus, it was difficult to conclude whether AR instructional tools' application can enhance students' conceptual understanding of physics. In addition, the researchers did not conduct interviews with the experimental group to capture students' attitudes towards the AR instructional tools. Such interviews could be used as a source of qualitative data for future studies comparing the quantitative and qualitative differences in students' learning attitudes.

5. Conclusions

The purpose of this case study was to investigate the learning attitudes of an experimental group of students using AR instructional applications and comparing the difference in the learning achievements of eighth-graders in the convex lens image-forming experiment in two learning environments. The study revealed that the mean scores indicated by the experimental group increased more than those indicated by the control group; however, there appeared to be no significant difference between the two groups in post-tests. In addition, most students have positive attitudes towards using AR for their learning in physics courses. According to the results of the learning attitudes questionnaire, they believe that AR tools' instructional application can attract their attention and increase their learning motivation in physics courses. Although there is insufficient evidence to determine whether the students' conceptual understanding may be enhanced, the AR tools provided students with different opportunities for scientific learning. The AR experiments supported the students' understanding of concrete and observable physical concepts and

assisted in the development of their experimental skills through practical experiences.

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