Chen, W. et al. (Eds.) (2017). Proceedings of the 25th International Conference on Computers in Education. New Zealand: Asia-Pacific Society for Computers in Education

An Empirical Case on Integration of Immersive Virtual Environment into Primary School Science Class

Jian SUN[a], Hao LI[a], Zhanhao LIU[a], Su CAI[ab*] & Xiaowen LI[c]

[a]*School of Educational Technology, Faculty of Education, Beijing Normal University, China*

[b]*Beijing Advanced Innovation Center for Future Education, Beijing Normal University, China*

[c]*China Mobile Communications Corporation Government and Enterprise Service Company, China*

caisu@bnu.edu.cn

Abstract: Due to the technological advancement, the contemporary education is influenced to a great extent by high quality small displays, accelerometers and mobile devices. In this paper, two immersive virtual reality applications were developed and being applied to science classes in a primary school. During the in-field science classes teaching, students were divided into trios and they observed the resulting immersive VR applications by using VR Cardboard. With guidance of teachers, students were able to observe the virtual eclipse phenomenon from both ground and cosmic perspective staying in the classroom and thinking the reasons of eclipse. This research focuses on the effects of VR immersive applications on students' knowledge achievements, new technology acceptability, learning behavior and satisfaction. From the questionnaire, it is found that learners have a high degree of acceptability for VR, and they are satisfied about learning in this way except for suffering motion sickness. In addition, VR applications are able to effectively and efficiently help students to understand and memory the knowledge of scientific phenomenon. While in the same time, the effect is slightly worse in terms of understanding the scientific principle.

Keywords: Virtual reality; integrating; immersion; science class

1. Introduction

Virtual Reality (VR), a computer simulation system that is used to create and experience the virtual world (Keppell & Macpherson, 1998), originated in the 1960s. After Facebook spent two billion dollars acquiring Oculus in 2014, virtual reality boomed again. Augmented Reality (AR) is the extension of Virtual Reality, which enables the combination of physical and virtual objects in a physical environment (Azuma et al., 2001). Year 2016 is called the first year of VR in China, when 'VR heat' took place in many areas including education. Chen (2006) asserts that "although VR is recognized as an impressive learning tool, there are still many issues needed further investigation, including: identifying the appropriate theories and/or models to guide its design and development". Therefore, only rationally dealing with the relationship between technology and education can make educators better apply the technology to education.

More and more resources including time and capital have been being devoted to the designing and developing of desktop-based virtual reality instruction for teaching K-12 and higher education curriculum (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014). Besides, some positive research outcomes about VR-based learning have been reported as enhanced anatomy learning (Petersson, Sinkvist, Wang, & Smedby, 2009); better performance in business knowledge application (Cheng & Wang, 2011); higher efficiency in matching diagrams and models (Stull, Barrett, & Hegarty, 2013) and so on. Hsien-Sheng (2016) with his partners has developed an augmented reality system called Weather Observers, which can help students learn about the atmospheric system and other geographical knowledge. For example, during the teaching session in the museum, students can scan the identification cards to get the model of the corresponding weather elements. The research shows that the augmented reality system has great advantages in motivating students' interest in geography and improving their learning effects. Cai, Chiang, Sun, Lin and Lee (2017) combined the AR with the Kinect somatosensory device to visualize the magnetic field. When learning about the knowledge of the magnetic field, students can interact with the device by hand gesture in order to understand the distribution and change of it. Another research conducted by Cai's team is about microscopic particle interaction experiment(Cai, Wang, & Chiang, 2014). They developed a chemistry learning tool based on augmented reality, which is intended to be introduced to middle schools. The research has shown that compared to traditional classes, teaching with AR based software can mobilize the enthusiasm of students, and make them more concentrated, so that students can perform better in remembering the structure of the atom. At the same time, the students are more impressed with what they have learned after they intuitively see the simulation models and interact with them. In addition, AR tools can improve students' ability in experimental inquiry comparing to keyboard, mouse and computer operation. However, there are still some drawbacks of this tool. For example, the model is not exquisitely-designed, as well as the scene is not attractive enough.

On looking through the database, there are a few examples of integrating fully immersive virtual reality with science classes. This paper aims to design an immersive application of virtual reality based on the primary science curriculum standards. Then this application is used in classes and integration effect is verified. Some recommendations for the future work are also provided based on the experimental results.

2. Related Work

2.1 How to Integrate VR with Education

Virvou and Katsionis (2008) points out that "if games are to be introduced in classrooms, they have to be usable and likeable by the majority of students". Similarly, virtual reality immersive application should also be 'useable and likeable' when introduced to classes. There is no "best way" to integrate technology into curriculum. Instead of that, integration efforts should be creatively designed and structured for particular subject matter ideas in specific classroom contexts (Koehler & Mishra, 2009). Therefore, when virtual reality is integrated with the class, educators should also pay attention to adjust the teaching structure in classroom flexibly. He (2014) believes that the "deep integration of technology and education" should achieve a structural transformation of the teaching system, which is, changing the role of teachers and students, so that students can become the leading part of classroom; change the teaching content and increase the computerized teaching resources；change the role of teaching media and make it an auxiliary learning tools. The Zone of Proximal Development (ZPD) theory proposed by Vygotsky (1964) requires that a learner should work in collaboration with a more capable partner, who is willing to provide appropriately challenging activities and a proper quantity and quality of assistance. And when integrating technology in classrooms, the role of teacher is supposed to be this more capable partner.

2.2 Three Categories of Virtual Realty

There are basically three different kinds of VR, categorized by the quality of the immersion provided by Cronin (1997), including "Non Immersive Systems", "Semi-Immersive Immersive Systems" and "Fully Immersive Systems"(Kalawsky, 1996). Fully immersive VR is generally considering the best option for several reasons, including the ability to almost completely filter out interference from the outer reality world and thus allowing oneself to focus entirely on the virtual environment (Fällman, Backman, & Holmlund, 1999) And the study (Cronin, 1997) shows that immersive VR, where the learner is in a CAVE or wearing a head-mounted display, can be more efficient than monitor based desktop VR. Therefore, when doing experiments in classes, students are supposed to wear head-mounted display experiencing the full immersive VR.

2.3 Head-Mounted Displays used in Education

As VR technology is becoming more and more cost-effective, there are currently many Head-Mounted Displays (HMDs) in the market. Most of them have stereoscopic displays and tracking systems, enabling the user to see 3D images through a big field of vision and have the virtual camera moving according to the position of user's head (Boas, 2013).

When creating an immersive environment in education, developers can use HTC Vive, Oculus and other professional heavyweight equipment as well as the lightweight equipment like Google

Cardboard. Take the Oculus as an example, it has been shown to present a significantly more realistic and compelling virtual world experience in comparison to traditional computer monitors (Reiners, Wood, & Gregory, 2014). There is a famous platform called "Unimersiv" (https://unimersiv.com/), which is one of the first VR-dedicated learning platforms available on Samsung's Gear VR, the Oculus Rift, Day Dream and Google Cardboard. The developers publish new educational applications every month on the platform and the content concerns about history, space, human anatomy and etc. Some of the applications like "A Journey into the Human Brain" and "Explore the International Space Station" are graphically well designed and friendly to users.

Considering there is no enough space and high configuration computers in the classroom, it is decided to use the lightweight Head-Mounted Displays. Between two common lightweight displays, Google Cardboard is much easier to use than Gear and able to be matched with larger range of mobile phones, therefore, it is chosen to use displays like Google Cardboard in this study. However, people in PRC have no access to Google, so VR Cardboard which is nearly the same as Google Cardboard is used. In addition, although there are many wonderful VR applications on Google Play, they cannot be downloaded due to the network limitation. Also, the applications do not really match the teaching content of science education in primary school. Therefore, new immersive virtual reality applications were designed and developed to present an appropriate virtual learning environment.

3. Method

3.1 Development of Immersive Virtual Reality Application

Pantelidis (2010) proposes the 10-step model to determine when to use virtual reality in his study. According to this model and the benefits of virtual reality discussed by Mantovani (2001), "eclipse" was chosen as the course objective and two applications were designed. The development of immersive virtual reality application are consisted of five steps: selecting content, designing scene, designing user interface, piloting and modifying, and then being used in class (Figure 1).In order to help students observe a relatively lifelike phenomenon, the level of realism should be high. After the application was designed and built, it was tested and evaluated by a group of students from Beijing Normal University. Based on the evaluation results, the virtual environment was modified and the user-interface was improved.

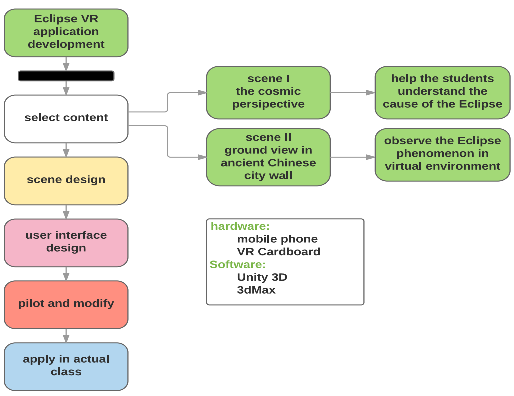

Figure 1. The development of VR immersive application

3.1.1 Content Selection

Mastery of abstract scientific concepts require students to build flexible and runnable mental models (Redish, 1994). Frequently, these scientific models describe phenomena for which students have no real-life referents (Halloun & Hestenes, 1985). Students' lack of real-life referents for intangible phenomena, coupled with an inability to reify abstract models, may result in their struggling with abstractions in science (Dede, Salzman, Loftin, & Sprague, 1999). Therefore, technology is supposed to aid students in experiencing the intangible phenomena in the classroom. Before the content selection, the sixth-year students were set as the experimental object. Then we looked through the content of the "Primary School Science Curriculum Standard", looking for content which is abstract or unobservable, and finally "eclipse" was selected to design the application.

3.1.2 The Basis of Designing

According to Piaget's division of children's cognitive development (Piaget, 2000) in four stages, six-grade students are in the Concrete Operations Stage where the feature of students' thinking is that logical reasoning needs to rely on concrete image support. As a result, for the eclipse, we need to let students firstly have a specific perception in the virtual scene, and then let the students think about the causes of eclipse. In addition, according to Dede (2009), the more a virtual immersive experience is based on design strategies that combine dynamic, symbolic, and sensory factors, the greater the participant's suspension of disbelief that she or he is "inside" a digitally enhanced setting. Therefore, when designing the virtual eclipse scene, all those domains should be taken into consideration.

3.1.3 The Scenes and Function of the Applications

The virtual reality immersive application designed for this paper is divided into two parts. The first part is about the walls of ancient Chinese city. Where the students can observe the eclipse phenomenon in virtual environment with the help of user interface. Students can also choose "playback" to observe again. The second part is observing the eclipse in a cosmic perspective. It can help students understand reasons of the eclipse by observing the trajectory of the sun, the moon and the earth in the universe. Specific content is shown in Figure 2.

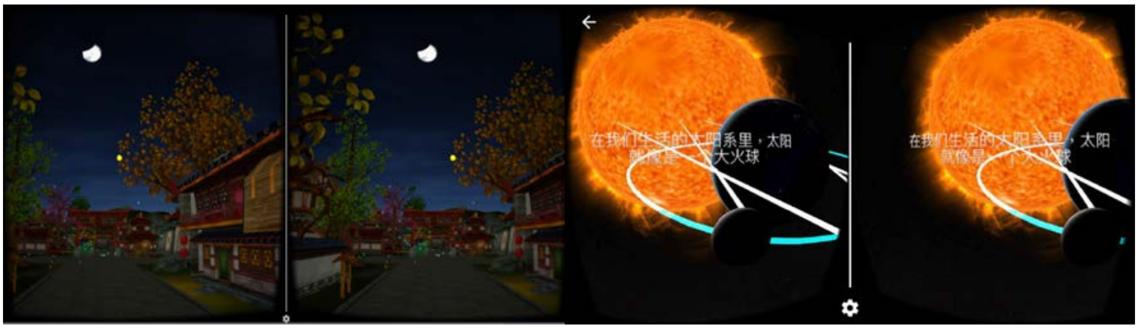

Figure 2. Scenes - the eclipse occurs and comsim perspective

3.2 Design of the Four Elements in Class Structure

3.2.1 The Role of Teachers and Students

According to the Meaningful Learning Theory of Ausubel (1968), there are two ways to realizing meaningful learning. The first one is reception learning, which is a teacher–oriented teaching model, and the other discovery learning, is a student–oriented teaching model. Though the two models cast significant importance on the meaningful learning of students, both of them are not perfect with some minor defects. Based on these two teaching models, He (2007) puts forward Leader-Subject Instructional Structure, which underscores not only the leading role of teachers, but also the role of students as the subject of cognitions. Leader-Subject Instructional Structure was implemented in the process of immersive virtual reality-based instruction in this study, in which the teacher played the role as a director, and students were the subject of cognitions and learning activities.

3.2.2 Designing the Teaching Content

The content of eclipse, which is compulsory according to the curriculum standard, was chosen as the content of this experimental class. In the purpose of helping students get a better understanding of the eclipse, the class was consisted of several integrated parts from students' perspective: watching a video of the eclipse playing on an electronic white-board, answering questions posted by the teacher, exploring the immersive virtual reality scene and taking part in group discussions.

3.2.3 Usage of Media

Teaching media was used for two reasons. First, when the teacher guided the students, an electronic white-board was used to assist the teacher. Second, when students started to observe the scene and discuss their findings, the usage of VR Cardboard and the application purported to assist the students. With the assistance of media, the goal of the class was easier to be achieved.

3.3 Experiment

3.3.1 Participants and Procedure

Twenty-seven students from a primary school in Beijing District participated in this study. They were all in sixth year and had not taken any science class discussing the eclipse. None of the participants had prior exposure to VR Cardboard or immersive virtual reality applications. They were randomly divided into nine groups and were organized to take a two-period science class. Each group was given two sets of VR Cardboard and two mobile phones with the applications pre-installed.

During the first period, two videos introducing virtual reality technology were presented to students, and then students were asked to have an attempt on the VR Cardboards given to them. The purpose of the first period is to let students learn about and get familiar with virtual reality technology, prevent them from getting overexcited when using the immersive virtual reality application and thus get rid of factors interfering with the learning process and outcomes. During the second period, students were asked to observe the scenes presented by the application, discuss with their partners and answer questions posted by teachers, including explaining the cause, the whole process and the features of the eclipse. At the end of the class, all students were asked to fill in a questionnaire, including several questions about the eclipse and a scale testing the effect of applying virtual reality technology into science classes. The whole class was videotaped for further coding and analysis. Figure 3 shows the students experimenting with the application.

Figure 3. The experiment in class - students observe the immersive VR APP by using VR Cardboard

3.3.2 Coding and Scale Analysis

This study used a coding system combining ITLAS Coding System by Jin and Gu (2010), and Teaching Media Coding System by Zhang and Wang. The system and the result is as below in Table 3.

The record was kept in a table in the format as Table 1 presents. According to rules of using ITLAS, coding was done every three seconds.

In order to test the effect of VR and the integration of primary school science curriculum, this paper designed a classroom integration effect test scale. Zhiye Li (2015) pointed out that in the evaluation of information technology and curriculum integration, it is necessary to consider not only the traditional evaluation of content, such as obtainment of knowledge and skills, but also the improvement in learning performance of students, such as learning outcomes, learning efficiency, learning methods, innovation ability and emotional attitude values. In addition, with the objects of applying virtual reality technology, a recent rise of new technology, to future classrooms, the degree of acceptability of the technology should also been taken into consideration.

This study divided the structure of VR and scientific classroom integration test into three parts: scientific knowledge, new technology acceptability, classroom performance and satisfaction. Science knowledge refers to the mastery of the knowledge about the eclipse. The new technology acceptability is based on the "Unified Theory of Acceptability and Use of Technology (UTAUT)" (Venkatesh & Davis, 2000) model, which includes four decisive factors – performance expectations, hard work expectations, social impact, and promotion conditions.

A total of twenty questions were set in three dimensions, as in Table 2. The first two questions are short answer questions. The rest are scale questions. The four choices of those questions are: “disagree” (1 point), “partly disagree” (2 points), “partly agree” (3 points) and “agree” (4 points).

The teacher of the science class and other teachers attending this class were given a short interview when the class was finished. They were all asked about opinions and suggestions on the integration of virtual reality technology into classroom.

Table 1: Sample of the coding record

Starting time	Behavior code	Instructional Media code	Comments
0:00	6	verbal	Introduction of the class
0:03	6	IL	Video playing
......	......	......	......

Table 2: Structure and questions in the questionnaire

Goal	Category	Questions
Effects of integrations of virtual reality into science class of primary school	Mastery of knowledge	1.The shadow first appears on which side of the moon observed from Earth?
		2.Please briefly describe the cause of the eclipse.
	Efforts expectation	3.When using the VR application, I could easily control movements and observations in the scenes.
		4.It didn't take me a lot of effort to learn to use VR Cardboard and the VR application.
		5.As for me, the content of the activities in the scenes are clear and easy to understand.
		6.The content in the space scene helped me clearly understand the cause of the eclipse.
		7.This application can be used everywhere
		8.I easily managed to move in the scene and observe the eclipse
		9.I felt dizziness or discomfort in my eyes.
	Performance expectation	10.I think using applications like this makes learning activities more plentiful.
		11.Using applications like this is helpful when I am learning new knowledge.
		12.The guidance provided by the VR application make my learning smoother.
		13.Applications of this kind is helpful in improving my learning interest.
		14.Applications like this makes learning easier.
	Classroom Performance and Satisfaction	15.Using VR applications made this class more interesting than the classes before.
		16.I can discover new problems by learning with VR applications.
		17.I think VR applications helped me to be more willing to cooperate with my classmates.
		18.I like learning with VR.
		19.I hope other subjects can also use VR applications.
		20.I will recommend this way of learning to other fellow students.

4. Results

4.1 Video Coding Analysis Results

The result of coding analysis of the video is presented as follows. In instructional media dimension, some types of media were not used in the class, thus they were not presented in Table 3. Based on the results, several indicators evaluating integration of technology in class were calculated. The results are as follows in Table 4.

Table 3: Coding record results

Category		Content	Code	Count
Teacher's Language	Indirect Influence	Teacher's acceptability of feeling	1	6
		Encouragement or praise from teacher	2	6
		Adoption of suggestions	3	5
		Posting open-ended question(s)	4	33
		Posting closed-ended question(s)	5	5
	Direct Influence	Instruction	6	210
		Direction	7	46
		Criticizing	8	0
Students' language		Answering passively	9	14
		Answering actively	10	59
		Asking questions	11	2
		Discussion with partners	12	108
Silence		Chaos in teaching	13	2
		Thinking of students	14	19
		Practice of students	15	0
Instructional Media		traditional declarative media (blackboard)	TL	10
		traditional interactive media	TI	27
		technology assisted declarative media	IL	125
		technology assisted interactive media	II	309
		No media, only language is used	verbal	32

Table 4: Coding record analysis results

Indicators		Result
Dominance of class	Ratio of teacher's speaking	29.87%
	Ratio of students' speaking	17.58%
Interaction behaviors between students and teachers	Ratio of indirect and direct influence	21.48%
	Ratio of open-ended questions and closed-ended questions	660%
	Ratio of student activeness	33.33%
	Ratio of students' discussion	59.02%
Appliance of technology	Ratio of technology usage	50.53%
	Ratio of technology usage by teacher	14.63%
	Ratio of technology by students	85.36%

Ratio of teacher's speaking over students' speaking is approximately 1.7:1, which means over a third of total speaking time is used by students. In addition, when students were using interactive media, the learning process was dominant by students. Teachers only walked around the classroom, giving instructions on operating of virtual reality devices occasionally. Thus, the instructional structure could be regarded as Leader-Subject Instructional Structure.

Ratio of indirect and direct influence was the result of dividing counts of indirect influence by direct influence. The ratio is 21.48%, which is below expectation, indicating that teacher mainly used instructional methods. However, the instructional methods were mainly used to give necessary instructions on operating mobile devices. Moreover, the teacher designed and asked much more open questions than closed questions (at a ratio of 33:5), indicating that there was abundant interaction among students and teachers.

The total time of technology using took up half of the class time. Students learnt knowledge of the eclipse mainly by interacting with instructional media.

4.2 Analysis of Scale

Each student was asked to fill in a questionnaire at the end of the class and all of the 27 questionnaires were collected and validity checked.

In the mastery of knowledge analysis, the correction rate of the first question was 100%. The correction rate of the second question was 88.8%. Among the answers, 11.2% didn't answer, indicating they did not understand the cause of the eclipse. And 14.8% used graphs or language description to illustrate their ideas. From the result, conclusion can be concluded that the immersive virtual reality scenes were able to effectively help students understand and memory scientific phenomenon. The reason of this phenomenon is that further directions from the teacher need to be fully understood by all students.

Table 5: Scale results part I – Mastery of new Technology

Category	Efforts Expectation							Performance Expectation				
Question	3	4	5	6	7	8	9	10	11	12	13	14
Average	3.67	3.81	3.67	3.67	3.37	3.52	2.59	3.89	3.81	3.74	3.81	3.67
St. d	0.54	0.47	0.47	0.54	0.67	0.63	1.04	0.31	0.39	0.44	0.47	0.47

Table 6: Scale results part II - Classroom Performance and Satisfaction

Question	15	16	17	18	19	20
Average	3.93	3.70	3.59	3.89	3.81	3.70
St. d	0.26	0.53	0.68	0.42	0.55	0.53

According to Table 5, five questions from the efforts expectation dimension scored above 3.5, indicating students tended to accept virtual reality technology, and were able to learn how to interact with the technology, including understanding the content of the scenes and controlling camera movements. In the performance expectation dimension, all questions scored above 3.5, indicating that immersive virtual reality technology were able to enrich students' learning experience, increase their interest and help them get a better understanding of scientific knowledge.

Based on the two dimensions, students had high acceptability of immersive virtual reality applications and possessed strong willingness of using this technology.

According to Table 6, all questions in classroom performance and satisfaction dimension scored above 3.5, and the question "I found learning more fun when using virtual reality technology" had the highest score indicated that the most advantage of integrating virtual reality applications into science class was that it could effectively improve students' interest on learning. Also, by integrating virtual reality technology into science classes, students' creativity and cooperative ability can also be enhanced. In addition, students were eager to combine the using of virtual reality technology with learning, not only in science class, but also other subjects.

5. Conclusion & Discussion

From the instruction perspective, Leader-Subject Instructional Structure was successfully presented with the integration of virtual reality. From students' perspective, they tended to accept the usage of virtual technology in their classes. Immersive virtual reality technology enriched students' learning experience, increased their interest and helped them get a better understanding of scientific knowledge. In addition, students were eager to combine the using of virtual reality technology in learning, not only in science classes, but also in other subjects.

From the perspective of this experiment, some parts of the video were hard to code into one category, as several activities happened at the same time period. For example, when students were using the application, they might also be discussing with partners. This could result in an inaccuracy of the coding analysis. The coding system needs further development to be matched with different activities.

A criterion of the assessment of the scale needs to be further determined. The four choices of the question are "disagree" (1 point), "partly disagree" (2 points), "partly agree" (3 points) and "agree" (4 points). It can be seen that the value of the average scores indicates the opinions of most students in the class. Thus, a score above 3.5 means that most of the students agree with the statement. However, further research is needed to evaluate its effectiveness.

5.1 Advantages and Disadvantages of Integration of VR in Science Class

Virtual reality technology possesses strong expressive ability and sustainability. Compared with pictures and video instructional resources, it can provide more stimulation during study. Results of this study shows that the leading advantage of the integration of virtual reality into science classes is that it can inspire students' interest. Virtual reality applications can make students easily immersed into scenes and exploring scientific knowledge. It also enriches the teaching methods in science classes. Students are willing to accept this learning method in terms of other subjects. Virtual reality applications also have advantages in improving learning efficiency and better understanding of knowledge.

Despite the advantages that VR possesses, there are still considerable obstacles towards widely integration of virtual reality into science classes. Unless a virtual reality application containing a systematic set of knowledge of science classes is developed, teachers with inadequate technology background would not be able to apply this technology to their classes.

Also, most of the students felt dizziness after using the application with VR Cardboard. The dizziness might be caused by several technical reasons. Fernandes and Feiner (2016) point out in their study that for moving users, high-quality tracking systems can minimize the mismatch between their visual perception of the virtual environment (VE) and the response of their vestibular system, diminishing VR sickness. For users who don't move, by strategically and automatically manipulating field of view (FOV) during a VR session, the degree of participants' VR sickness can be reduced, without decreasing their subjective level of presence.

Moreover, due to the limitations of development platforms, scientific details of the real world are difficult to be presented in the scenes. Some unreal details would make learners confused, which would not fully meet the requirement of education.

5.2 Suggestions

To solve the problems listed above, some suggestions are provided. First, an integrated, easy-to-use virtual reality instructional material developing platform need to be developed. For this platform, teachers should be able to develop and modify their own scenes based on given models and materials. These models and materials needed to be scientific and close to real world. Therefore, to take advantage of applying virtual reality to classes, a simple, easy-to-use and scientific platform is required. Second, a new instruction environment and new learning activities need to be designed for the integration of immersive virtual reality into class, to avoid motion sickness. Students' experience using the technology would be continually improved. When using VR application in classes, educators can design some activities to ensure students' actual movements matching their visual perception.

Acknowledgment

This work is supported by the National Natural Science Foundation of China (Grant No 61602043).

References

Ausubel, David Paul, Novak, Joseph Donald, & Hanesian, Helen. (1968). Educational psychology: A cognitive view.

Azuma, Ronald, Baillot, Yohan, Behringer, Reinhold, Feiner, Steven, Julier, Simon, & MacIntyre, Blair. (2001). Recent advances in augmented reality. *IEEE computer graphics and applications, 21*(6), 34-47.

Boas, YAGV. (2013). *Overview of virtual reality technologies.* Paper presented at the Interactive Multimedia Conference 2013.

Cai, Su, Chiang, Feng-Kuang, Sun, Yuchen, Lin, Chenglong, & Lee, Joey J. (2017). Applications of augmented reality-based natural interactive learning in magnetic field instruction. *Interactive Learning Environments, 25*(6), 778-791.

Cai, Su, Wang, Xu, & Chiang, Feng-Kuang. (2014). A case study of Augmented Reality simulation system application in a chemistry course. *Computers in Human Behavior, 37*, 31-40.

Chen, Chwen Jen. (2006). The design, development and evaluation of a virtual reality based learning environment. *Australasian Journal of Educational Technology, 22*(1).

Cheng, Yufang, & Wang, Shwu-Huey. (2011). Applying a 3D virtual learning environment to facilitate student's application ability–The case of marketing. *Computers in Human Behavior, 27*(1), 576-584.

Cronin, Paul. (1997). Report on the applications of virtual reality technology to education. *HCRC, University of Edinburgh, 4*.

Dede, Chris. (2009). Immersive interfaces for engagement and learning. *science, 323*(5910), 66-69.

Dede, Chris, Salzman, Marilyn C, Loftin, R Bowen, & Sprague, Debra. (1999). Multisensory immersion as a modeling environment for learning complex scientific concepts. In *Modeling and simulation in science and mathematics education* (pp. 282-319): Springer.

Fernandes, Ajoy S, & Feiner, Steven K. (2016). *Combating vr sickness through subtle dynamic field-of-view modification.* Paper presented at the 3D User Interfaces (3DUI), 2016 IEEE Symposium on.

Fällman, Daniel, Backman, Anders, & Holmlund, Kenneth. (1999). *VR in education: An introduction to multisensory constructivist learning environments.* Paper presented at the Conference on University Pedagogy (Umea University, Umea, Sweden, February 18-19).

Halloun, Ibrahim Abou, & Hestenes, David. (1985). Common sense concepts about motion. *American journal of physics, 53*(11), 1056-1065.

Hsiao, Hsien-Sheng, Chang, Cheng-Sian, Lin, Chien-Yu, & Wang, Yau-Zng. (2016). Weather observers: a manipulative augmented reality system for weather simulations at home, in the classroom, and at a museum. *Interactive Learning Environments, 24*(1), 205-223.

Jianfeng, Jin; Xiaoqing, Gu. (2010). An Analysis of Classroom Teaching Behavior in Information Technology Environment. *China Educational Technology, 09*, 5.

Kalawsky, Roy S. (1996). Exploiting virtual reality techniques in education and training: Technological issues. http://ww/. *man. ac. ukMCV/SIMA? vrtech/title. html/.*

Kekang, He. (2007). Teaching Structure Theory and Deepening Teaching Reformation. *e-Education Research, 7*.

Kekang, He. (2014). How to Implement "Depth Fusion" of Information Technology and Education. *Curriculum, Teaching Material and Method, 2*, 012.

Keppell, M, & Macpherson, C. (1998). "Is the Elephant Really There?— Virtual Reality in Education. *Australian Journal of Educational Technology, 14*(1), 60-74.

Koehler, Matthew J, & Mishra, Punya. (2009). What is technological pedagogical content knowledge. *Contemporary issues in technology and teacher education, 9*(1), 60-70.

Li, Zhiye. (2015). The Basic Problems on Integration of Information Technology and Curriculum. *Education Reaserch, 11*, 7.

Mantovani, Fabrizia. (2001). 12 VR Learning: Potential and Challenges for the Use of 3D Environments in Education and Training. *Towards cyberpsychology: mind, cognition, and society in the Internet age, 2*(1ntroduction), 207.

Merchant, Zahira, Goetz, Ernest T, Cifuentes, Lauren, Keeney-Kennicutt, Wendy, & Davis, Trina J. (2014). Effectiveness of virtual reality-based instruction on students' learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education, 70*, 29-40.

Pantelidis, Veronica S. (2010). Reasons to use virtual reality in education and training courses and a model to determine when to use virtual reality. *Themes in Science and Technology Education, 2*(1-2), 59-70.

Petersson, Helge, Sinkvist, David, Wang, Chunliang, & Smedby, Örjan. (2009). Web-based interactive 3D visualization as a tool for improved anatomy learning. *Anatomical sciences education, 2*(2), 61-68.

Piaget, Jean. (2000). Piaget's theory of cognitive development. *Childhood cognitive development: The essential readings*, 33-47.

Redish, Edward F. (1994). Implications of cognitive studies for teaching physics. *American Journal of Physics, 62*(9), 796-803.

Reiners, Torsten, Wood, Lincoln C, & Gregory, Sue. (2014). *Experimental study on technology-induced authentic immersion in virtual worlds.* Paper presented at the Proceedings of the 47th Hawaii International Conference on System Sciences.

Stull, Andrew T, Barrett, Trevor, & Hegarty, Mary. (2013). Usability of concrete and virtual models in chemistry instruction. *Computers in Human Behavior, 29*(6), 2546-2556.

Venkatesh, Viswanath, & Davis, Fred D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management science, 46*(2), 186-204.

Virvou, Maria, & Katsionis, George. (2008). On the usability and likeability of virtual reality games for education: The case of VR-ENGAGE. *Computers & Education, 50*(1), 154-178.

Vygotsky, Lev S. (1964). Thought and language. *Annals of Dyslexia, 14*(1), 97-98.