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Drawing as reflection strategy for immersive virtual reality learning to enhance students' science outcome

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Abstract

Immersive virtual reality (IVR) technology has a great potentiality in providing high presence and in-time interactions to simulate real learning situations by presenting 3D visualization to enhance the effectiveness of learning about biology, especially genetics topics which on a submicroscopic level including genes, chromosomes, and DNAs are abstract and cannot be directly perceived or touched. In this study, different types of media learning environments, including traditional PC-slides and IVR, such as VR-game, which were employed for experiential learning of science courses with 109 students in the middle school. The purpose of this study was to investigate the effects of reflection strategy and type of media on participants' cognitive outcomes. Significant interaction between media and methods illustrated the reflection strategy enhanced learners' cognitive performance through immersive VR learning environments (IVREs), but not traditional PC-slides. By using the drawing method, the VR-game made students the most engaged in learning and focus on the key points of important concepts; non-reflection learners focused on games and their learning was easily disturbed. It was concluded that the immersive virtual reality with the specific reflection method was effective in increasing learning performance and the drawing as a generative learning strategy indeed reduced the external cognitive load of learning and promoted the effectiveness of cognitive processing.

Keywords: immersive virtual reality, game-based learning, reflection strategy, drawing, science education, genetics

1 Introduction

In recent years, many studies have shown that the application of virtual reality (VR) technology for education has been confirmed to help students to learn. Brelsford (1993) pointed out that virtual reality can make the task of learning more intuitive, and users have more interaction with information.

Many knowledge concepts of biology such as genetics take place on a submicroscopic level, which is abstract and cannot be directly perceived or touched. Teaching in middle school classrooms disables students to learn and apply these concepts through practical operation in problem-solving situations. Thus, simulating 3D visualization with VR technology can be a method to enhance the effectiveness of learning about genetics.

Immersion is an important feature of virtual reality in the context of teaching, which can make learners more engaged in learning. But until now, there have been many disputes about the relation between important features of VR technology and learning outcomes. Studies have also pointed out that a higher immersion environment can enhance students' motivation and learning outcomes. However, in the study of Makransky, Terkildsen, and Mayer (2018) and Parong and Mayer (2018), different results were shown. Thus, Parong and Mayer (2018) recommends focusing on the addition of instructional strategies or adding teaching design to improve the effectiveness of virtual reality learning.

In addition to VR-simulation, many studies have also pointed out that game-based learning can make learners more engaged in learning activities (Killi, 2005) and improve learning effectiveness (Merchant et al., 2014). If immersive VR provides a more interactive and embodied game-based environment could be more helpful for learning.

Until now, few studies have focused on customized VR game materials with immersive VRLEs (virtual reality learning environments), most experiments implemented in the laboratory setting for university students, and the lack of appropriate instructional methods may result in poor learning effects of VR learning. For the above reason, we wanted to understand that how to use the immersive VR technology to help students to learn better in the middle school classroom setting, focusing on genetics concepts including genes, chromosomes, and DNAs, which is an important and difficult topic for learners in biology. And another problem is that the immersive VR equipment is expensive for general schools, our results also will provide practical value on that whether to invest in VR equipment at the middle school stage.

The purpose of this study was to investigate cognitive outcomes by employing the instructional method of drawing as a reflection strategy through comparing traditional PC-slides and immersive VR, VR-game especially, in experiential learning of science courses. Furthermore, results from this study could provide evidence about how do media or methods affect learning performance.

2 Literature Review

Virtual reality is an emerging technology medium in education. Many studies have started to discuss how the special features of this new technology affect cognitive processes (Shin, 2018). the special features that are often discussed in VR technology are I^3 as "immersion-interaction-imagination" (Huang, Rauch, & Liaw, 2010). Learning in high levels of immersion lead to a higher sense of presence, this is a subjective sensation of "being there" in a virtual environment, which promotes users' motivation and willingness to engage (Makransky, Terkildsen, & Mayer, 2018).

VR was confirmed to influence learning motivation and effectiveness, especially in the learning of science (Makransky, Terkildsen, & Mayer, 2018, Parong & Mayer, 2018, Meyer, Omdahl & Makransky 2019, Klingenberg et al.,2020). Some studies also discussed appropriate instructional methods or strategies (Parong & Mayer, 2018, Meyer, Omdahl, and Makransky, 2019).

Most of these studies compare the immersive VR media (presented by a headed-mounted display, HMD) with low-immersion media (computer simulation or video/slideshow learning). These studies have pointed out that highly immersive virtual reality can help acquire procedural knowledge (Bertram et al., 2015), but few studies have proved that virtual reality can be used as an effective learning tool to acquire declarative knowledge. The results of the research have also pointed out that a higher immersion environment can enhance students' motivation and learning outcomes (Webster, 2016). However, different results were shown (eg, Makransky, Terkildsen, & Mayer, 2019; Moreno & Mayer, 2002; Parong & Mayer, 2018). In a highly immersive environment, students can improve their motivation but the learning outcome is worse than the general computer simulation because of the redundancy effect. The effect increases the learner's cognitive load.

The reasons were explained by Cognitive Theory of Multimedia Learning (CTML; Mayer, 2009; 2014). Makransky, Terkildsen, and Mayer (2018) pointed out that because of the redundancy principle, the cognitive load affects learning. Parong and Mayer (2018) also showed that the VR content violated the principle of consistency, segmentation, and higher learner control, users were distracted by 360-degree viewing of animations that were not related to the narration of material. Above all, media does play a certain role in learning, but how much influence contributes to learning?

Kozma (1994) emphasized that a certain kind of media might help a certain pedagogy should be considered, instead of a strong distinction between the two. In addition, Parong and Mayer (2018) suggested paying attention to the addition of teaching strategies or adding teaching method design to improve the effectiveness of virtual reality learning. For example, the study of Meyer, Omdahl, and Makransky (2019) adopted the pre-training instructional method to compare the learning effectiveness of the two media, virtual reality, and video. Although there was no significant difference in the retention and transfer of declarative knowledge between the two media, the use of pre-training was helpful to knowledge acquisition in the virtual reality media, but it was not effective in the video group. Therefore, it could be seen that there was an interactive relationship between the media and the instructional method. Another study on the use of teaching as generative learning strategies (GLSs) had similar results (Klingenberg et al., 2020).

Another one of GLSs is the drawing strategy (Fiorella & Mayer, 2016) often used in experimental observation and reflection in biology, refered to the visual drawing thinking strategy (Model-Based Reasoning Strategy: Drawing) proposed by Quillin and Thomas (2015), as the thinking framework, the purpose is to provide the scaffold of the learner's observation and reflection in the virtual experience.

In addition to the VR-simulation, Merchant et al. (2014) evaluated the learning effectiveness of VR in K-12 by a meta-analysis. He found that under three VR technology-enhanced learning environments (virtual world, game, and simulation), the game show higher learning gains than the other two. Therefore, through the immersion and interactivity VR technology combined with game-based design allowed learners to engage themselves in challenging learning situations and actively acquire knowledge, which could effectively reduce the cognitive load of learners and enhance learning.

However, past studies had many limitations. For example, VR contents were off-the-shelf, entertaining value usually was higher than learning. The experiment time was too short, and in a lab setting. Thus, we further focus on different types of immersive VR media learning environments, integrated instructional methods of experiential learning, and game-based design, to help students to learn science in the general school's condition.

3 Research Methods

3.1 Participants

The participants of this study were 109 students (50 female; 59 male) from a middle school in the north of Taiwan. These students were ninth-grade (average age of 14 to 15) and had learned genetics chapter in biology course in seventh grade. The participants took 3-class-per-week formal biology courses in a summer semester. The treatment learning activity occupied three weeks, replacing traditional lecture courses.

3.2 Research Design

In this study, a 2 x 2 quasi-experiment was implemented. All students from four classes were randomly assigned to one of two media conditions (PC-slides/ VR-game), and one of two method conditions (RS/no-RS).

For the media conditions, the PC-slides group used only PowerPoint slides which were self-paced on a desktop computer. Students can click on the mouse to slide the pages. The content of the slides was screenshotted from VR materials including words and 2D pictures of the scene, covering all knowledge points to make the lessons as similar as possible (see Figure 1. a and c).

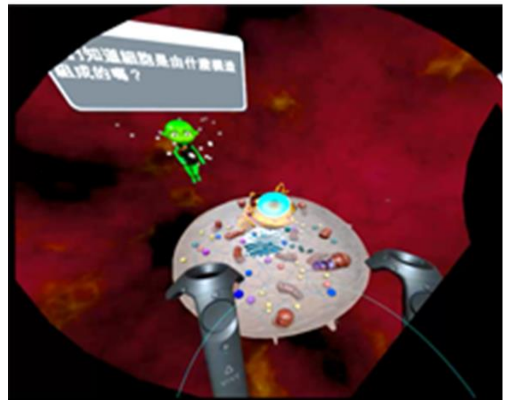
The VR-game condition (see Figure 1. b and d) was employed in immersive VR, used an embodied virtual reality system including a head-mounted display and two wireless hand controllers which were presented to participants with Steam Software on a desktop computer and a high-end HTC Vive HMD. The controllers allowed the user to interact with the virtual environment using intuitive gestures, and users received haptic feedback for certain interactions. The console also included wall-mounted sensors in the room to allow the software to map the space in which the user could move in 2x2 meters space.

In the RS conditions, students conduct drawing as a reflection strategy following the questions of the task on the learning worksheet after exploring and observing VR content or when they complete a task of level (see Figure 1. e). In the no-RS condition, students had not been given a specific time to reflect by drawing in the process of learning.

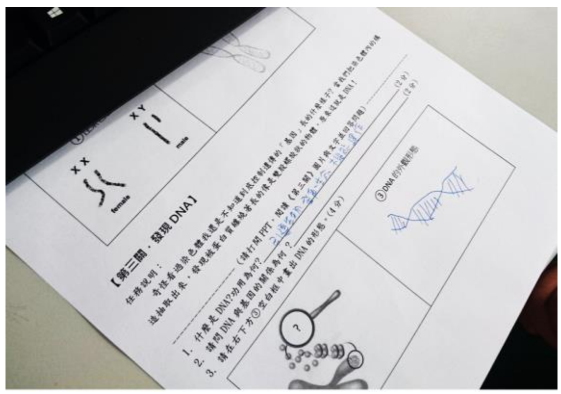
(a) PC-slides group used PowerPoint slides which were self-paced on a desktop computer.

(b)VR-game group used embodied VR HMD moving in 2x2 meters space.

(c) Screenshots from VR content including words and 2D pictures for PC-slides: Introduction of cell structure.



(d) Screenshots from VR-game content: Introduction of cell structure with fixed narrative scenario and interacted with virtual agent.



(e) Students' drawing following the questions of the task on the learning worksheet.

Figure 1: Media conditons(a) (b) with materials (c) (d), and methods conditons (e)

3.3 Materials

The VR content used for this experiment was an interactive biology game called The Genetic Action: A Cell Journey for Forensic Science (see Figure 1. c and d). In this game, the player is as a forensic investigator taken through a body tour inside of a cell, to explore the composition and function of chromosomes and DNAs and find evidence to pursue the criminal. During the process, students are overwhelmed by the like-real 3D scene inside the human body and intracellular space. They could grab and move the chromosomes in front of them, even operate a special machine to extract DNA and synthesize dominant and recessive genetic factors.

The learning task contains five main subject knowledge concepts, including (1) Where is the genetic material: understanding cell structure (2) What is the role of chromosomes: Understand the form and function of chromosomes (3) Discovery of DNA: The form of genetic material and the relationship with genes (4) Guess the gene is dominant or recessive: Human traits and genotype combinations (5) The genetic code of blood type: ABO blood type "phenotype" corresponding to the "genotype" combination.

The VR content was developed by a team composed of graduate students as game developers and middle school teachers by the MOEVRAR project funded by the Ministry of Education in Taiwan.

Both types of media learning environments employed the same experiential learning stages based on David Kolb's Experiential Learning Model (ELM), including (1) Concrete Experience (2) Reflection Observe (3) Abstract Conceptualization (4) Active Experimentation. *At stage 1*, participants explored and engaged in the 2D image or 3D virtual reality experience, interacting with the objects and the agent where they received the instructions and text prompts of the task. *At stage 2*, participants observed the scene and focused on details associated with the questions of the learning worksheet, and drew concrete images on the worksheet. *At stage 3*, the instructional design and scaffolding prompted the learner to transform empirical materials connected with conceptual knowledge to a structured process of systematic ideas and had to solve every problem of the task. *At stage 4*, at the end of the learning task, a new and more difficult situation was provided for learners to take the initiative to complete new challenges.

3.4 Procedure

The PC-slides group experimented with a real classroom setting. We provided enough equipment for every student in a class including the computers for the PC-slides group to learn simultaneously. The VR-game group experimented with two people at a time because the number of high-end VR equipment was limited. all students are divided into four treatment classes and different conditions (a~d): (a) PC-slides with RS (n=30) (b) VR-game with RS (n=25) (c) PC-slides with no-RS (n =30) (d) VR-game with no-RS (n =24) (see Figure 2).

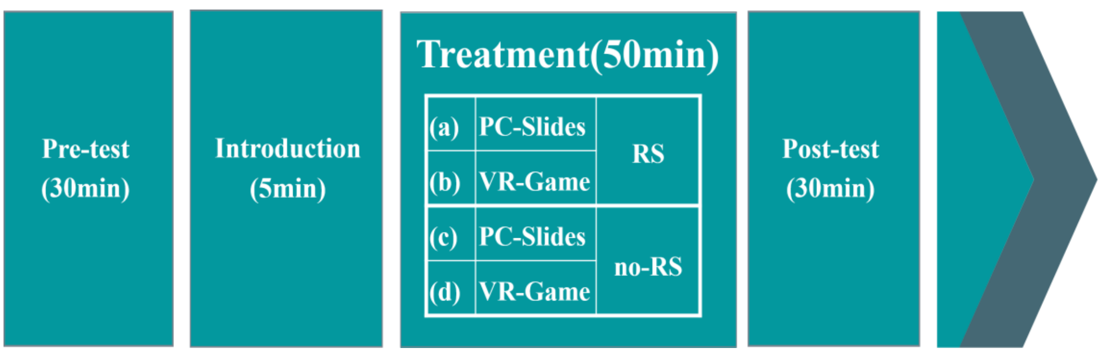


Figure 2: Overview of the experimental procedure and four conditions.

Initially, students received an introduction and learning objectives about the course. Then, basic demographic information of the questionnaire and a biology content cognitive outcomes pre-test about genetics topic with 20 single-choice questions with four response options, each question was 5 scores, and the total test scores were 100, was administered by 30 minutes before treatment. Second, the instructor conducted a five-minute oral instruction and demonstration on how to set up and use the HMDs before starting the course. Third, the biology lesson was presented for about 50 minutes, after passing a unit in the process, the participants answered the questions and completed the drawings on the learning worksheet. Finally, they completed a post-test with the same content as the pre-test.

4 Results

The group means of participants' learning performance in the genetics of biology are shown in Table 1. The overall mean scores by media type were 65.93 for PC-slides group, 64.97 for VR-game group, and the overall mean scores by the method were 65.23 for no-RS group, 65.76 for RS group.

Table 1: Group mean scores and deviations in the post-test.

		Method								
		no-RS			RS			Total		
		M	SD	n	M	SD	n	M	SD	n
Media	PC-slides	69.81	20.51	30	62.3	24.15	30	65.93	22.56	60
	VR-game	59.49	20.56	24	70.22	21.45	25	64.97	21.49	49
	Total	65.23	20.99	54	65.76	23.12	55	65.49	21.99	109

Because the groups of experiments came from different classes, the learning had been different before the experimental treatment. Therefore, the covariate analysis method (ANCOVA) was used to treat the pre-test results as the covariate excluded from the experimental effect, and to understand whether these groups are differently effective in the experimental treatment.

Before conducting ANCOVA analysis, the homogeneity test of the regression coefficients within the group did not reach the significant level $F = .78$, $p = .56$, indicating that the linear relationship between the covariate and the dependent variable within the group is consistent. As shown in Table 2, the ANCOVA summary indicates that prior content knowledge was significant on learning achievement $F_{(1.104)} = 314$, $p < .001$. That is to say, employing prior knowledge as a covariant in analysis can eliminate the impact of prior knowledge on participants' learning achievement.

Table 2: ANCOVA summary of the learning performance on dependent measures.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Prior Knowledge	37484.93	1	37484.93	314.41*	.00	.75
Method	16.99	1	16.99	0.14	.71	.00
Media	179.57	1	179.57	1.51	.22	.01
Interaction	892.67	1	892.67	7.49*	.00	.07
Error	12399.38	104	119.23			

*p <.05

A two factorial ANCOVA with media (PC-slides/VR-game) and methods (RS/no-RS) as independent variables, with learning achievement as dependent variables. Table 2 shows that the main effect of method $F_{(1.104)} = 0.14$, $p = .71$ and media $F_{(1.104)} = 1.51$, $p = .22$ was not significant, indicating that there was no significant difference between the learning achievement when learning through traditional media and immersive media environments or learning with and without reflection strategy.

However, the interaction between media and methods was significant $F_{(1.104)}$ = 7.49, p < .01, indicating that the media learning environment and using reflection strategies interacted with each other to affect the learning achievement.

The simple main effect analysis and post-hoc analysis (Table 3 and Figure 3) showed that, for the factor of instructional method, with non-reflection group (no-RS) the impact of media environment (PC-slides/VR-game) on learning achievement was not significant ($F_{(1,104)}$ = 1.27, p = .26), showing that without reflection strategy there was no significant difference in the learning achievement of the PC-slides group, and the VR-game group.

Table 3: Summary of simple main effect analysis of learning performance

Source	Group	*F*	*Sig.*	*partial Eta-squared*	Comparison
Media	no-RS	1.27	.26	.03	/
	RS	8.03*	.00	.13	VR-game > PC-slides
Method	PC-slides	2.92	.09	.05	/
	VR-game	4.75*	.04	.09	RS > no-RS

**p* <.05

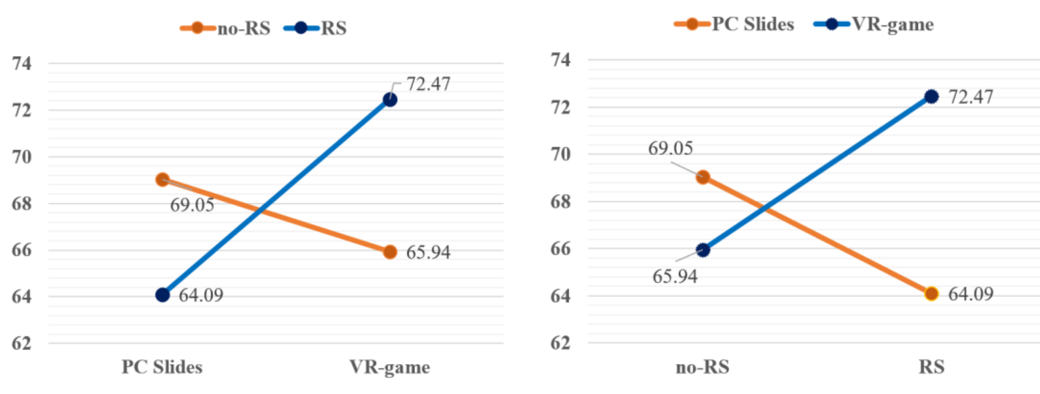


Figure 3: Profile plots of estimated marginal means (a) for the media, with the interaction of the method (no-RS, RS) to learning achievement. (b) for the methods, with the interaction of the media (PC-slides, VR-game) to learning achievement.

However, for the use of reflection group (RS), the media had a significant effect on learning achievement ($F_{(1,104)}$ = 8.03, p < .01), the VR-game group was better than the PC-slides group, indicating that VR-game group with reflection strategy outperformed the PC-slides group.

Finally, for the factor of media learning environment, regarding the PC Slide, method (no-RS, RS) was not significant in learning achievement ($F_{(1,104)}$ = 2.92, p = .09). However, with the VR-game group, the method has a significant effect on learning ($F_{(1,104)}$= 4.75, p < .05), showing that the use of reflection for VR-game group was better than the non-reflection group.

5 Conclusions

This study employed the instructional method of drawing as a reflection strategy to implement different types of media learning environments, including traditional PC-slides, immersive virtual reality (VR game) to improve learners learning outcomes. The immersive VR context provided high-fidelity 3D presentation promoting learners to explore and interact with the intracellular structures that could not be observed in the real world. These materials were designed by the circle of experiential learning model which was combined situated learning and narrative scenario, aimed to increase participants' presence and encourage learners to engage in the learning tasks, expected to effectively improve learners' learning performance.

The results of the experiment confirmed the research hypotheses as follows. Firstly, both media learning environments and instructional methods were not the main effects to affect cognitive effectiveness, however, being an interaction relationship. Secondly, with the reflection strategy, learners' cognitive performance in the immersive VR environments outperformed traditional image-based presentation. Conversely, the influence of media is not significant without using appropriate instructional methods. Because VR learning environment provided free observation and exploration effectively to establish abstract concepts of genes and chromosomes, the traditional media presents a limited and fixed picture, which could not be fully observed and explored, and it was difficult to establish abstract concepts.

Thirdly, VR games make students more engaged in learning by reflection to focus more on the key points of learning; non-reflection learners focus on games, and learning was easily disturbed. On the other hand, when learners were employed appropriate reflection strategies and game-based design could most effectively increase their learning performance through immersive VR, which implied that the drawing as a generative learning strategy indeed reduced the external cognitive load of learning and promoted the effectiveness of cognitive processing.

Finally, future studies are suggested to further examine the achievement, distinguished the different cognitive levels of knowledge retention and transfer, and to assess students' immersion or presence which was related to learning flow condition, considering some affection factors such as motivation, attitudes, and enjoyment, which will provide a more comprehensive explanation for the mechanism of the learning process.

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