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Perceived Effectiveness of Science Inquiry in the 3D Virtual World

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ABSTRACT

Many researchers claim that inquiry-based learning offers proper solutions to engage students in the 3D virtual world (3DVW), while little literature has reported how to conduct inquiry-based learning and to what extent it influences learning in this world. This study investigates the perceived effectiveness when students exhibit in the inquiry-based learning compared with the standard learning in the 3DVW. Forty-eight students voluntarily participate in the experiment. Half of them learn in the inquiry-based environment, and the other half learn in the standard environment. The effectiveness is measured by the perceived experience and perceived knowledge gains. The data is analyzed by combining the quantitative with qualitative approaches. The results show students who exhibit in the inquiry-based environment perceive more effectiveness than those who don't. Also, the reasons why students perceive in the way are obtained. This study indicates the inquiry-based learning conducted in the 3DVW can effectively enhance learning.

Keywords: inquiry-based learning, 3D virtual world, perceived effectiveness, perceived experience, perceived knowledge gain

INTRODUCTION

Nowadays, the 3D virtual world (3DVW) is a promising virtual learning system (Chau et al., 2013) and is widely used by many educators (Berns, Gonzalez-Pardo, & Camacho, 2013; Bosch-Sijtsema & Haapamäki, 2014). It uses computers to simulate the real situation and human interaction. Not only do users construct information actively but also, they become actors who play specific roles. Many research projects report that this world can effectively improve learning motivation, engagement, learning achievement and so on (Cruz-Benito, Therón, García-Peñalvo, & Lucas, 2015; Diane Jass Ketelhut, Brian C. Nelson, Jody Clarke, & Chris Dede, 2010a; Brian C. Nelson & Ketelhut, 2008). Usually, the 3DVW is used for conducting the simulated scientific experiment (Dmitriyev & Daineko, 2015; Diane Jass Ketelhut, Brian C Nelson, Jody Clarke, & Chris Dede, 2010b) so that students can get access to laboratory resources conveniently (Maiti, Maxwell, Kist, & Orwin, 2015) and obtain real-life experience. However, one big challenge is how to engage students in the student-centered activities in this world.

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State of the literature

- There are dozens of works propose to use the 3DVW for the simulated scientific experiment. One big challenge of learning in this world, however, is how to effectively enhance students' engagement.
- Many researchers claim that inquiry-based learning can offer proper solutions. However, little literature has reported how to conduct inquiry-based learning and to what extent it influences learning in the 3DVW.
- The perceived effectiveness is studied by many literatures. However, few of them address it from the perceived experience combined with perceived knowledge gains point of view.

Contribution of this paper to the literature

- This paper presents how to designs an inquiry-based learning environment based on an on-going Virtual Campus program by considering the scientific research process.
- This paper designs instruments to investigate the perceived effectiveness by measuring both the perceived experience and perceived knowledge gains.
- This paper obtains results that students who exhibit in the inquiry-based 3DVW have better effectiveness perceptions than those who don't. Also, the underlying reasons are analyzed and discussed.

Many researchers claim that inquiry-based learning can offer proper solutions. The inquiry-based learning is a strategy that emphasizes the active participation (Hwang, Chiu, & Chen, 2015). The students should revolve around the learning target to seek answers. It imitates the process of scientific research to explore, comprehend, apply the scientific approaches (Raes, Schellens, De Wever, & Vanderhoven, 2012) and ultimately foster their inquiry abilities. The inquiry-based learning enables students to participate actively and gain hands-on experience. They learn by raising questions, collecting and processing data they have collected, and using it to find answers to the questions. The goal is to develop the abilities to analyze and solve problems (Kogan & Laursen, 2014; Pedaste et al., 2015). It highlights the process of acquiring knowledge rather than the final results. In the formal education, the inquiry-based learning has now been issued to the national plans. For example, the promulgated National Outline for Medium-and-Long Term Educational Reform and Development (NEP, 2010-2020) in China points out "to develop elicitation-, inquiry-, discussion-, and participatory-based learning...to foster the learning ability in information environment" (Dong & Lv, 2017; Postiglione, 2015); also, the National Science Teachers Association (Pratt, 2013) in the US proposes to use inquiry for improving students' understanding of the processes and content. However, little literature has reported how to conduct inquiry-based learning and to what extent it influences learning in the 3DVW. Therefore, this study attempts to develop an inquiry-based learning environment and further investigate the perceived effectiveness of students compared with the standard learning in the world.

The perceived effectiveness is studied by many literatures (Grissom, Loeb, & Mitani, 2015; Lowerison, Sclater, Schmid, & Abrami, 2006). Often, it is defined as the degree to which a person believes that using a system would enhance his/her job performance (Davis, 1989; Liaw & Huang, 2013). This follows the definition of being useful that people are generally reinforced for good performance by raises, promotions, bonuses (Yang & Brown, 2015). A system high in perceived effectiveness is one for which a user believes in the existence of a positive use-performance relationship (Davis, 1989). The perceived effectiveness is usually included in the technology acceptance model (TAM) (Cheung & Vogel, 2013) which has identified significant values in measuring the information technology adoption process. However, there is also some literature refers that the perceived effectiveness can be extended from the theory of technology acceptance (Karahanna & Straub, 1999). The extended interpretations of this term include positive attitudes toward systems, intentions to use these systems, perceived accessibility, and availability of user training and support (Hsu & Liao, 2014). This is what we called perceived experience in the present study. Besides, we also measure the perceived knowledge gains of students because it concerns the beliefs about the academic values and knowledge friendliness of the inquiry-based environment in improving students' performance.

LITERATURE REVIEW

In the last decades, there are dozens of papers propose to use the 3DVW for education. Berns et al. (2013) used the virtual world to design game-like applications and investigate the impact on student motivation and learning. They tried to explore the possible benefits in the area of foreign language learning. Bosch-Sijtsema and Haapamäki (2014) focused on how the 3DVW is perceived to enable learning and innovation in virtual teams. The virtual teams consist of geographically distributed employees working with a common goal and mostly using technologies for communication and collaboration. The authors tried to address the challenges of communication through technology, difficulty in building trust, conveying social cues, and creating awareness. There are also considerable works used the 3DVW for conducting the simulated scientific experiment. Dmitriyev and Daineko (2015) described an implementation of specialized software applications primary dedicated to enhancing experience in teaching physics subject, and Ketelhut et al. (2010b) used the 3DVW as a pedagogical vehicle and helped teams of middle-school students collaboratively solve problems around disease in a virtual town called River City.

As is known, the 3DVW usually characterizes as high immersion, interactivity, and presence (Yilmaz, Baydas, Karakus, & Goktas, 2015). The characteristics may not present advantages when they are not properly used. Scholars are very interested in the possibilities of using this world to improve students' performance, and they suggest designing and developing student-centered learning activities (Yilmaz et al., 2015). One big challenge of learning in this world, however, is how to effectively enhance students' engagement when it refers the specific structured learning and training process in the world. The engagement directly relates to the student motivation level rather than the characteristics of the environment. Because of this, the integration of deeper learning models has significant values. For example, works of the problem-based learning (Beaumont, Savin-Baden, Conradi, & Poulton, 2014), virtual experiment (Winkelmann, Scott, & Wong, 2014), experiential learning (Jarmon, Traphagan, Mayrath, & Trivedi, 2009)、game-based learning (Callaghan, McCusker, Losada, Harkin, & Wilson, 2013; Craig, Brown, Upright, & DeRosier, 2016) and collaborative learning (Kahai, Jestire, & Huang, 2013) are well established in the 3DVW. In the recent years, researchers claim that the use of science inquiry enables developments of active participation and problem-solving abilities. This is because the inquiry-based learning has now been issued to the national plans (Dong & Lv, 2017; Postiglione, 2015; Pratt, 2013). Unfortunately, the current studies of inquiry-based learning are limited in the class teaching, and no sufficient reports regarding the emerging information technology environment such as 3DVW appear in the mainstream academic databases. Ketelhut et al. (2010b) investigated pedagogies for helping teachers infuse inquiry into a standards-based science curriculum. They used a 3DVW called River City to make students interact with avatars, digital artifacts and computer-based agents so that students could find the bacteria. Brian C Nelson and Ketelhut (2007) implemented authentic scientific inquiry curricula in schools and the emerging use of 3DVW to support interactive scientific inquiry practices. They investigated the impact of 3DVW on learning and engagement for underserved students and the impact of virtual experimentation tools designed to scaffold student inquiry processes on engagement and learning of individuals. However, most authors in their works didn't show how to conduct inquiry-based learning in the world and how students perceived effectiveness from the perspectives of perceived experience and perceived knowledge gains.

BACKGROUND OF THE STUDY

This study is part of Virtual Campus (VC) program launched in 2009. This program was developed based on an open-sourced software called Open Simulator. It was used for instructional design and engineering practice. Now it becomes a campus-wide social platform and we develop a few courses for learning. The VC is a 3DVW, aiming to assist students, especially the underserved and low-interest students, to improve their interest, engagement and social communication. In this world, we create a vast area like a real university, including the virtual classroom, lecture hall, laboratory and discussion area which are populated with virtual tools, multimedia material, interactive navigation, and computerized animated agents. Previously, we have studied how animated agents affect students' learning (Xie & Luo, 2017). What we haven't studied is the scientific inquiry in this environment.

Figure 1. Virtual experimental environment

To enable the inquiry-based learning, we consider teaching "the law of current in series and parallel circuits" in the VC. According to the textbook, the electrical section comprises six chapters. They are respectively the current and circuit, voltage, resistance, Ohm's law, electric power, and information transmission of electricity and magnetism. Therefore, the selected subject is very basic but important. According to the new curriculum standard, the learning target is to explore the law of current of series and parallel circuits and to master the skills of connecting the circuits. We use the laboratory as the main place. It includes experimental apparatuses, texts, audios, videos and online resources. The experimental apparatuses are virtual powers, voltage meters, current meters, light bulbs and sliding rheostats. The current meter is used to measure the current value; the voltage meter is used to measure the voltage value, and the slide rheostats are used to control the resistance. Each displays the value whenever students touch it. Different bulbs are distinguished by the color and light intensity. In addition, the web resources are used to present information about the electrical experiment, including the introductions of apparatuses, the experiences of celebrities and their academic contributions. This environment is shown in Figure 1.

METHODOLOGY

Participants

There are 48 students (28 boys and 20 girls) from a junior high school voluntarily participate in the experiment. The mean age is 14.84 (SD = 2.48). They are evenly divided into two groups. Students in the experimental group learn in the inquiry-based environment, and students in the control group learn in the standard environment. This study is performed with the approval of the local ethical committee.

Instruments

The instruments include two scales. The first scale is to investigate the students' perceived experience. The questionnaire consists items to examine the ease of use and usefulness when students explore in the inquiry-based environment. We follow the definitions from Hyman, Moser, and Segala (2014) that the "ease of use" means the degree of effort required on the part of the user to complete an activity, and the "usefulness" means the tendency to use or not use a system to the extent the user believes it will help them complete an activity successfully. To

Table 1. Interviewing items and corresponding open-ended questions

Step	Interviewing items	Open-ended questions
1	Introducing the apparatuses.	What are the apparatuses you have used? What are the natures, characteristics, or functions?
2	Designing the circuitry with the apparatuses.	Why do you choose the apparatuses? What is the plan in designing the circuitry?
3	Connecting the circuit with the circuitry you have designed.	How to connect the circuit? Why do you do it like this?
4	Talking about the circuit with the removal of some components.	Is the circuit workable when you remove some components? Why do you remove this rather than the other?
5	Showing and explaining your work.	Can you tell us more about your work?

measure the ease of use, we include "I find it easy to use the ammeter to work as what I want it to do" and "I am often confused when I connect the circuit". To measure the usefulness, we include "the environment enhances my understanding of concepts" and "the environment enables me to accomplish experiment more efficiently". Besides, the inventories of science laboratory environment (Fraser, McRobbie, & Giddings, 1993) and scientific attitude (Moore & Foy, 1997) are included to test students' attitudes towards the environment. There are twenty-three items in total and each item adopts the five-point Likert rating scheme where "1" represents strong disagreement and "5" represents strong agreement. The internal consistency reliability of the scale is .83 as measured by alpha.

Procedure

Before the experiment, all the participants take 30 minutes to explore the 3DVW. They can freely obtain any information relating to this environment, including the basic operational skills regarding the software interface and the virtual positions of the laboratory and instruments etc. They can also use the web resources and animated agents to provide the learning support. Thirty minutes later, all the objects in the environment are reset, which initializes the program codes and interactive animations. The participants gather in a hall and take a 30-min lecture. The teacher introduces the objectives of the coming experiment and presents the use of instruments. The participants are then evenly assigned to the control and experimental groups. We issued a pre-test scale to measure their knowledge base and preliminary perceptions towards the environment.

In the experiment of following two weeks, students log in the system once a week. The control group is exhibited in the standard environment and the experimental group is exhibited in the inquiry-based environment. The teacher issues a topic and tells the students to explore the 3DVW freely. They tell some of them to acquaint with the knowledge of related celebrities in the Electrical Hall of Fame, some of them to watch videos, some of them to surf online with the virtual computer interface, and some of them to observe the changes of bulbs. The teacher controls the tempo without disturbing the inquiry process. Students gather in a meeting room for group discussion. They talk about the process and make circuitry with tracers. After the discussion, they go to the operating room where they touch the circuit switches to observe the phenomena and get data from the instruments. After that, the students proceed the steps shown in **Table 2**. In addition, the system should support this process so that students know where they are and what they have done. For example, the system illustrates questions and tasks when students enter the world. It prompts "dear X, you're the second time to log in, your last login was on March 21th. Which place do you want to visit?" Then the environment popups multiple choice questions in a card. Students can touch one of them. When students stroll from whichever room to the laboratory, it prompts "this room is for you to freely manipulate all the apparatuses, but you would better follow the instructions you have just learned". The information is triggered by students' behaviors through personal channel instead of the public channel. But the prompts won't disturb students despite they are in the neighborhood.

After the experiment, we issued the scale one as the post-test to get the results of perceived experience. Also, the scale two is used as an interviewing inventory to measure the perceived knowledge gains.

Table 2. The inquiry procedure

Step	Students	Time limit
1	Watch a video/picture or read a material or provide a question "what are the relations of multiple points in Series/parallel circuit?"	5min
2	Speculate the relations of different points in the circuit and interpret the Speculation.	5min
3	Discuss in groups and generate the final experimental scheme.	10min
4	Carry out the experiment, and record the process and data.	15min
5	Analyze the data and explain them logically.	15min
6	Provide evidence and elaborate the results.	5min
7	Share the experience, conclusion, and reflection	10min
8	Use other complimentary materials.	Out of class

Table 3. Results of the analysis of covariance

Post-test	N	Mean	Adjusted Mean	S.D	Std. Error	R^2	Adjusted R^2	F
Experimental group	24	89.37	88.92	2.11	0.43	0.50	0.48	22.78
Control group	23	75.36	74.34	2.98	0.61			

Data analysis

To analyze the data, we use the quantitative approach combined with the qualitative approaches. Firstly, we carry out the analysis of covariance using the pre-test as the covariance to eliminate the effect of the pre-test on post-test scores. This is to examine the effect size of using or not using the inquiry-based learning. Besides, we consider the possible effects of student genders on statistics and use the one-way ANOVA to analyze the significant difference using the gender as the factor. The analysis software is SPSS V.18 and we use an alpha level .05 to establish significance. Then, the thematic analysis is used to obtain the reasons why students use or not use the inquiry-based environment. This is based on students' responses to the scale one, and we analyze the polarity and support of each response. To show whether students who exhibit in the inquiry-based environment learn as much as those who exhibit in the standard environment, we sum up scores of the scale two in term of the accuracy, proficiency, and sophistication, and show the extent to which the scores are improved. Besides, the use intention is obtained from the last item. We analyze the pros and cons of experience according to students' descriptions.

RESULTS

Because the interaction between the independent variable and the dependent variable is not significant ($F= .82$, $p = .15 > .05$), the analysis of covariance is conducted. Table 3 presents results eliminating the effect of the pre-test on the post-test. It shows that the post-test results are significantly affected by the inquiry-based environment ($F = 22.78$, $p = .000 < .001$) which means students who use the inquiry-based learning in the 3DVW could effectively enhance the degree of perceived experience compared with the students who don't. The experimental group gets the mean value significantly higher than the control group, and the standard deviation is significantly lower than the control group. Considering the possible effect of student genders on the results, we test the variance homogeneity which shows no significant difference in the pre-test ($F = 2.120$, $p = .159 > .05$) and post-test ($F = .007$, $p = .936 > .05$), thus one-way ANOVA is conducted. It shows genders had no significant impact on perception scores in both pre-test ($F = 1.194$, $p = .286 > .05$) and post-test ($F = .292$, $p = .595 > .05$). This means the gender is not a factor significantly influences the results.

Table 4 shows the perceived ease of use and usefulness as well as attitudes when students use science inquiry in the laboratory. It is showing that the positive reviews outnumber the negative reviews. Averagely, there are 74.2% (n=17.8) for the positive and 20.8% (n=5) for the negative. In the positive reviews, the most prominent phenomenon is that the students want to understand course concepts (91.7%) and acquire skills (79.2%). The underlying reasons that cause negative comments are that the students encountered difficulties that cannot be

Table 4. Reasons for use or non-use

Reasons for use or non-use	Polarity	Support	Percentage (%)
I want to better understand the physics concepts.	+	22	91.7
I want to gain insight into the characteristics of the apparatuses.	+	16	66.7
I want to practice more adept operational skills.	+	19	79.2
I want to have an exciting experience.	+	18	75.0
It's more effective to meet the demand for the experimental course.	+	14	58.3
I've no idea how to get the readings of the apparatus.	-	2	8.3
I'm not sure how to connect the circuit.	-	6	25.0
It doesn't work although everything I bet is right.	-	6	25.0
I spare more efforts to make everything under control.	-	7	29.2
It costs me more time that should have been spent on the assignment.	-	4	16.7

Table 5. Students' descriptions of the inquiry-based experience

Aspects	Students' descriptions of experience
Flow	It's real as if I was walking in.
Interactivity	I can make interaction with the apparatuses, and I prefer to use voice function instead of text to communicate.
Accessibility	Although I can seek information in the Lab with the help of the instruction, I often confused when I change my destination".
Sense of fun	I'm not interested in all the components, but the experimental phenomena are fascinating and surprising.
Efficacy	The environment can basically meet our demands of exploration, communication, plotting and seeking materials.
Future use	I am willing to explore again in my spare time and recommend to my friends.

resolved during a limited time so that negative experience are obtained. Besides, seven students deem that they must make more efforts to keep pace with steps even though they are the expert users already. There are six students don't know how to use the virtual apparatuses to connect the circuit, albeit they can design the circuitry successfully. Six students' circuits don't work although they bet no mistakes. And four students think that the time cost is high exceeding the normal level.

After testing the mastery of physics concepts and skills, the results show students who exhibit in the 3DVW get more average scores (respectively 13.6%, 17.4% and 13.9% in term of the accuracy, proficiency, sophistication) than those who do not. Moreover, students who use science inquiry in 3DVW sense different aspects of the environment as shown in **Table 5**. Four students say that "It's real as if I was walking in." This is the function of 3DVW and was advertised by many literatures. Using the science inquiry makes students have a sense of presence and immersion. Besides, there are also some students reported the inconvenience when they conduct inquiry although they can get the information they want. For example, two students say that "although I can seek information in the Lab with the help of the instruction, I often confused when I change my destination". This indicates the inquiry in the 3DVW has some negative effect on the perceptions of students. Nevertheless, they can still afford the inquiry process and are willing to use it again and share with friends in the future despite the challenges.

DISCUSSION

At present, the standard learning in the 3DVW has adopted by many researchers. However, the answers of how to engage students in this world to a large extent and whether they perceive effectiveness are not clear yet. The inquiry-based learning highlights the active participation and the process of scientific research. Thus, it

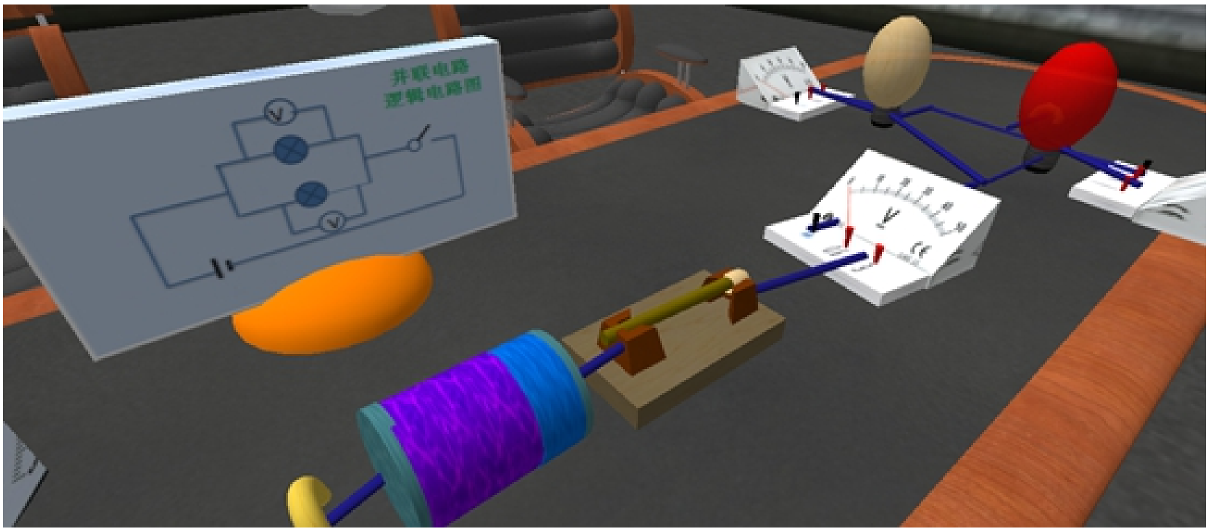

Figure 2. The work that students completed in the inquiry-based environment

provides a promising opportunity to address the questions. Our findings are showing a positive effect when students exhibit in the inquiry-based environment compared with the standard environment. The effect validation comprises aspects of perceived experience and perceived knowledge gains. Literatures have noted that the most common objective of education in the information technology environment is to increase user experience and engagement with the system (Cano, Perry, Ashman, & Waite, 2017; DomíNguez et al., 2013). In this paper, we claim that the user perceived experience is one aspect to measure the effectiveness of the system. Another important measurement is the perceived knowledge gains because they reflect beliefs about the academic values and knowledge friendliness of the inquiry-based environment in improving students' performance. The "experience" term is widely used in the context measuring user experience regarding systems. But it is a vague expression sometimes when it refers "good" or "bad". This subjective perception is difficult to present the extent to which students perceive it good or bad. Instead, this paper redesigns the inventory of perceived experience based on the previous technology acceptance model and further extends to the scientific attitude dimension.

As to the knowledge gains, students need to describe the understanding of physics concepts and the improvement of problem-solving abilities when they exhibit in the inquiry-based environment. It should act as an important role to be included in the inventory of measuring the perceived effectiveness. As is known to all, the traditional assignment and examination are becoming less and less suited to the new information technology environment and they have shown significant disadvantages in testing student abilities. While the new evaluation requires flexibility and diversity, and it allows different understandings of a problem. Therefore, the perceived knowledge gains not only examine the awareness of new knowledge and the sense of accomplishment but also, they reflect the confidence of completing tasks, and tendencies and reasons in the future use. Certainly, this measure also has some flaws. For example, the descriptions of students don't always get the ground truth because the information processing abilities of language areas in brains and the metacognitive strategies which are adopted to describe an object are different. Nevertheless, it doesn't significantly influence the results in this paper.

In the view of the work shown in Figure 2 and descriptions that students share, they are showing that students are more likely to use the inquiry-based learning environment because it makes them more engagement with the system. Also, the inquiry-based learning in the 3DVW enhances students' hands-on experience by simulating the situation and connecting the circuit. The student describes that he uses the tracer tool to draw a circuit diagram and then validates whether the circuit is typically workable. To do this, he needs to find out the proper electronic elements and learn their properties. More importantly, he must connect these elements in the right way and explore the points of interest in the circuit. For example, he needs to know the impacts of the battery's positive and negative poles, the brightness changes of a bulb after removing another bulb, and how the position of the slider of the rheostats influences the readings of the ammeter and voltmeter, etc. This inquiry process not only enhances the concepts in the brain but also develops the problem-solving abilities.

The inquiry-based learning is sometimes difficult to carry out in the information technology environment because there is no proper standard to measure whether the inquiry process is good or bad. The core of inquiry-based learning is constructing the student-centered activities so that students use the scientific research method to approximate the learning targets progressively. However, the inquiry process is always affected by the prior experiences, habits, fixed thinking modes, among others. It requires that the learning should follow the individual's development patterns. Thus, we consider multiple activities when designing the inquiry process. This allows students to play their strengths and find the points of interest. Moreover, students can complement knowledge structures among the group members based on the experience of different activities. In a sense, the students perceived effectiveness relates to their learning motivations. The effectiveness can be used to interpret whether students do something and the extent to which they do it. This enables students to perceive the direct learning outcomes in the specific environment, such as obtaining good user experience and gaining new knowledge based on the previous level as studied in this paper. In other words, when students feel the learning environment is effective, they have greater possibilities to maintain learning in the system. As a result, it has great potential to effectively promote learning in the 3DVW.

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