Case Studies of Augmented Reality Applications for Authentic Learning

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Abstract The advancement of Augmented Reality technology is having a great influence on the design of learning activities in schools. In this chapter, a serial of simulation cases based on 3D Augmented Reality (AR) environments are presented, including probability learning in mathematics, convex imaging and magnetic field learning in physics, inquiry-based microparticles interactive presentation in chemistry and EFL children's vocabulary studying in language learning, etc. By AR technology, the camera detects the presetting markers which will later generate 3D virtual objects, interposing the virtual objects on the real scene to produce a blended environment. Experimental results show that in an AR-based authentic learning environment, students adopt a natural interactive method and enjoy the same experience as in real environments due to the abandonment of mouse and keyboard devices. It facilitates an innovative and fascinating learning mode which eliminates isolated feelings in learning. Furthermore, the AR-based learning environment is able to interpose objects which are inaccessible in real life due to high expenses, safety consideration or other factors in real-world settings.

Keywords Augmented Reality · Authentic learning · Natural interaction

1 Introduction

Augmented Reality (AR) is a variation or extension of virtual environments. AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world (Azuma 1997). Therefore, AR supplements reality,

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rather than completely replaces it. Traditional 3D virtual environments give people an isolated feeling in their interactive experience. However, the scenarios based on AR technology provide opportunities for more authentic learning with diverse learning types. Ideally, AR would appear to the user that the virtual and real objects coexist in the same space, in which obstacles between learners and information are eliminated to some extent; teachers and students interact with learning objects as generally as natural. AR displays abstract knowledge in front of the learners. Students can simply drag, drop, grab, flip and perform other operations to interact with virtual learning objects, which make up the gaps of interaction shortcomings in current remote video teaching system.

The main point of authentic learning is to let students encounter and master situations that resemble real life (Cronin 1993). Some researchers assert that emerging technologies are uniquely capable of enabling inquiry-based environments by creating "authentic" science learning environments, and perhaps more importantly, by engaging students in scientific discovery (Chang et al. 2010; O'Connor 2016; San Chee 2014). The ability of AR technology should be considered to engage students and generate an environment for authentic scientific inquiry and discovery.

With the rapid development of AR technology, authentic learning environment by the integration of AR into disciplinary teaching has emerged to a significant extent and been increasingly used in the field of education (Wu et al. 2013). The presentation of AR, 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.

The rest of this chapter is organized as follows: Sect. 2 will discuss recent literature about AR for authentic learning in education. Several case studies will then be illustrated in Sect. 3. We conclude with a short summary and predict five trends of AR learning environment in Sect. 4.

2 Related Works

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 et al. 2012) and (2) when real experiments are dangerous or have practical concerns (Cai et al. 2013; Cai et al. 2014; Chang et al. 2013a). For example, 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 et al. (2013a) designed an experiment to examine student's learning behaviors under the nuclear radiation pollution environment near the 1st Fukushima Daiichi Nuclear Power Plant in Japan after the 3.11 earthquake. Cai et al. (2014) targeted "the composition of substances" segment of junior high school chemistry classes and further involved the design and development of a set of inquiry-based Augmented Reality 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 may not 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 cognition load caused by the information migration. The experiment would have been more interesting if not only the virtual objects were integrated into a real scenario with AR, but also the learner's interactive operation behaviors were the same as the real experimental condition. The latter is the human–computer interaction technology which is representative of a motion sensing interaction.

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 et al. 2012; Johnson 2014, 2015; Johnson et al. 2010; Johnson et al. 2011). Stemming from games, this motion sensing technology enables users to operate and control games through gestures and body motions. Utilizing this technology usually requires a proper hardware and software package. Some cases have shown the potential of Augmented Reality-based natural interaction technology in 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 and 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, since the system required expensive helmets, stereoscopic glasses and other equipments, the learning experience might have been undermined. Researchers from Arizona State University developed a multimedia art learning environment in mixed reality called SMALLab (Johnson-Glenberg et al. 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. Even though the simulative teaching environment was created by combining motion sensing and AR techniques, the environment requires a separate space and sophisticated equipment. Chang et al. (2013b) 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 these particular individuals to obtain job skills.

AR-based natural interaction technology has also been applied in teaching magnetism. In the AR simulation developed by Buchau et al. (2009), a previously calculated magnetic field is applied, while it is static with invisible real-time effects and two-magnet models are absent. Mannus et al. (2011) taught basic magnetic concepts with two handheld devices and AR techniques, which demonstrated that AR techniques improved the students' understanding of magnetic fields. Matsutomo et al. (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 et al. (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 et al. (2014) have 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 obtain higher-level experiences.

As these applications show, an AR-based simulation has more advantages than the rigid mouse-controlled mode. This conforms to the AR operational advantages generalized by (Carmichael et al. 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 mouse and 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 the AR works as an interface). Vogt and Shingles (2013) experimentally demonstrated that the AR technology can be independently applied and utilized 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 student's prior knowledge. This also leads to the question of what influence an AR-based authentic learning environment has on 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 chapter, we present several AR-based learning cases to explore the influence of an AR authentic environment on learners' attitudes and learning outcomes.

3 Case Studies in AR-Based Learning Environment

We introduce five case studies in AR-based learning environment in different disciplines, including probability learning in mathematics, convex imaging experiment and magnetic field study in physics, inquiry-based microparticles interactive experiment in chemistry and EFL children's vocabulary study in language learning.

3.1 Case Study in Mathematics: Probability Learning

The main goal of this study was to investigate the influence of Augmented Reality on the secondary school students' learning experience as well as the learning achievements (Li et al. 2016).

3.1.1 Participants

Fifty-nine seventh grade students in a middle school of an urban–rural fringe area participated in this study. At the beginning, the experimental group had 31 participants and the control group had 28 participants. Six participants in the experimental group and 3 participants in the control group were removed from the final analysis of the study due to the incompletion of responses.

3.1.2 Research Design

We implemented a mobile game, magic coins, using AR technology on Android OS. Before the start of the first round of the game, students can set two parameters: interval time and recognition time. Interval time refers to the shortest time between two rounds of recognition, and recognition time refers to the shortest time the coin stays in front of the camera. When playing the game, the camera captures the head side or tail side of the coin and the screen will show 3D model in the reality scene in order to prompt students to a successful identification as shown in Fig. 1. Once the recognition is successful, the system will record and update the numbers of head side or tail side as shown in Fig. 2. When students exit the game, the historical data will be recorded in the local database for students to access.

3.1.3 Research Findings

Pretests and posttests were given to students, respectively, to measure the learning achievements of the students. To be specific, the pretest consisted of ten blank-filling questions to assess the participants' prior knowledge of the subject matter: Four addressed empirical probability, four addressed theoretical probability and two addressed the relations between the two probabilities. The posttest consisted of five blank-filling questions to assess the students' learning achievements: One of them addressed empirical probability, two of them addressed theoretical probability and the rest addressed the relationships. In addition, five open-ended questions were also created to determine the AR learning experience of students.

We find that in the pretest the mean score of students in the experimental group is lower than the ones in the control group. On the other hand, the mean score in the posttest of students in the experimental group is higher than that in the control

Fig. 1 The camera caught the tail side of the coin

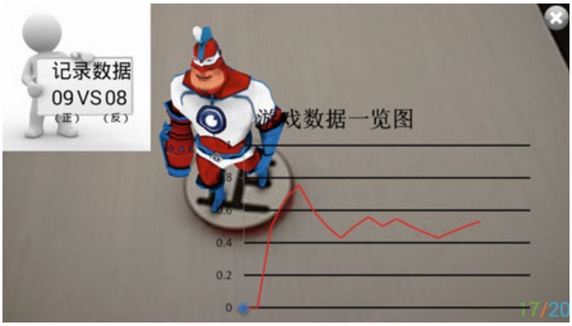

Fig. 2 The system recorded the numbers of the coin's head and tail side and updated the line graph of the empirical probability of the head side

group. The improvement in apprehending the relations between empirical probability and theoretical probability in the experimental group was to some extent better than that in the control group. Such insignificance indicated in the data we collected may be explained by the relatively small class size and other research limitations.

Nevertheless, despite the fact that the quantitative analysis of students' learning achievements was not statistically salient, the qualitative analysis of the answers to the open-ended questions in the posttest illustrated strong improvement of student engagement in the mathematical learning process under the instruction that featured Augmented Reality technology.

3.2 Case Study in Physics: Convex Imaging Experiment

The main purpose of this case study was to explore eighth graders' learning achievements and learning attitudes toward the convex lens experiment with AR instructional applications (Cai et al. 2013).

3.2.1 Participants

Two classes of eight grade students from Nankai Foreign Language Middle School in Tianjin, China, participated in this study. The experimental group consists of 24 students (female, 16; male, 8), using AR tools as a supplemental instructional activity; and the control group consists of 26 students (female, 14; male, 12), proceeding with their traditional instruction. The two classes' selection process was based on students' previous academic achievements.

3.2.2 Research Design

This study incorporated a quasi-experimental design consisting of a questionnaire survey in order to collect data on learning outcomes of convex lens image forming experiment and students' learning attitudes toward using AR tools. This study followed a pre-post test with an additional posttest quantitative measure in the experimental group. The research objectives of this study are as follows: (1) to compare physics learning achievement between the experimental and control groups and (2) to explore students' feelings about the AR tools learning after they experienced it.

Convex imaging Augmented Reality teaching aids can directly simulate convex imaging experiment, by using three different markers to substitute candle, convex and fluorescent screen. 3D model of convex, and a straight line parallel to the axis which is used to mark focal length and twice focal length, will be displayed on the screen when the camera captured the convex marker. By putting the candle marker and the screen marker on each side of the convex marker, respectively, the screen will automatically present relevant objective image based on the position of the distance from candle to convex, as shown in Fig. 3. If the distance between candle and convex is adjusted, the image on screen would change correspondingly and simultaneously according to the convex imaging rule.

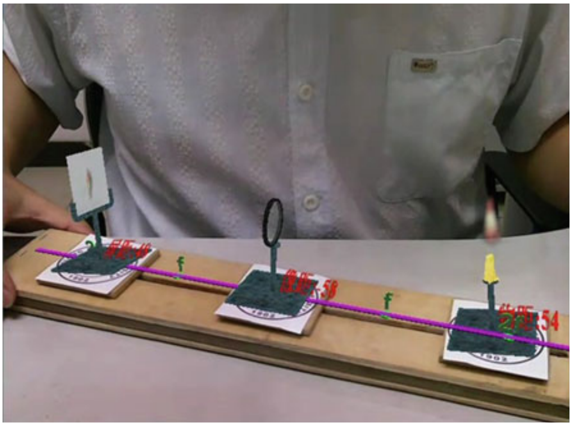

Fig. 3 AR simulation convex imaging experiment

Assuming object distance as u, image distance as v and focal length as f, when $u < f$, virtual image will be visible, according to the formula of convex imaging $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$.

After the teacher instructed students how to use AR tools, students from the experimental group have to practice and learn these concepts of convex imaging with AR tools. Meanwhile, students from the control group studied the same learning content through traditional instructional methods. Figure 4 illustrates the process of students' accomplishing convex imaging experiments.

3.2.3 Research Findings

The study revealed that mean scores indicated by the experimental group increased more than those indicated by the control group, yet there appeared to be no significant difference between the two groups in posttests. In addition, most students have positive attitudes toward using AR for their learning in physics courses. They

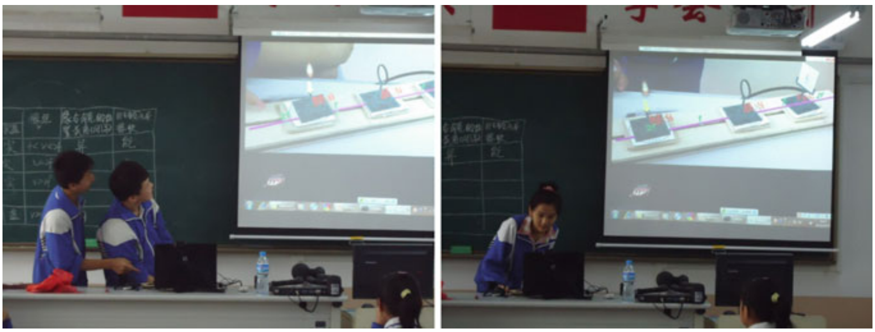

Fig. 4 Students accomplishing convex imaging experiments

contended that AR tool instructional applications can attract their attention and promote their learning motivation in physics courses, according to the results of learning attitudes questionnaire. Although there is insufficient evidence to determine whether students' conceptual understandings can be promoted, AR tools applications provided students with different opportunities for science learning. Furthermore, AR tool experiments not only scaffold students' understandings of concrete and observable physics concepts, but also assisted the development of experimental skills through practical experiences.

3.3 Case Study in Physics: Magnetic Field Visualization

In this study, we used AR and natural interaction technology in a class that teaches magnetic fields to explore the influence of an AR natural interactive environment on learners' attitudes and learning outcomes (Cai et al. 2016).

3.3.1 Participants

The sample consisted of 42 students in grade 8 at a junior high school in Beijing, China. 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 roughly four students in each subgroup.

3.3.2 Research Design

We built 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 situated the model on Kinect environment and adjusted coordinate system as well as the interactive mode between users and 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 helped to return the distance between users and the Kinect device, so we were able to control the rotation of the virtual model by changing the relative distance.

The system included four parts: a magnetic induction line model 1 with a magnet and small magnetic pins (Fig. 5a), a magnetic induction line model 2 with a magnet and magnetic pins (Fig. 5b), an S-N model with two magnets and a small magnetic pin (Fig. 5c) and an N-N model with two magnets and small magnetic pins (Fig. 5d), as shown in Fig. 5.

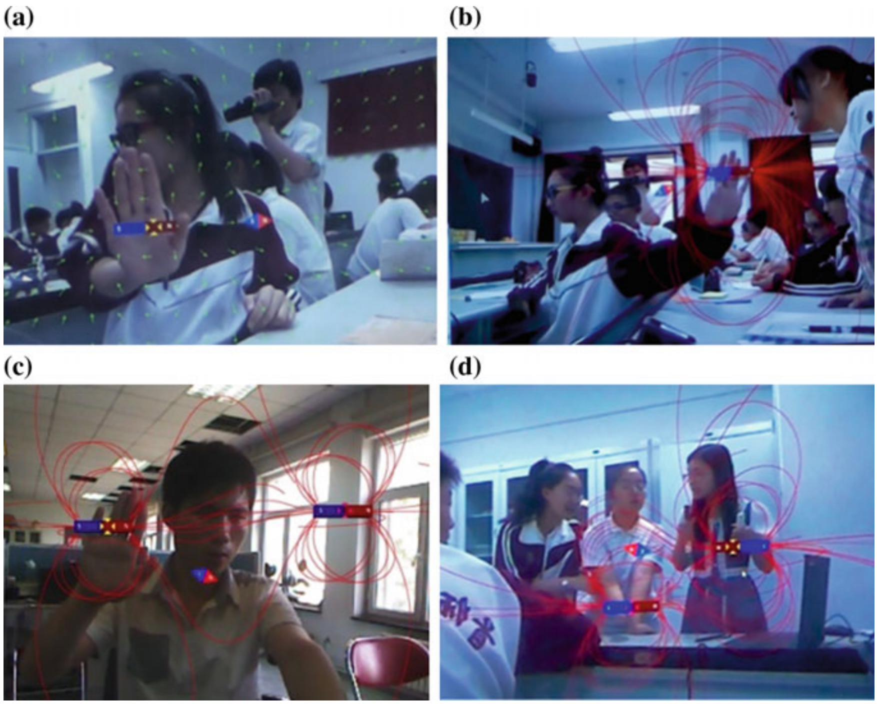

Fig. 5 Magnetic induction line model

3.3.3 Research Findings

Overall Analysis of Test Results

According to test scores, while the prior scores of both groups were not significantly different, the average scores of Group B of immediately after and one week after the experiment were both higher than Group A's. One the one hand, that the average score of Group B one week after the experiment was higher than Group A's suggested that the inquiry experiment in the AR-based environment with the motion sensing devices had a positive influence on students' learning and was able to maintain that the positive influence for a longer time. On the other hand, the difference between the two groups was not statistically significant.

Attitude Questionnaire Analysis

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 in future researches.

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. We expected students to share their feelings about the teaching method as well as comment on the AR-based motion sensing program in the experimental operation. 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 none of them experienced it in classroom. Therefore, for the students, the method was very innovative and interesting. They thought it was *"very novel because Augmented Reality is a new interactive way that hasn't been done before"; "I felt the lesson was very uniquely designed"; "I have not used the motion sensing 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 was welcomed and affirmed by the students. In a word, 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.

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 checkpoints. They believed*: "the lab facilities used in the experiments can be reduced and found again in the virtual world, which helped us easily approach to the knowledge, understand it better, and master it eventually"; "I felt it was playable, students who love it would get intrigued in it, and then grasp the knowledge better. This method is brand-new. If the method is applied in class, students' enthusiasm will be stimulated. Moreover, the instructor teaches very well, and the PPT was also well-designed"; "I have grasped 90% of the above."* These expressions showed that the students were acquiring knowledge of magnetic induction lines. Therefore, we are convinced that the teaching method of using AR-based motion sensing software can bring about positive teaching outcomes.

3.4 Case Study in Chemistry: Inquiry-Based Microparticles Interactive Experiments

This study mainly focused on the supplemental learning effect of AR-based learning tools in a chemistry course (Cai et al. 2014).

3.4.1 Participants

This study involved 29 students in grade 8, including 16 boys and 13 girls. The experiment of the software's impact was conducted in a junior high school in Shenzhen, China.

3.4.2 Research Design

The class taught content related to "The composition of substances" only during the week covered in this experiment. Before this study, we interviewed the chemistry teacher, she pointed out that her students were not very motivated and did not completely comprehend the learning materials, which were perceived as dull and abstract. Therefore, she expressed a wish to review the content using an AR tool in order to promote learning attitudes and learning effects. For these reasons, the experiment did not include a control group. Pretest scores would represent students' learning outcomes when textbooks are used, and posttest scores would represent students' learning outcomes after using an AR inquiry-based learning tool. None of the tools used in the activity, including the software, markers and activity form, presented the exact knowledge points included on the test, which means that students' test answers must be the outcomes they achieved by themselves through their observation and exploration during the inquiry-based learning process. Additionally, in this case, we believe that the vertical difference between pretest and posttest scores would represent the AR tool's learning effect. The questionnaire primarily investigated students' learning attitudes toward this AR learning tool.

Experiment Design

The subjects of the empirical study are the 29 students (16 boys and 13 girls) of class 9, grade 2. Before the experiment, researchers installed the AR software on each computer of the classroom. The experiment design contains 4 sections as shown in Table 1.

Table 1 Experiment design

Experiment content and operation methods	Source of measure instrument
Pretest: a paper-and-pencil quiz test every student, required to complete independently	The quiz was devised by Ms. Shengyan Wan of Meishan Junior High School, Shenzhen
Divide the class into groups of 3 randomly. Each group is required to use the AR tool to learn as indicated on the exploration form and complete the form in cooperation without teacher's guidance. (the tool contains AR-based software, markers and the activity form)	The exploration form is devised by the researcher, which corresponded with the software and the learning objectives
Posttest: repeat the same quiz test in pretest	The paper quiz test was the same with the one in pretest
Paper-and-pencil questionnaire survey with every student, required to complete independently	The scale consists of 4 constructs, which, respectively, based on the following 3 papers with minor revisions: learning attitude (Hwang and Chang, 2011), satisfaction toward the software (Chu, Hwang and Tsai, 2010a) and cognitive validity and accessibility (Chu, Hwang, Tsai and Tseng, 2010b))

Application Design

The software was programmed in Java and the extra packages used included NyArToolkit, Java 3D and JMF (Java Media Framework). In addition to accurate modeling, the essence of human–computer interaction with this software is to detect and record the position of each marker in the camera's view, as the application will trigger different animations when the marker is at different positions. That is, the interaction between users and computer is position-based. In other words, we used position of markers to present different phases of a structure and various combinations of atoms. The markers' behavior can be consistent with real particle behaviors in some cases, while being inconsistent in other cases. For example, when two markers get closer, a new molecule can be formulated, which is what really happens in microworld. In another example, when lifting a marker, the molecule changes from molecular structure into substantial form, or specifically from H_2O molecular structure into a water drop. The behavior "lifting a/an molecule/atom" does not really happen in microworld, whereas with these special behaviors and operations, we expect students to acknowledge the transformation between atoms, molecules and substances. The following figure shows operation screens from two applications, the water and the diamond cases.

As shown in Fig. 6a, three atoms, including 2 hydrogen atoms and 1 oxygen atom, are interposed in the scene. When we move the two hydrogen atoms close to the oxygen atom, a water molecule is formed, as shown in Fig. 6b. Users are allowed to lift the water molecule closer to the camera to view its structures, and if we keep lifting, it turns into a water drop, as shown in Fig. 6c and d.

(a) Models of three atoms (b) Three atoms form a water molecule (c) The structure of a water molecule (d) Water molecules from a real water drop

Fig. 6 Water molecule interaction

In the second application, the inquiry-based activity requires students to construct the diamond crystal using carbon atoms. First, we construct a basic tetrahedron unit of diamond crystal using carbon atom and chemical bond, as shown in Fig. 7a. Further we will use this unit to construct a more complete structure of diamond crystal, as shown in Fig. 7b. Students can get hints from another marker to deduct the structure they have built is the structure of diamond, which combines chemistry with daily social life.

After students finished the inquiry-based activity, researchers expected them to (1) know that there are three particles that can compose substances, explain the formulation of water, graphite, diamonds and NaCl, understand the structure of atoms of different elements and connect the features of substances with microstructures; (2) be able to generalize abstract concepts and master basic chemistry research methods; (3) form the habit of respecting objective facts and a serious attitude toward science and inspire interests in learning chemistry.

3.4.3 Research Finding

Most students looked excited, curious and motivated during the inquiry-based learning activity. During the process of the whole experiment, researchers observed carefully and made records of students' performance. The first 2 groups to

(a) Basic unit of diamond crystal (b) Part of diamond crystal

Fig. 7 Diamond crystal interaction

accomplish the whole activity were all boys. At first, 2 girls did not participate in the learning activity; meanwhile, they were doing homework; with the teacher's encouragement, they joined the experiment later. We found that most students did not like to consult the papery activity form; on the other hand, they like to interact with the software on their own. According to the responses of the activity form, we found there were conspicuous mistakes which can be avoided with careful observation and proper teacher guidance.

After the experiment, we picked 5 students tested randomly for face-to-face interviews. In the interview, we asked them to talk about their feelings about the learning tool. First of all, they admitted the AR tool could help them remember the structure of atoms. In traditional class, it is difficult to remember all these with merely teacher's plain instruction. On the contrary, the software was more attractive which left a deeper impression in their mind. Secondly, compared with previous flash courseware and other 3D modeling software, AR tool helped them develop their operation capabilities. The natural and direct interaction was better than keyboard and mouse interaction for them to remember especially the procedural knowledge. At the same time, students also proposed some suggestions toward this tool. Firstly, the model could be instable and twinkling at times. Moreover, they hoped that the simulation of substances can be more analogous to reality. Thirdly, they suggested that some cartoon or animation elements to make the software more fascinating. Last but not least, when the researcher asked the 5 student interviewees whether they would like to use AR tool in their future studies, they said "yes" with one accord.

3.5 Case Study in Language Learning: EFL Children's Vocabulary Study

This study investigates the learning achievement of students as well as teacher's attitude after participating in the mobile-based AR learning activity (He et al. 2014).

3.5.1 Participants

The participants were from two classes of a preschool in Beijing, China, whose ages ranged from four to six. There were 20 children in each class. One was assigned to be the experimental group named A, while the other was the control group named B. None of them had experience in mobile devices and the new words were never taught before.

3.5.2 Research Design

The mobile learning application used to arouse interest in learning English has been developed with AR (Augmented Reality) technology. This system was implemented with Java 1.7 Android SDK and Wikitude SDK. The functions of the application include fetching and recognizing words, showing the corresponding picture and pronunciation.

Figure 8 shows the users' interface of the mobile AR application. The top one is the welcome page, including three buttons—"Fetching Words," "About the Developers" and "Exit." By clicking "Fetching Words" button, learners can enter the "the word-fetching page" of the application. Aiming at the words on card with the mobile camera, it will show the clickable corresponding picture. The application will pronounce the word after the click. Learners need to fetch the word, connect it with the appearing picture, click it, listen to the pronunciation and repeat them. Figure 9 shows the experimental students are studying words using the mobile-based AR application.

3.5.3 Research Findings

The "learning achievement test" were conducted before and after the experiment. As there are unavoidable difficulties in testing the attitude of the kindergarten children, we interviewed the English teacher of the class at the end of the experiment.

Analysis of Learning Achievement

To explore whether mobile-based AR learning activity was helpful in this experiment, an independent test was used to collect data from the pre- and posttest of the two groups. We found that the students in Group A have made remarkable progress,

Fig. 8 Users' interface

Fig. 9 The experimental students are studying words using the mobile-based AR application

as their mean score changes from 23.125 to 73.125. No significant difference ($p = 0.930$) was found in the pretest of the experimental and control group, but an extremely significant difference ($p = 0 < 0.001$) appeared in the posttest between the two groups. Hence, we can conclude that mobile-based AR learning software is helpful for students who are non-native speakers in learning English vocabulary.

Analysis of Teacher's Attitude

Since the kids in kindergarten were too young to express their attitude, and in order to have a deeper understanding of this experiment, we interviewed the English teacher of these two classes. The teacher's opinions are summarized as below. "This type of learning combines tactile sense, auditory sense and visual sense together. It is easier to mobilize the kids' enthusiasm. That using mobile phone to scan words, present matched pictures and the pronunciation aligns with the cognitive rules of children. However, mobile phones may distract students' attention. This type of teaching may be more suitable for one-to-one situation. Also, the number of vocabulary may have been too large for kids at these young ages. It would be much better if a comprehensive learning environment was created in the beginning."

4 Conclusion

From those cases above, we could see that only a computer or mobile device with a camera can achieve real-time interactions between students and 3D virtual learning materials based on AR, which satisfies the instructional requirements of the interaction and the exemplification of abstract knowledge. In general, students possess a positive learning attitude and provide positive evaluations of the AR tool, which is consistent with the results of Nunez et al. (2008). Furthermore, there exists a significant positive correlation between students' learning attitudes and their evaluation of the AR tools.

Finally, we predict five trends of AR learning environment. (1) It will enable users to participate in the composing process. AR-based learning environment returns the rights of composing learning materials to users. Learning contents and activities are both designed and accomplished by students, which indeed embodies the concept of student-centered. (2) More exploration space will be provided. When teaching activities are migrated into an AR-based environment, traditional interactive methods may not be suitable. How to design teaching activities, how to realize better communication between learners, etc., are all questions to be discussed and solved by developers and educators of the blended AR environment. (3) It will combine with learning management system. The integration of the AR-based learning environment with existing 2D information systems and 3D virtual environments requires further exploration on how this integrated environment can elevate learning outcome and keep with existing and new teaching methods. (4) It will merger with intellectual technologies. Ideal AR-based learning environments can imitate real teachers' experience, methods and behaviors, and automatically fulfill the task of analyzing and explaining students' questions. (5) It will connect with mobile technologies. At the present, the AR application on mobile device remains on a 2D level such as geographical positioning. How to ensure the 3D learning experience of AR on computers and at the same time enable learners to enjoy mobile learning anywhere at any time needs unyielding efforts from both technicians and educators.

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