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Effects on Patterns of Learning-support Design in Immersive Virtual Reality System

Chia-Mei Lu and Pai-Lu Wu
Department of Digital Multimedia Design and Center for Teacher Education
Cheng Shiu University
840, Chengcing Rd, Niaosong Dist, Kaohsiung, 83347, Taiwan
k1024@gcloud.csu.edu.tw and pailu@gcloud.csu.edu.tw

Yuh-Ming Cheng
Department of computer science and information engineering
Shu-Te University
59, Hengshan Rd, Yanchao, Kaohsiung, 82445, Taiwan
cymer@stu.edu.tw

Shi-Jer Lou*
Department of Graduate Institute of Technological and Vocational Education
National Pingtung University of Science and Technology
1, Shuefu Road, Neipu, Pingtung, 91201, Taiwan
lou@mail.npust.edu.tw

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Abstract. *This study aims to explore the impact of varied learning-support design strategies on the biology learning of middle school students in Virtual Reality (VR) system. Practically, this study employed the immersive VR technology in a biology learning course. Through different learning-support designs in VR system, namely 1) structure sightseeing pattern, 2) structure and maneuvering, and 3) freedom to explore the impact of VR on biology learning effectiveness, learning attitudes, perception, cognitive load, and presence among middle school students. This study divided 104 subjects into two experimental groups (Group A, N=34; Group B, N=35) and a control group (Group C, N=35), and conducted biological knowledge test, questionnaire, collected interview data, and quantitative and qualitative data analysis. Based on the collected data and analysis, the following results are reached: 1) VR helps to improve students' biology learning. 2) Learning-support in VR is conducive to enhancing students learning outcome in biology. 3) Perceptual response during the VR learning process affects learning experience, but not learning desire. 4) Equipment operation, learning strategies, and high-fidelity environment trigger cognitive burden. 5) Realistic picture and sense of control will urge learners to present more initiative and activeness in learning performance.*
Keywords: Cognitive load, Learning-support, Navigation, Sense of presence, Virtual Reality

1. **Introduction.** Virtual Reality (VR) is already a trend in teaching[1, 2, 3]. VR interactive technology helps to impart and understand knowledge[4]. In terms of traditional teaching, biology is commonly explained with images and videos. Salzman(1999)[5] proposed that a multi-sensorial 3D environment can help students develop a more complete mental pattern. Teachers also generally believe that a multi-sensorial environment can help students to understand better and learn more[6]. In this regard, the introduction of

multi-sensory 3D VR into biology class can make learning more vivid, and solve problems that cannot be presented in physical classes. The application of VR technology in biology learning may yield significant learning outcomes.

While recent research concerning scientific and educational applications of VR have shown that VR has a profound impact on science and education[7]. VR is one of the computer simulation techniques. Over the past decade, computer simulation practically improves the understanding of students, their task performance, and ability to explain[8]; However, it is not sufficient for computer simulation learning to simply present a simulation environment to students[10]. Some scholars have suggested that good learning strategies should be provided in computer simulations[11], to help learners accomplish assigned learning tasks and to enable them to better understand the interrelationships between goals and tasks, and improves their learning outcomes[12]. However, research pertaining to the promotion of VR to students learning through teaching design is rarely seen.

Hence, it is necessary to make the students understand the specific and related learning tasks in the VR system through instructional design. However, Scheiter, Gerjets(2009)[13] argued that, when learners adopt improper learning methods in a virtual environment, regardless of the teaching design, high cognitive load (CL) may be resulted for learners. Therefore, attention should be paid to how to reduce learners cognitive load in VR through teaching or learning-support design. On the other hand, multiple studies have suggested that learners lack of experience in technology-assisted learning, such as: familiarity with interface operations and navigation problems (disorientation) will lead to learning overload[14], which in turn will affect the learning completion order and learning attitude[15]. Great importance should be attached to the interrelationship between learners cognitive load and learning outcomes in VR.

Regarding the cognitive load generated in VR, Whitelock(2000)[16] proposed that a high degree of VR presence in virtual environments may take up too much of the users attention, and thus, generate cognitive load. VR is characterized by a sense of presence of learnersAwhich enables first-person independent navigation interaction[4]. Numerous studies have indicated that a sense of presence contributes to positive learning outcomes[17, 18]. To sum up, how to maintain the sense of presence, reduce cognitive load, and enhance learning effectiveness in a VR is an issue that should be solved when VR is applied into teaching.

It is necessary to provide learners with learning-support strategies[11], and learning-support in a virtual simulation system[19]. Sound learning strategies and learning-support will help learners reduce their cognitive load. Thus, this study focuses on the impact of learning-support design in VR system. VR can be divided into immersive and non-immersive. However, a large majority of studies adopted non-immersive VR in educational applications, where the mouse and keyboard served as users devices for interacting with the system[18]. Educational research on immersive VR is rare.

Previous learning-support research in virtual simulation system showed that it is crucial to provide students with a balanced learning environment that is both free and structured[20]. For immersive VR system, the impact of free and structured learning-support on learners has not been verified or studied. Accordingly, this study explores the impact of free, structured, and maneuvered learning-support in immersive VR, as well as the influence of cognitive load and sense of presence in immersive VR. Route planning is a kind of travel technology and interaction method in virtual space. In terms of learning path, it is defined as pre-structured or designed learning steps in a general manner (as a navigation map or directory) or in a very specific order (completing the first step before starting the second step)[21].

Therefore, this study takes the blood cells in biology as the theme, and focuses on exploring the impact of different learning-support patterns on students' learning outcomes, cognitive load, and sense of presence in immersive VR. Moreover, based on the experimental results, an Immersive VR learning-support design and construction pattern is proposed for learning. Based on the above information, the objectives of this study are, as follows:

1.Explore the impact of different Learning-support patterns on learning outcomes in Immersive VR.

2.Analyze the impact of different Learning-support patterns on learners' cognitive load and sense of presence in Immersive VR.

3.Put forward a design proposal for a learning-support pattern in Immersive VR for learning

2. **Literature Review.**

2.1. **Educational support in VR.**

Immersive VR refers to experiencing a multi-sensory environment through a stereo head-mounted display[22, 23]. Users can interact with objects through a handheld device[1], and explore and move in a VR 3D virtual environment[4, 24]. Non-immersive VR is also called desktop VR, which displays a virtual simulation environment on a general computer screen, and interaction is conducted via a mouse[25].

In retrospect, in terms of research concerning the learning effects of scientific education in virtual simulation over the past decade, sound learning-support has been found to be necessary for calculating the learning effects of scientific education[11, 19]. In previous scientific virtual simulation learning on a computer, learning-support usually refers to the virtual experimental simulation design, and the processes of planning and monitoring learning activities[26, 27]. Fund (2008)[28] proposed support programs (with structure components: structure vs. without structure component: freedom) for the process planning of learning activities in scientific empirical studies, and held that the structural component had the most impact on learning outcomes. Then, Kirschner, Sweller(2006)[20] deemed it necessary to offer students a balanced learning-support environment. Hence, learning-support in this study follows the research design of Fund(2008)[28], and explores the impact of structural learning-support and design in VR.

The operation design of learning-support in this study is characterized by structure and maneuvering learning path design (with structure component) and freedom pattern (without structure component). Freedom is an important feature in VR, which refers to the free exploration of the first-person [4]. Route planning is a kind of travel technology and interaction in virtual space[29]. Traveling in a virtual environment may achieve the following: 1) exploration; users are free to browse the environment without any clear goals; 2) search; users search for a specific target; 3) maneuvering; users design with a specific target under relevant guidance. However, a large number of studies have also conducted empirical studies pertaining to structure and freedom, and found that excessive freedom in the learning process actually weakened the learning outcomes [10, 30, 31].Accordingly, this study explores the impact of VR learning-support (path design) on learning, as well as the impact of cognitive load and sense of presence on VR learning in the process.

2.2. **Perceptual features in virtual reality education.**

Computer simulation and virtual experiments can practically improve students performance, ability to explain[8], and understanding[9]. However, factors related to perceptual features, content features, and social interactions appear to be crucial for learning, as the study of virtual simulations from 2003 and have not been extensively studied[32]. Thus, this study also intends to explore impact of individual's perceptual features (cognitive load and sense of presence) on learning in VR.

Regarding cognitive load, Marcus, Cooper(1996)[33] proposed three factors that affect cognitive load in the learning process: prior experience, nature of the material, and organization. In VR, cognitive loads are generated due to the following reasons: 1) insufficient learning methods adopted in the VR. Scheiter, et. al(2009) [13] and Chang, et. al (2010)[34] indicated that, when learners adopted inadequate learning methods in a virtual environment, high cognitive load (CL) may be caused regardless of the learning design; 2) lack of experience in technology aided learning[14]. Due to a lack of experience in technology aided learning, learners may be plagued by interface familiarity and navigation issues, thus, in a multimedia learning environment, learners tend to lose their direction, causing learning overload[35, 36].

Sense of presence means the immersive feeling of learners in VR as a part of the virtual environment. Sense of control, simulation, and multiple sensory input in virtual environments help users to generate a sense of presence[37]. In addition, users can increase their sense of presence by traveling in a virtual environment through physical technology applications[29]. The relationship between sense of presence and learning is proposed in the empirical studies of semi-immersive virtual reality. Sense of presence has significant effect on learning outcomes, interactive attitudes, staying focused, and completion of learning tasks[17]. Sense of presence is considered a key feature of computer simulations[17]. Moreover, the sense of presence is affected by various factors, including age, gender, computer experience, psychological factors, and learning styles[18].

In the study of CL differences among individuals with a high sense of presence, multiple studies have found that sense of presence has significant effect on learning outcomes in VR-assisted learning. However, Whitelock, Romano(2000)[16] proposed that, in a virtual learning environment, a high degree of sense of presence in VR may occupy too much of the users' attention, thus, generating cognitive overload. Crosier, et al.(2000)[15] also indicated that high simulation effects in VR distracted students to the largest extent during the learning process, thus, a high degree of immersive sense in VR may occupy too much of the users attention and cause cognitive overload. In addition, as interaction with new technologies in VR is novel and unfamiliar to a large majority of students, their sense of presence may be affected, or they may employ larger attention to address all the received information, causing distraction or generation of cognitive load[35, 36]. Beginners or passive learners are easily lost when handling multimedia or in a multimedia learning environment, which may cause learning overload. In this regard, how to maintain the sense of presence of students, reduce their cognitive load, and enhance their learning effectiveness in high simulation VR is an issue to be solved during the application of VR in learning, in order that VR can be used in learning to solve problems. Hence, this study focuses on the impact of different learning-support patterns in VR system on cognitive load and the sense of presence of students.

2.3. **Educational applications - VR for biology courses.** Regarding the educational applications in this study, "The Body VR: Cell" is a biology VR learning course. Developed by The Body VR LLC. The units of this course include blood cells, cell membrane structure, cytoskeleton, nucleus, cell center, cytoplasm, and virus attack. In terms of The Body VR, learners may explore the human body, understand blood cells, and observe how the organelles work through head-mounted devices and the VR system design. The VR Device's support for THE Body VR software design enables three different patterns of learning-support patterns: 1) sightseeing pattern, 2) structure and maneuvering, 3) freedom pattern. The "Sightseeing pattern": Learners learn in an observer pattern. Through the internal design of "The Body VR: Cell", the system will automatically guide and explain to learners how blood works in our body and how blood cells work to spread oxygen throughout the body. In this pattern, users cannot interact with the scenes in The Body VR. The Structure and maneuvering pattern employs a structured path design, in which learners can interact with the scenes or objects; for example, using a controller to reach out and pick up cells for observation. In the "Freedom pattern", learners can independently navigate and explore the learning patterns.

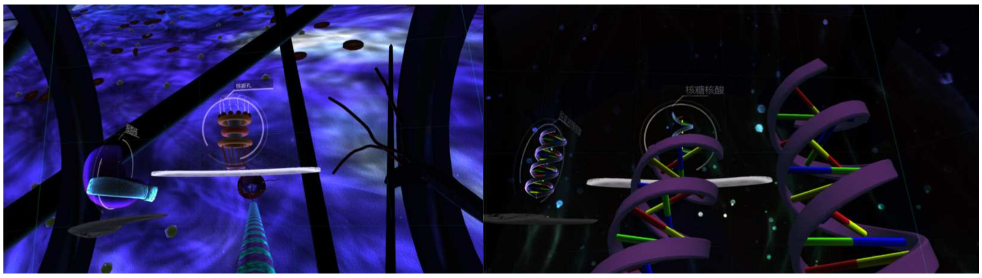

Figure 1. Learning Content in The Body VR

3. Experiment.

3.1. Participants and Experimental Design.

This study adopts the inter-laboratory experimental design to conduct three experimental activities. The independent variable of "Learning-support" in this study refers to the sightseeing pattern, structure and maneuvering, and freedom pattern in the control group. This study selects 104 students from the 12^{th} grade of a high school in southern Taiwan as the subjects, and divides them into experimental groups (Group A, N=34; Group B, N=35) and a control group (Group C, N=35). The experimental process of this study includes biological knowledge test, a questionnaire, the collection of interview data, and quantitative and qualitative data analysis. The experimental design is shown in Table 1.

Table 1. Experimental Design

Group	Pre-test	Experimental treatment	Post-test	Retention-test
Experimental group A	O1	X1	O2	O3
Experimental group B	O1	X1	O2	O3
Control group C	O1	X1	O2	O3

This study collects data through quantitative knowledge tests and qualitative data. The experimental groups and control group participated in pre-test before learning any unit, post-test after learning, and retention test 2 weeks after learning, in which the same test questions are used, but in different order. To ensure the validity of the test, the test questions are compiled by senior teachers in the experimental school, and confirmed by two senior teachers after preparation. Test questions are in the form of multiple choice questions, which mainly test memory and understanding, with 6 questions for each part and one point for each question. In this regard, the learning effectiveness test questions in each unit have a total of 12 questions, with a total score of 100 points.

This study uses the Presence Questionnaire (PQ) to evaluate participants sense of presence in the VR environment. The PQ, as developed by Witmer and Singer(1998) [37], is to measure the degree to which the participant is "... experiencing the computer-generated environment, rather than the actual physical locale". Revised by the UQO Cyberpsychology Lab(2004)[38], and after translation and editing, there are seven items in the questionnaire: Realism, Possibility to act, Quality of interface, Possibility to examine, Self-evaluation of performance, Sounds, and Haptic, for a total of Items 1 to 19, and a seven-point Likert scale is used.

The cognitive load questionnaire is adapted based on the Online Digital Reading Cognitive Load Scale, as prepared by Chang(2016) [31]. The questionnaire is divided into the two facets of mental effort and psychological load, with a total of 15 questions. The following are two Cronbach's coefficients: reliability of mental effort is .781; reliability of psychological load is .818. This indicates that the internal consistency of the scale is high, and exceeds the requirement of over 0.7 [39]. A five-point Likert scale is used.

Table 2. Experimental process of experimental group and control group

Process	Content	Time
1	Pre-test: Subjects participate in pre-test	10 minutes
2	After the pretest, explain the pattern of operation, and allow subjects to carry out systematic operation	10 minutes
3	Start VR learning	30 minutes
4	After test: paper test. After the test, subjects should immediately participate in the post-test	10 minutes
5	Fill in the form: After the post-test, subjects should immediately fill in the form	20 minutes
6	Retention test: 2 weeks later, the same students participate in a paper test	10 minutes

In addition, to gain a better understanding of learners' feedback on VR experiences, learning attitudes, and learning outcomes, a semi-structured open questionnaire is used to conduct interviews for data collection. The following are example questions from the interviews, "After learning, did you feel unpleasant when you could not use VR experience activities?" "In the virtual environment, did you feel stressed, nervous, and want to stop learning?" These questions are designed based on the orientations in the VR Experience Activity Questionnaire. After the quantitative questionnaire survey, 9 participants are selected from the 3 groups (3 subjects from each group). These data are presented in text. In terms of text encoding; taking "A-3" as an example, "A" means the student's text message and "3" means the third student in the group.

3.2. **Experimental process and data collection of this study.** The learning time of VR learning materials in this study is 30 minutes, where learners can carry out thematic learning and operate VR learning materials. The entire experimental process is shown in Table 2.

4. Results and Discussion.

4.1. **Learning effect analysis of different learning-support designs in VR.** Learning effect analysis of pre-test, post-test, and retention test for both experimental group and control group. According to the pre-test results of the experimental and control groups, the P value of homogeneity is 0.08 (<0.05), which is not significant. In the ANOVA analysis of "pre-test" learning, F (2, 87) =2.798, and P=0.066<0.05 is not significant after comparison. In the pre-test section, the students of Group 3 have no significance.

1.Statistical analysis of post-test of students in different Learning-support design.

In "Post-test" ANOVA analysis, F (2,87) = 19.39, p=0.00, and W2=0.29, which shows high effect value; and Group B (M=84.64) is significantly higher than Group A and Group C with a statistical power of 1, indicating high statistical power. Moreover, it shows that, the students of Group B are obviously better than those of Group A and Group C in post-test. That is, in terms of knowledge concerning biological cells, students who study "structure and maneuvering" perform significantly better than those who accept the "sightseeing pattern" and "freedom pattern". The post-test performances of students under "structure and maneuvering" and "sightseeing pattern" are better than those of the "freedom pattern". In fact, in terms of the identification of learning objectives and the setting of the learning structure, when learners are provided with specific learning tasks, they may have a better understanding regarding the relationship between learning objectives and tasks, which will in turn enhance their learning effects. Providing learners with virtual simulation learning objectives helps improve their learning effects, which is consistent with the research results of Lee(2014)[2], Chang(2008)[30] and Gelbart, el.al[40].

2.Statistical analysis of the retention test of students in different Learning-support designs.

In the "retention test" of ANOVA analysis, F (2,87) = 6.48, p=0.002, and W2=0.11 of Group A show high effect value; Group B (M=55.83) is significantly higher than the subjects of the second group (M=48.25) and Group 501 (M=31.28) with a statistical power of 0.89, indicating high statistical power. Moreover, it shows that the students of Group B are obviously better than those of Group A and Group C in retention test. That is, students who study "structure and maneuvering" perform significantly better than those who accept the "sightseeing pattern"' and "freedom pattern" in terms of knowledge concerning biological cells. In fact, according to Manlove, Lazonder(2006)[41] a fully specified tool (including a hierarchy of goals, sub-goals, hints, and explanations) may enhance learning effects. Providing learners with a sense of control in the learning environment urges learners to take the initiative to learn, which helps improve learning effects, and achieves higher degrees of perceptual learning and satisfaction. The "Structure and maneuvering" learning-support design not only specifies learning objectives, but meets the exploration demands of learners, which is consistent with the research results of Manlove(2006)[41] and Lazonder(2014)[2].

4.2. Analysis of learning attitudes toward different learning-support designs in VR.

1.Stress and nervousness affect learning experience but not willingness to learn in VR.

In the "learning experience", regarding the item "In VR, one feels stressed, nervous, and wants to stop learning", Group A (M=4.10, t = -2.594, p < .015), Group B (M=3.10, t = -6.238, p < .00), and Group C (M=3.00, t = -5.91, p < .00). This indicates that students who adopt different patterns of Learning-support in VR feel pressure and nervousness during the learning process. In "learning attitude", regarding the item "After learning, one wants to study again", Group A ((M=2.83, t = -6.586, p < .000), Group B (M=2.53, t = -7.446, p < .000), and Group C (M=2.27, t = -10.985, p < .000). This indicates that students who adopt different patterns of Learning-support in VR want to learn again. In fact, VR is a new learning pattern for students, which is novel and fun, thus, attracting a large majority of students, which is consistent with the research results of Jackson(2000)[42].

2.Appropriate learning objectives contribute to the improvement of learning achievements and learning interests in VR.

In the item "are you becoming more interested in biology learning when VR is used", Group A (M=4.33, t = -2.163, p < .039) and Group C (M=3.90, t = -3.568, p < .001). This indicates that students who adopt various Learning-support patterns in VR are more interested in biology learning when VR is used, which is consistent with the research results of [43]. In the item "In the future, will you use VR for content of other subjects?" Group A (M=5.70, t = 3.175, p < .004); in the "learning effect" item, "whether VR is helpful to your learning performance?" Group A (M=4.10, t = 2.878, p <.007), while Group B and Group C are not significant. The situations of Group A students are consistent with the findings of Cheng.et.al(2011)[44]: VR are favored by students, and have positive impact on academic performance and interest. It can also be inferred that, a structured learning pathway design provides proper guides and optimizes students' learning, enhances students' academic achievement, and urges them to use VR in other subject learning, which is consistent with the research results concerning guidance and the optimization of students' academic achievements of De Smet et al(2016)[21].

4.3. Sense of presence and cognitive learning effect analysis of different learning-support patterns in VR.

1.Impact of Sense of Presence on Different Learning-support Patterns in VR.

In this study, based on the experimental design, the sense of presence of the three groups are subject to ANOVA analysis, to understand the impacts of different VR Learning-supports on the cognitive load of students during biology learning. The variable of the sense of presence of the three groups are analyzed by ANOVA and undergo homogeneity test. Results show that the subjects of each group, regarding the seven facets of the sense of presence: "Possibility to act", P=0.785, "Realism", P=0.535, "Quality of interface", P=0.638, "Possibility to examine", P=0.970, "Self-evaluation of performance" P=0.103, "Sounds", P=0.708, "Haptic", P=0.908, indicate that these three groups show homogeneity in the variable of sense of presence. This study conducts single sample t test on the seven facets of the sense of presence in biology learning in VR. Test value 5 is used to assess the seven facets for further analysis, as shown in Table 3.

Table 3. Group A: Single Sample T Test of Sense of Presence (Test Value=5)

Variables/groups	A	B(Coach)	C(Independent)
	t	t	t
Realism	-6.70*(.00)	-6.66*(.00)	-7.72*(.00)
Possibility to act	1.25(.22)	.021(.98)	-.15(.88)
Quality of interface	3.09*(.01)	2.43*(.02)	3.05*(.01)
Possibility to examine	-2.29*(.02)	-3.40*(.00)	-4.19*(.00)
Self-evaluation of performance	-2.64*(.01)	-1.51(.14)	-4.47*(.00)
Sounds	-1.79(.08)	-2.16*(.03)	-.86(.39)
Haptic	-15.18*(.00)	-16.00*(.00)	4.30*(.00)
Mental efforts	-6.56(.00)	-5.39(.00)	-6.44(.00)
Mental load	-10.63(.00)	-15.65(.00)	-19.90(.00)

In terms of Realism, Quality of interface, Possibility to examine, Self-evaluation of performance, and Haptic, the three groups all show positive results. It is inferred that, in a VR, learners show strong realism and positive quality of interface. Realism contributes to cognitive experiences and arouses the positive feelings of learners toward the learning environment. In this regard, it is consistent with the findings of Sylaiou, Mania(2010)[45], meaning that highly immersive virtual environments are helpful to arouse learners high sense of presence, and enhances their positive feelings during the task. In addition, Haptic is positive Lee and Wong(2014)[46], and provides control and active learning. In this way, learners may perform better, and reach a higher level of perceived learning and satisfaction. Therefore, the control and active learning of learners in VR help to motivate self-expectations.

2.Impact of VR Learning on Cognitive Load in Different Learning-support Patterns.

In this study, and based on the experimental design, the cognitive load of the three groups are subjected to ANOVA analysis and homogeneity test of the variables. Results indicate that these three groups show homogeneity in the variable of "mental effort" P=0.905 and "mental load" P=0.206. This study further examines the "cognitive load of VR on biology course" in the three kinds of VR Learning-support and two facets of mental efforts and mental load. Single sample t-test is performed to assess seven facets with a test value of 5, as shown in Table 3. Mental efforts and mental load are both positive among the three groups. It can be inferred that, due to the limited experimental time of this study, learners adopt insufficient learning strategies and methods, thus, causing cognitive load, which is consistent with findings of Gerjets and Scheiter(2003)[47], and Whitelock(2000)[16], meaning that immersive sense and distraction in virtual learning environments divert students attention and give rise to cognitive overload.

4.4. Comprehensive analysis of VR learning with different learning-support patterns

1.Hysical and physiological side effects, as caused by equipment fitness, affect the sense of presence in learning.

The experimental equipment of this study may cause serious discomfort due to improper operation or improper wearing of the headset. For instance, "dizzy head and overweight machine, (A-3)"; "Unclear picture (B-1)", and "heavy machine (C-3)". It can be inferred that, when learners are learning with VR, the so-called computer disease (Cybersickness) will appear, which refers to motion sickness, as generated during interaction with the virtual environment, or when immersed in the virtual environment. The main symptoms include eyestrain, disorientation, postural reflex, anxiety, and nausea[48]. It also affects students' learning. Witmer and Singer(1998)[37] also pointed out that, the discomfort symptoms in a virtual environment will show negative correlation with the sense of presence, that is, if users in a virtual environment feel uncomfortable, their attention may be weakened in such environment.

2.Generation of cognitive load in the VR learning process is affected by the physiological side effects caused by the degree of technology fitness.

"I need to operate the device with care, (C-2)"; "Operating the device can sometimes distract me, because I want to explore what happens after the operation, (C-2)"; "I'm not familiar with the operation and may be affected by it, so I do not remember the learning content, (C-2)"; "I do not feel overly stressful or nervous, and it's very novel (C-2)"; "It's very real, it's fun, and I'm interested in biology, (C-1)". It can be inferred that, interaction with these new technologies is novel and unfamiliar to a large majority of students, thus, affecting their sense of presence or requiring more attention to process the messages received, leading to distraction or cognitive load[35, 36]. For beginners or passive learners, it is easy to lose direction in handling multimedia or in multimedia learning environments, thus, leading to learning overload, which is consistent with the research results of previous studies.

3.Teaching materials design and interface quality of real sensory images help to enhance the sense of presence and interest in learning.

"It feels so real, and I know more about my body structure. It is funny (B-2)"; "It's interesting, and cells come to life (A-1)"; "It's so real, (B-2)"; "It's very real and funny, and I became interested in biology, (C-1)"; "It's easier to remember than normal learning, (C-1)"; "Very interesting, I learned the tricks the first time (C-1)"; "I think this is a great experience for me to become more interested in biology, (C-2)". It can be inferred that immersive learning and exquisite 3D graphics enhance students' sense of presence and interest in learning, which is consistent with the findings of Fortin and Dholakia(2000)[49]; IJsselsteijn, et al (2000)[50].

5. Conclusion.

5.1. VR learning helps to enhance students' biology learning effect.

This study was based on the following research designs: 1) sightseeing pattern, 2) structure and maneuvering, and 3) freedom pattern without learning-support; though there are differences in the post-test scores, all three groups had better performance in post-test than in pretest, which shows that VR can help enhance students' performance in biology learning and arouse students interest in the use of VR, which is consistent with the findings of Peterson, et al(2000)[43]; Cheng and Wang(2011)[44].

5.2. Learning-support patterns in VR help to enhance students' biology learning effects.

To integrate learning objectives into the structural design and guide the "sightseeing pattern" and "structure and maneuvering" during the learning optimization process of the three groups; the post-test results are better than those of the "freedom pattern", showing that Learning-support in VR helps to enhance students' biology learning effects. In addition,Manlove, Lazonder(2006)[41] and Lazonder, Wilhelm(2009)[12] proposed that, the setting of learning targets in virtual simulation is conducive to enhance learners' learning effects; De Smet, et al(2016)[21] provided learners with the learning path design, while Chang, et al(2008)[30] provided the Menu and step guidance to achieve better learning effects.

5.3. Perceptual response in VR learning process affects the learning experience, but not the learning will.

While the students of each group felt pressure and nervousness in the learning process, it did not affect their wish to use VR to learn again. This indicates that a new learning pattern with VR arouses students' curiosity, and is attractive to students, which is consistent with findings of meaning that VR may improve students' performance and learning[42].

5.4. Equipment operation, learning strategies, and high-fidelity environments trigger cognitive load.

In terms of the generation of cognitive load, the three groups showed positive Mental efforts and Mental load. Equipment operation, learning strategies, and high-fidelity environments trigger a cognitive burden on students. However, such findings are not consistent with the findings of the technology fitness of Clark(2001)[35] and Mayer(2014)[36]; the findings of Gerjets and Scheiter (2003)[47] show that learners fail to have sufficient learning strategies and methods; and findings of Whitelock, et. al(2000)[16] show that high immersive sense in the virtual environment will take up too much attention of the learners, causing distraction and cognitive overload.

5.5. **Realistic pictures and control helps learners to perform actively and positively.** The control and active learning of learners in a VR does motivate self-expectations, which is consistent with the findings of Sylaiou, Mania(2010)[45], that a high sense of presence of learners is helpful to active performance, as well as that of Lee and Wong (2014)[46], that with control and active learning, learners may have better performance and a high sense of perceived level and satisfaction. The researchers offer some suggestions:

1. **Schools should integrate VR technology into biology learning courses and provide multiple learning programs.** This study shows that VR helps to improve students' biology learning and interest, thus, it is suggested that schools should improve the traditional teaching methods of biology, and integrate VR technology into biology learning, to solve the problem that some parts of biology learning cannot be presented in a physical classroom.
2. **Learning-support design in structure and maneuvering helps to enhance VR learning effect.** In terms of learning-support, it is suggested that structure and maneuvering should be integrated into the VR system, a structure and maneuvering may optimize students' learning process and achievements through the structural design of the learning objectives, which will urge students to use VR in other subjects.
3. **Interface quality design of VR learning materials helps learners to perform actively and positively in the VR learning process.** It is suggested that designers of future VR systems should ensure the quality of the interface design of VR learning materials, and enhance the control design of users in the VR.
4. **Provision of pre-learning strategies and technology fitness helps the integration of VR into biology courses.** With sufficient preparation, learners may seize the best chance to achieve better learning effects. This study suggested that VR should be integrated into biology teaching design; moreover, relevant methodological advice and strategies should be provided to learners to enhance effectiveness and their willingness to engage in VR.

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