Brief Version of Master's Thesis

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[Abstract]

Developing immersive Virtual Reality with Multimedia Learning Theory: Its Effectiveness on Middle School Students' Learning Outcomes and Motivation.

Immersive virtual reality (VR) can offer strong immersion through realistic graphics, but it is possible to generate unnecessary cognitive load in learners with it, too. In addition, in the case of the current immersive VR content for education, they were mostly developed without clear learning goals or pedagogical considerations. In this study, I developed educational immersive VR content that can reduce learners' cognitive load by applying clear learning goals and the multimedia learning theory. Then, I analyzed the developed content's effectiveness compared with a traditional multimedia "PPT slide." A total of 30 international middle school students participated in the experiment. Fifteen students were randomly assigned to an immersive VR group, and the others were assigned to a PPT slide group. All learners studied by themselves using each multimedia for about 30 minutes. The experiment revealed that learners felt fewer negative emotions and were interested in learning methods when learning with immersive VR. In addition, no major difference was found between the two groups in terms of the learning outcome right after learning, but the four-weeks-delayed post-test showed that the immersive VR group had a significantly higher score compared with the PPT slide group.

Keywords: immersive VR, multimedia theory, learning outcome, motivational theories, science learning

I. Introduction

1. Statement of the Problem

The immersive virtual reality (VR) industry market is expected to grow $15.9 billion by 2019 (Fildes, 2015), and immersive VR technologies are increasingly pervasive in our daily lives. Suh and Prophet (2018) conducted a systematic literature review of immersive VR research in diverse settings, including education, marketing, business, and health care, which was published from 2010 to 2017. They found that 46% of the research papers had been published in journals related to education, and the number of studies on immersive VR has been rapidly increasing. In other words, efforts are being made to apply these technologies in the field of education.

However, there are two problems that are commonly discussed. The first problem is that most immersive VR content has not been developed based on clear learning outcomes or pedagogical considerations (Fowler, 2015). It is often developed by relying on technical novelty or by adding entertainment factors. The effect through technical novelty is easy to achieve, but educational media should not be used in learning situations simply because it is available (Gandolfi, 2018). This is because new and innovative technologies do not necessarily lead to educational innovation, and the technology-centered approach generally fails to lead to lasting improvements in education (Cuban, 1986, 2009). For example, as immersive VR is based on brilliant graphics in configuring an environment as the real one, it easily results in cognitive load for the learner, which could interrupt learning activities. In a learner cognitive load measurement experiment conducted through the electroencephalogram test, immersive VR was found to cause cognitive load for the learner more than the desktop personal computer (PC)–based virtual learning environment did (Makransky, Terkilsen, & Mayer, 2017). In addition, the learning performance of the immersive VR environment was lower than that of the desktop PC–based virtual learning environment. In other words, it is necessary for the development stage to reduce the learner's cognitive load and to concentrate on the learning content itself, rather than increase the learner's immersion and interest through colorful graphics based on technical novelty.

The second problem is that a gap still exists among statements on the usefulness of immersive VR as educational media, and scientific research studies verify these statements (Parong & Mayer, 2018). Immersive VR is a technology that breaks the boundaries between the physical and virtual worlds and that allows users to feel a sense of immersion (Lee, Chung & Lee, 2013). Students may also be able to generate excellent learning outcomes through these immersion experiences and might be interested in learning content compared with traditional (non-immersive) media. However, not enough scientific research exists to support these claims yet.

To sum up the above two problems, learning outcomes and pedagogical considerations are essential when integrating emerging technologies into education, but these considerations are still lacking in educational immersive VR content. In addition, although claims and studies have been presented about the advantages of immersive VR as educational media, not enough research has been done on this for it to be scientifically verified.

2. Purpose of the Study and Research Questions

The goal of the present study was twofold. The first part was to develop educational immersive VR content, and the second part was to analyze the developed content's educational effectiveness.

The first goal was to develop immersive VR content for middle school students' solar system education. I focused on clarifying the learning content and goals and then tried to minimize the students' cognitive load based on the multimedia learning theory. Following content development, I analyzed whether the developed content was suitable for educational media through questionnaires and interviews. Second, I analyzed the effectiveness of the developed content as educational media. To this end, I compared immersive VR with a corresponding Microsoft PowerPoint (PPT) slideshow, which is traditional educational media. Although media comparison studies have some methodological challenges (Clark, 2001), the main purpose of this comparison method was to verify the effectiveness of immersive VR in a way that did not involve using a pre-post test.

Accordingly, the research questions in the current study are as follows:

1. Does immersive VR content developed based on the multimedia learning theory generate lower cognitive load for learners compared with PPT slide content?

2. When students learn through immersive VR content, do they show higher learning performance than they do with PPT slide content?

3. When students learn through immersive VR content, do they respond more positively than they do with PPT slide content?

II. Theoretical Background

1. Immersive Virtual Reality

Immersive VR is a subelement of VR. VR can be subdivided into three categories depending on the degree of immersion and the types of the interface: non-immersive, semi-immersive, and immersive

(Bamodu & Ye, 2013). Non-immersive VR refers to VR shown through a computer screen, such as Second Life. Semi-immersive VR provides a high level of immersion but uses the physical model partially, such as the Cave Automatic Virtual Environment (CAVE). Immersive VR provides the highest level of immersion and usually refers to the VR experienced through HMDs and tracking devices. An HMD is a display device that is attached to a user's head and carries images and videos in front of the user’s eyes. An HMD generally uses binocular disparity that enables users to have solid perceptions of the 3D environment. These devices’ head-tracking function and high-resolution displays offer a higher sense of immersion to users. HMD units include the Oculus Rift (Oculus VR LLC, Facebook Inc., Menlo Park, CA) and HTC Vive (HTC Corporation, Xindian, New Taipei City, Taiwan). This research focused on immersive VR in this point of view.

The potential benefits of immersive VR when one is conducting educational activities have been investigated during the past decade (Gutiérrez et al., 2017). Numerous research studies have been conducted on the effectiveness of integrating immersive VR into education. According to previous research, the use of immersive VR enhances learning effectiveness (Dede et al., 2017; Frank & Kapila, 2017; Yoon et al., 2012; Loup-Escande et al., 2017; Cheng & Tsai, 2014; Cho & Lim, 2017), fosters learning engagement (Ke et al., 2016; Chang et al., 2014), and increases learning attitude (Hsiao et al., 2012; Hwang et al., 2016; Grabowski & Jankowski, 2015; Ucar et al., 2017; Parong & Mayer, 2018).

However, some studies revealed negative results regarding the educational effectiveness of immersive VR. Rasheed, Onkar, and Narula (2015) found that when students were given information through traditional teaching methods, the factual data were actually more accurately delivered than they were with immersive VR. Polcar and Horejsi (2013) found that a self-navigated tour on a PC monitor was exactly as efficient for acquiring knowledge as a narrated tour watched in stereoscopy, whereas immersive VR achieved about two-thirds of this score.

Moreover, most studies have focused on a single or limited aspect of immersive technology, and very little research has examined the various effects of diverse technological stimuli on multiple aspects of user performance. Furthermore, the effects of particular and context-specific technological stimuli remain relatively understudied (Suh & Prophet, 2018). Therefore, a gap still exists between claims about the usefulness of VR in academic learning, and the scientific research testing these claims (Parong & Mayer, 2018).

2. Cognitive Theory of Multimedia Learning Theory

Mayer and Moreno (2003) defined meaningful learning as a deep understanding of presented material, which includes attending to important aspects of the presented material, mentally organizing it into a coherent cognitive structure, and integrating it with relevant existing knowledge. Meaningful learning is reflected in the ability to apply what is taught to new situations, so learning outcomes can be measured by using problem-solving transfer tests (Mayer & Wittrock, 1996). However, meaningful learning requires learners to engage in significant cognitive processing during learning, and learners' cognitive processing ability is severely limited. Instructional designers have come to recognize the need for multimedia instruction that is sensitive to cognitive load (Clark, 1999; Sweller, 1999; van Merriënboer, 1997).

To reduce the learner's cognitive overload, the multimedia theory tries to understand how the human mind works. It starts with three assumptions based on cognitive science: dual channel, cognitive capacity, and active processing (Mayer, 2009). First, the human information-processing system consists of two channels: an auditory/verbal channel for processing auditory input and verbal representations, and a visual/pictorial channel for processing visual input and pictorial representations. Second, each channel in the human information-processing system has a limited capacity. A limited amount of cognitive processing can occur on the verbal channel at any one time, and only a limited amount of cognitive processing can occur on the visual channel any one time. Third, meaningful learning requires significant amounts of cognitive processing on verbal and visual channels. These processes involve paying attention to the presented material, mentally organizing the presented material in a consistent structure, and integrating the presented material with existing knowledge (Mayer & Moreno, 2003).

Figure 1 summarizes these three assumptions within the context of the cognitive theory of multimedia learning. The boxes represent memory stores, and the arrows represent cognitive processes. On the left in *Figure 1*, the learner begins with the words and pictures in a multimedia instructional message—which can be a textbook lesson, a PowerPoint presentation, or even immersive VR. In the second column—sensory memory—spoken words impinge on the ears and are represented shortly in auditory sensory memory, whereas pictures and printed words impinge on the eyes and are represented shortly in visual sensory memory. In the third column—the leftmost part of working memory—the learner focus on certain sounds for further processing in the verbal channel and certain images for further processing in the pictorial channel. In the next column—the rightmost part of working memory—the learner organizes some of the sounds into a verbal model and organizes some of the images into a pictorial model. In the final column—long-term memory—the learner can activate prior knowledge to be integrated with verbal and pictorial models in the working memory and can store the resulting knowledge in long-term memory. Integrating refers to building appropriate connections between the verbal and pictorial representations in working memory, as well as relevant prior knowledge activated from long-term memory (Mayer, 2008).

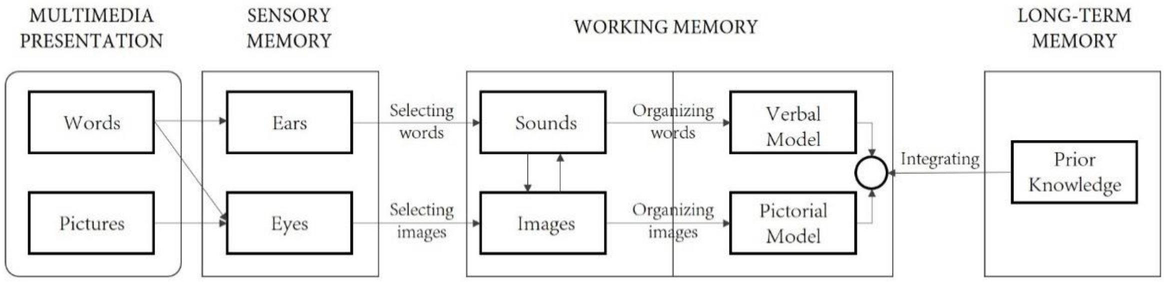

Figure 1 Cognitive theory of multimedia learning (Mayer, 2008)

To sum up, in multimedia learning, five essential cognitive processes exist: selecting words, selecting images, organizing words, organizing images, and integrating. Consistent with the active-processing assumption, these processes place demands on the cognitive capacity of the information processing system. Therefore, it is important to be sensitive to cognitive process in multimedia learning, since learners' cognitive capacity is severely limited.

When cognitive load is unnecessary and thus interferes with schema acquisition and automation, it is referred to as an extraneous or ineffective cognitive load (Paas, Renkl, & Sweller, 2003). Perhaps the most serious problem with most ineffective multimedia lessons is that they cause the learner to engage in extraneous processing—cognitive processing that wastes precious cognitive capacity but does not help the learner to build an appropriate cognitive representation (Mayer, 2008). According to Mayer (2009), the following five principles are solutions for reducing extraneous processing.

First, people learn better when extraneous words, pictures, and sounds are excluded rather than included. Therefore, it is better to exclude materials that are not related to learning as much as possible. For example, the more include words, pictures, sounds, and music that can cause learners' interest, but not related to learning, the more unnecessary cognitive load will be occurred. Second, people learn better when cues that highlight the organization of the essential material are added. Adding highlights or notifications to important learning content could helps learners to minimize cognitive processing when they build a link between core contents. Third, people learn better from graphics and narration than from graphics, narration, and on-screen text. The visual channel may overload to read both graphics and letters, and the learner can make mental efforts to connect letters and narrations. Fourth, people learn better when corresponding words and pictures are presented near rather than far from each other on the page or screen. When a corresponding word or picture are presented near, the learner can minimize cognitive load to find the relevant content on the screen. Fifth, people learn better when corresponding words and pictures are presented simultaneously rather than successively. This minimizes the cognitive load when the learner creates some link to the words or pictures in working memory.

3. Motivational Theories

Student motivation plays a significant role in deeper learning in the classroom. Motivated people can participate more in classes and tasks, make more of an effort to understand the learning materials, and work harder to overcome obstacles to understanding (Mayer, 2008; Wentzel, & Miele, 2016). This motivation can help learners to maintain their focus during continuous classes and to invest more energy in assigning cognitive resources to difficult areas. The use of immersive VR for teaching scientific material is based on a general expectancy-value model (Pintrich, 1988, 1989; Schunk, Pintrich & Meece, 2008).

According to Pintrich (2003), three general motivational components seem to be important: (a) belief in the ability or skill to perform a task (expectancy components); (b) beliefs about the importance, interest, and utility of the task (value components); and (c) emotions about self, or emotional responses to the task (affective components). First, expectancy components are students' answers to the question, “Can you do this?” If students are confident in their ability to exercise the skills they need, and if they believe that they can control their skills and work environments to some extent, they are more likely to choose to do tasks, be cognitively involved, continue their tasks, and achieve at higher levels. Second, value components are students' answers to the question, “Why am I doing this task?” These components should be associated with cognitive and self-regulation activities as well as results such as the selection of activities, efforts, and sustainability (Eccles, 1983; Eccles et al., 1998; Pintrich, 1999). Third, affective components deal with the basic question, “How does the task make me feel?” Affective components include students’ emotional responses to the task and their performance (i.e., anxiety, pride, shame), as well as their emotional desires for self-worth or pride, affiliation, and self-actualization (Covington & Beery, 1976).

In short, students’ motivation belongs to the value expectancy model, in which motivation depends on learners' values, which get the students started (e.g., liking the material), and expectancies, which keep them going (e.g., feeling competent). To motivate students, the lesson may attract students' attention first. Then, the interaction between the learner and the class can demonstrate self-efficacy to continue the lesson (Pintrich, 2003). In the case of VR, an immersion experience can trigger learners' personal interest, and feedback on interacting with the lesson should help them to maintain their ability to proceed (Mayer & Paring, 2018). Furthermore, an immersive VR lesson can be interesting to students and can attract learners' situational attention more than conventional lessons can (Kintsch, 1980; Wade, 1992).

III. Method

The main purpose of this study was twofold. First, the goal was to develop educational immersive VR content based on clear learning content, learning objectives, and pedagogical theories. Second, the aim was to verify the effectiveness of the developed educational immersive VR content as learning material. To do this, I compared the immersive VR content with the PPT slideshow. The goal of comparing immersive VR with the slideshow was not to verify which of the two media is more effective. However, to figure out the effectiveness of using immersive VR, I compared it with the slideshow, which represented typical and traditional educational media.

1. Development Stage

A. Clarification of Learning Content

The core learning content was organized after it was discussed with an incumbent middle school teacher, and learning objectives were clarified accordingly. In addition, the content was designed to teach the characteristics of each planet by dividing the planets into terrestrial and jovian planets. Specific information about learning content is as follows.

Table 1 Learning content description

Main Target	Middle School Student (ages 13 to 15)
Subject	Science – Solar System
Expected Learning Objectives	- Distinguish solar system planets into jovian and terrestrial planets. - Explain the characteristics of jovian and terrestrial planets according to seven criteria. (Seven criteria: distance from the sun, radius, mass, cycle of revolution, rotation period, average density, presence of rings) - Specify important characteristics of each of the solar system planets.
Contents Organization	This content encourages learners to first compare terrestrial and jovian planets and then to learn specific characteristics of each planet.

B. Building Learning Space

Here, players can learn the characteristics of solar system planets. In the frontal user interface (UI), eight solar system planets' photographic models are presented, and players can decide what they want to learn by touching the planet. When a planet is touched, information about the planet is displayed on both sides of the UI. The player's left-hand UI contains a description of the characteristics of the terrestrial and jovian planets, and the right-hand UI shows the features of the selected planet. Furthermore, when they select a planet, the planet is created on the right hand, and all areas of the planet can be observed by rotating the player’s right hand. All planets are presented at real scale.

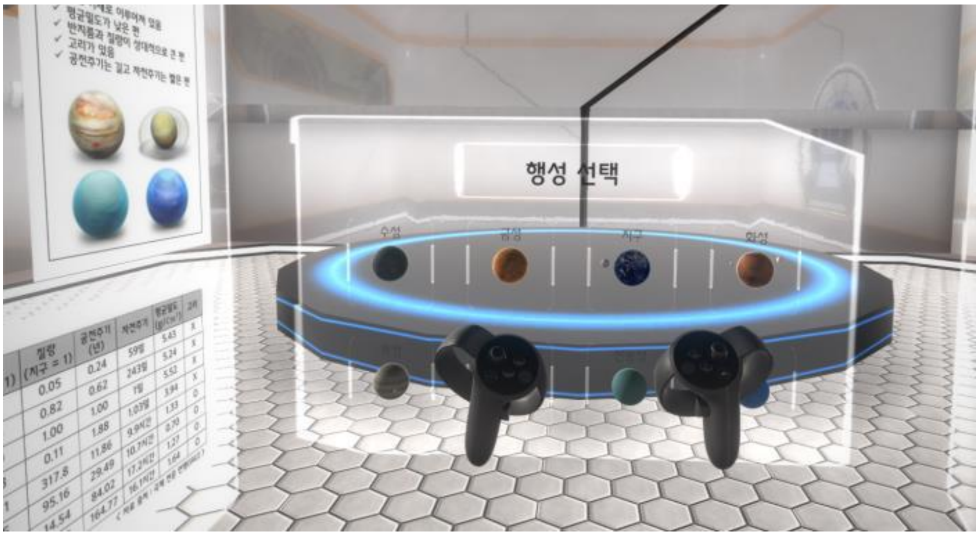

Figure 2 Frontal UI

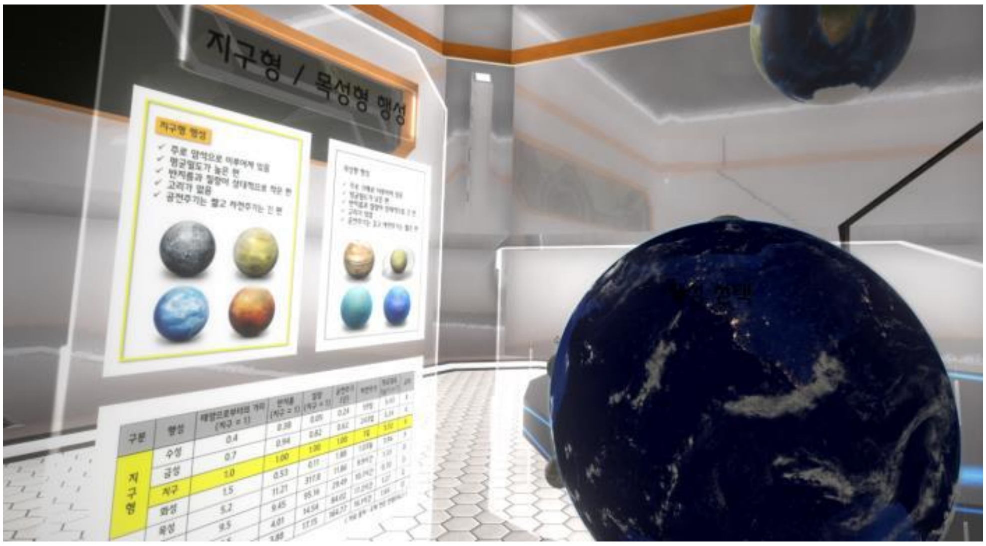

Figure 3 Left-hand UI with the selected planet

C. User Interaction

1) Physical Movement

Oculus Rift CV1 sensors provide room-scale position tracking, allowing the player to move freely in the virtual environment. However, because safety issues exist when it comes to walking while wearing HMDs in a real-world situation, the game is designed to move around within a two- to three-foot area.

2) Touch

The main target of the game is middle school students. Most middle school students have difficulty controlling the VR consoles because they have not yet experienced immersive VR. Therefore, the game is designed to operate with an intuitive "one touch" function.

UI screen Information appears automatically when the player touches a button on the UI. When the UI buttons are touched, this is designed to generate an effect and sound that make the player feel as though he or she is pressing a button.

Attach When the player touches the planet in the game, it automatically sticks to the player's hand. That is, players can observe the planet by rotating their hands.

D. Integrating Multimedia Learning Theories

When designing and developing this content, I tried to minimize the cognitive load of learners based on the cognitive theory of multimedia learning. In other words, when designing a multimedia presentation, I tried to minimize the cognitive waste that can occur in sensory memory and working memory.

In the sensory memory stage, the learning content presented in immersive VR were divided into visual and auditory content according to the dual channel assumption. Most of the learning-related content was presented as visual materials, and the auditory materials were presented briefly only as important content or signaling elements. For example, all descriptions of the characteristics of each planet were presented in letter form, and only the name of the planet and brief information were presented in sound form.

In the working memory phase, five principles for reducing extraneous processing were applied to minimize cognitive load. First, although splendid and realistic graphics are one of the biggest advantages of immersive VR, developed content minimizes graphics and sounds that are not relevant to learning. For example, in the present study, unnecessary background graphics were deleted to induce learners to concentrate on learning materials. Second, when the interaction between a learner and content occurred, the content signaled it through sound and effect. In addition, if the learner selected a specific planet, proper information was highlighted. Third, the same content was not provided simultaneously in narration and text; it was delivered in text form with most of the learning information, and narration provided instructions or notifications to avoid focusing elsewhere. Fourth, relevant pieces of content were placed as close together as possible. For example, terrestrial planets were placed close to one another. Fifth, I designed a multi-monitor to view related learning content at the same time. In addition, while holding a planet in his or her hand, a learner could read the description of the feature through the virtual screen in front of him or her. Furthermore, this content was organized—divided into seven criteria—so that learners could learn at their own pace. *Figure 4* summarizes the applied multimedia theory.

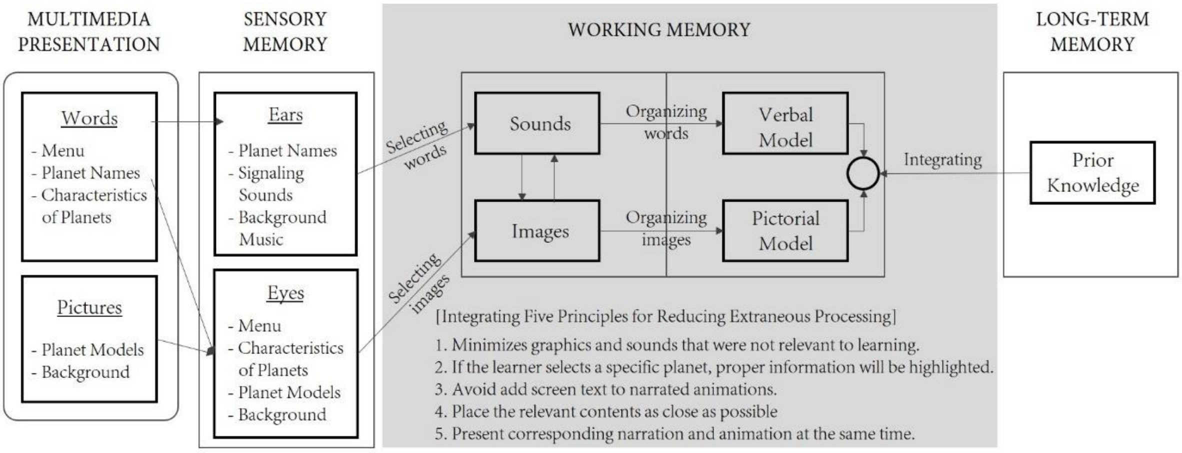

Figure 4 Integrated cognitive theory of multimedia learning

E. Developing Power Point Slideshow Materials

The slideshow lesson was developed based on the immersive VR game introduced above. The terms and pictures used in the immersive VR game were also used in the slideshow, and the learning time was limited to 30 minutes.

Figure 5 Examples of slideshow materials

2. Research Stage

A. Participants and Design

The participants were 30 middle school students recruited from a subject pool at Younghoon International Middle School in South Korea (19 women, ages 13-14). Fifteen participants were randomly assigned to the immersive VR condition (VR group, 10 women), and the rest were assigned to the traditional learning condition (slideshow group, nine women). Slideshow content was adapted from the immersive VR content, and the estimated learning time for both groups was about 30 minutes. Students from both groups studied under the supervision of the school's science teacher.

B. Pre-Questionnaire

The pre-questionnaire was for controlling preexisting differences between the two groups. I did not conduct a pre-test because there was a possibility that students might predict or organize their knowledge in advance through the pre-test. In response, rather than conducting a pre-test about the material in the developed content, I used a self-reported background knowledge questionnaire. The pre-questionnaire solicited basic demographic information, such as the participant's age, gender, interest in science, and year in school. It also asked about the participant's knowledge of the solar system on a five-point scale from "very low" to "very high." Items on the questionnaire were adapted from Parong and Mayer's (2018) research, and items were modified or added for the purpose of this study.

C. Post-Questionnaire

The post-questionnaire asked students to make self-ratings on a five-point scale from 1 (strongly disagree) to 5 (strongly agree). A total of 16 questions were made by modifying and adding the questions used in the study of Parong and Mayer (2018) to suit the purpose of this study. Questions 1 through 13 were designed to measure how positive the learner responded to the content learned, and questions 14 to 16 were designed to measure how much cognitive effort was used in learning. For example, it consisted of questions such as "I want to learn in this way in the future," "I felt bored during learning," and "I made a lot of mental efforts to learn."

D. Post-Test

The post-test consisted of seven factual questions in multiple-choice format and three conceptual questions in a short-answer format to examine students' learning outcomes. Because the developed learning materials (VR and slide materials) addressed factual knowledge more than conceptual knowledge, more questions were asked about factual knowledge in the post-test. An example of a factual question is, "Choose from the following in order from the smaller radius to the larger radius. (A) Mars → Venus → Mercury → Earth. (B) Mars → Earth → Neptune → Saturn. (C) Earth → Mars →

Saturn → Jupiter. (D) Jupiter → Saturn → Uranus → Earth (E) Mars → Earth → Venus → Neptune." An example of a conceptual question is, "Write about the characteristics that distinguish the terrestrial planets from the jovian planets."

E. Four-Weeks-Delayed Post-Test

Four weeks after the post-test, I conducted a delayed test with the same question as the post-test to check how much learners still remembered the learning content. This test was conducted separately under the supervision of the same science teacher and was performed under the same conditions as the post-test.

F. Interview

The interview was conducted for two purposes. First, its aim was to determine whether the developed immersive VR content was appropriate for use as learning material. Although the appropriateness of the PPT slideshow and the immersive VR content was compared through the questionnaires, it was difficult to judge whether the developed immersive VR content was suitable for learning situations. Therefore, I conducted an interview as a supplementary tool to provide additional information on whether the developed immersive VR content was appropriate as learning material.

Second, the interview's aim was to obtain concrete and rich information that could not be obtained through quantitative tools. Particular tendencies can be found through surveys and tests, but specific and rich information from interviews may still be needed to identify causes. In particular, it is important to conduct interviews based on the respondents who have shown remarkable results.

Accordingly, four students who showed unusual test results among the students of the VR group were selected and interviewed. Each interview was conducted for about 10-15 minutes, and six questions were asked.

G. Research Procedure

Participants were chosen randomly among the first and second graders of Young Hoon International Middle School. A total of 30 students were chosen, and they were randomly assigned to the immersive VR group and to the slideshow group. The immersive VR group conducted individual tests by setting the Oculus Rift CV1 in the school's science room. The selected science room was big enough to study using immersive VR equipment. The slideshow group members conducted tests in their classrooms. The members of both groups studied individually under the supervision of their science teacher.

First, the students agreed to participate this experiment before starting. Second, the students completed the pre-questionnaire. Third, an individual study was conducted. The VR group learned using a developed VR game, and the slideshow group learned through PowerPoint slideshow materials. The total study time was limited to 30 minutes. Fourth, a post-test was conducted right after the individual study. Fifth, after four weeks of individual study, I conducted a delayed post-test again. Finally, interviews were conducted with students with special results.

All research procedures were compliant with the ethics regulations, and the participants were informed that participation in the experiment was not related to grades.

VI. Results

No big difference was found between the two groups in terms of age and grade because all participants are made up of first and second graders in middle school between the ages of 13 and 14. Furthermore, the two groups did not significantly differ in terms of mean science-knowledge score, t(28) = -1.634, p = 0.113, and the proportion of men and women, $\chi^2(1, N=30) = 1.44$, p = 0.705. Therefore, I conclude that the two groups did not differ in elemental characteristics.

1. Cognitive Load of the Developed Immersive VR Content

The results of the analysis in study 1, "Does immersive VR content developed based on the multimedia learning theory generate lower cognitive load for learners compared with PPT slide content," are as follows.

In the post-questionnaire, I asked students how they thought about the appropriateness of the content and the degree of cognitive load. No significant difference was found in the content adequacy and cognitive load of the students between the two groups.

Table 2 Questionnaires for cognitive load and content adequacy

	Immersive VR (N=15)		PPT Slide (N=15)		p
	M	SD	M	SD	
“I was given enough time to learn.”	3.20	1.014	3.73	0.799	0.121
“The content of the study was presented effectively.”	3.60	0.910	3.47	0.915	0.692
“I used a lot of mental effort in the lesson.”	4.07	0.96	3.60	1.05	0.216

However, the above results revealed that the developed immersive VR content was not significantly different from the PPT slide as learning media, but it is not enough to conclude that immersive VR is appropriate as learning media. Therefore, I interviewed four students to obtain more information about the appropriateness of the developed immersive VR content as learning media.

Among the VR group students, students who showed unusual results in the questionnaires and tests were selected and interviewed. Student A had a very positive assessment of immersive VR learning (post-questionnaire), but she received the lowest score on the post-test. Student B had both a low pre-questionnaire and a low post-test score, which meant that she was less interested in science, less knowledgeable, and had a lower test score than the other students did. Students C and D were highly rated in the pre-questionnaire due to their high interest in science and their abundant background knowledge, and they also had very positive evaluations of immersive VR learning on the post-questionnaire. Furthermore, their test scores were good. The table below summarizes the results of the questionnaires and tests of the four students who responded to the interview.

Table 3 Interview respondents' experiment result

	Pre-Questionnaire	Post-Questionnaire	Post-Test	Four-Weeks-Delayed Test
Average Score	38.7	62.2	4	6.2
Student A (Woman)	38 (Average)	76 (Very High)	1 (Very Low)	5 (Low)
Student B (Woman)	34 (Low)	61 (Average)	2 (Low)	6 (High)
Student C (Man)	45 (High)	72 (Very High)	6 (High)	9 (Very High)
Student D (Woman)	48 (High)	67 (High)	6 (High)	8 (High)

The first question was, “Have you had any trouble with manipulating the controller or interacting with content while playing the developed immersive VR game?” Students B and D said they had never experienced immersive VR before, and both said they did not usually enjoy other games, such as mobile or PC games. Consequently, they all had difficulty with interacting with the developed content. Student B said, "The controller click seemed to be not working well." In addition, student D said, "Itablet was awkward to move the console, and it took time to get used to the invisible movement of my hand. Because I cannot see my hands while I’m wearing headgears." On the other hand, student A had experienced immersive VR once before, and student C had done it 3-4 times already. Both students said they enjoyed playing games as usual, and they said they had no difficulty with interacting with the content. In particular, student C said, “I didn’t have any trouble controlling the console. I usually like games, and I think this game is much simpler than the usual games that I play.” The interview results revealed that the first time one experiences immersive VR, one needs time to get used to controller manipulation. However, if one has experience with or enjoys playing games, one can conclude that one will have no major problems with interacting with the content.

The second question was, “What was the hardest part when you were playing an immersive VR game?” In this question, students A, B, and D all talked about the inconvenience of the text used in the immersive VR game. Student A said, “I felt so hard to reading all the letters, and the letter size was so small that I cannot even read them. I didn’t know if it was because I was wearing glasses, but anyway, it was uncomfortable to read letters in VR situation." "I was a little tired to learn about all the planets in letters," said student B. "I wish I had explained the planet in a more interesting way." In addition, student D said, "I did not read all of the reading materials because there were so many letters. I hope the number of letters will be reduced." In other words, students A and D, who positively evaluated learning with immersive VR, also expressed discomfort with having a large number of letters.

The third question was, “What was different about studying immersive VR compared with studying with books?” Student A said, "It was difficult to memorize knowledge when I study through books. However, when I study through immersive VR, I think I have had the better memorizing ability because there were visible objects right in front of me. Also, it was good to have a photographic planet shape." Student B said, "Although I felt like I was studying rather than playing a game, it was much more fun than studying with books." Student C said, "The books are all composed of static letters and pictures, so it is hard to understand. Furthermore, I have to sit tight on the chair while I'm studying. On the other hand, VR was fun to get up and move around and to control the virtual space freely with the console." Student D said, "I felt like studying, but it was much more fun than the workbooks."

2. Learning Effectiveness of the Immersive VR Content

The results of the analysis in study 2, "When students learn through immersive VR content, do they show higher learning performance than they do with PPT slide content," are as follows.

A. Post-Test

In the post-test conducted shortly after the lesson, no significant difference was found in test scores between the two groups. In other words, regardless of the media, the learner showed a similar level of learning outcomes. Therefore, the null hypothesis cannot be rejected because students who learned using immersive VR had similar test scores as those who learned using a slideshow. The results of the independent sample t-test are as follows.

Table 4 Post-test result

	VR group (N=15)		Slideshow group (N=15)		
	M	SD	M	SD	p
Total test score (out of 10)	4.00	2.236	4.07	1.751	0.928
Factual questions (out of 7)	2.40	1.882	2.13	1.302	0.655
Conceptual questions (out of 3)	1.60	0.910	1.93	0.961	0.338

B. Four-Weeks-Delayed Post-Test

An analysis of covariance (ANCOVA) was conducted on the four-weeks-delayed post-test scores of the VR and slideshow groups, which had background science knowledge scores (pre-questionnaire) as covariates. Between the post-test and the four-weeks-delayed post-test, the school did not conduct any classes on the solar system and did not instruct students to learn related material. Nevertheless, the fact that the test scores of the VR group students were clearly rising is worthy of attention. As shown in the top line of Table 5, the immersive VR group (M=6.20, SD=1.424) scored significantly better than the slideshow group (M=4.53, SD=2.200) did on the four-weeks-delayed post-test overall. As displayed in the next two lines of Table 5, additional ANCOVAs revealed that the immersive VR group performed significantly better than the slideshow group did on the conceptual questions (immersive VR group: M=2.53, SD=0.516; slideshow group: M=1.67, SD=1.047), but not necessarily on the factual questions (immersive VR group: M=3.67, SD=1.175; slideshow group: M=2.87, SD=1.457). The same pattern of significant differences was found when I conducted t-tests (i.e., without covariates). Therefore, the null hypothesis that the test score will be the same after four weeks of the VR group and the slideshow group can be rejected.

Table 5 Four-weeks-delayed test result

	VR group (N=15)		Slideshow group (N=15)		
	M	SD	M	SD	p
Total test score (out of 10)	6.20	1.424	4.53	2.200	0.032**
Factual questions (out of 7)	3.67	1.175	2.87	1.457	0.142
Conceptual questions (out of 3)	2.53	0.516	1.67	1.047	0.013**

**p<.05.

To find out why the immersive VR group's score rose, I conducted additional interviews with four students who scored much higher on the four-weeks-delayed post-test than on the post-test. I asked the students about whether they had studied. Student A said, "After learning with immersive VR, I wanted to study more about the solar system, so I looked for books related to the solar system and read science magazines." In the case of student A, she answered very positively about learning with immersive VR on the post-questionnaire, and the test score rose from one point to five points. Student B said, "After learning with immersive VR, I looked for a reference book related to the solar system, and I was studying because I thought it would be related to the next test rather than being interested. Also, when I looking at the reference book, I recalled that things I learned with immersive VR came up and helped me to learn." The test score rose from two points to seven points. In the case of student C, he said, "I learned the contents of elementary school while learning with immersive VR, so I looked back at the materials I studied in elementary school." He was very positive about learning with immersive VR, and his test score rose from six points to nine points. Student D said, "I enjoyed learning with immersive VR so much. After the lesson, I went home and searched the solar system related materials on the Internet." This student also responded positively to learning with immersive VR, with the student's test score rising from six points to eight points.

3. Whether Students Responded Positively to Immersive VR Content Learning

The results of the analysis in study 3, "When students learn through immersive VR content, do they respond more positively than they do with PPT slide content," are as follows.

Table 6 shows the mean rating (and standard deviation) for each of 13 items for the immersive VR and slideshow groups. More students who learned with immersive VR felt that it was difficult to learn compared with students who learned with PPT slides. Nevertheless, students responded that they enjoyed learning by using immersive VR and that they wanted to learn with immersive VR in the future. In addition, no big difference was found between the two groups with regard to feeling positive emotions, but the immersive VR group felt much fewer negative emotions.

Table 6 Post-questionnaire result

Items	VR group *(N=15)* *M (SD)*	Slideshow group *(N=15)* *M (SD)*	p
"I felt that the subject matter was difficult."	2.93 (0.79)	2.27 (0.88)	0.039**
"I have a good understanding of the material."	3.33 (0.81)	3.13 (0.64)	0.461
"I enjoyed learning in this way."	3.80 (0.94)	2.87 (0.99)	0.013**
"I would like to learn in this way in the future."	3.80 (0.94)	2.67 (1.04)	0.004**

“I felt that the lesson was engaging.”	3.67 (0.72)	3.27 (0.79)	0.162
“I found the lesson to be useful to me.”	3.53 (1.06)	3.33 (0.97)	0.595
“I felt motivated to understand the material.”	3.50 (1.09)	3.53 (0.74)	0.924
“I felt happy during the lesson.”	2.87 (1.64)	3.00 (0.84)	0.782
“I felt excited during the lesson.”	2.47 (1.64)	2.93 (0.88)	0.341
“I felt bored during the lesson.”	1.67 (1.17)	2.87 (0.83)	0.003**
“I felt confused during the lesson.”	1.67 (1.12)	2.87 (0.99)	0.007**
“I felt sad during the lesson.”	1.13 (0.35)	3.73 (0.96)	0.000***
“I felt scared during the lesson.”	1.27 (0.59)	3.87 (0.99)	0.000***

**p<.05. ***p<.001.

V. Discussion

In this study, I developed immersive VR content for science by applying the multimedia theory. To examine its effectiveness, I compared it with a PPT slideshow, which represents typical traditional media.

According to the experiment results, immersive VR media is less efficient for knowledge acquisition compared with a PPT slideshow. This is because the difference between a PPT slideshow and immersive VR content is not significant right after the lesson. Rather, the PPT slideshow group’s prescience knowledge level (measured by the pre-questionnaire) was slightly lower than that of the immersive VR group (although it is not meaningful), but the post-test results were slightly higher. Students were familiar with the PPT slideshow media, and the developed immersive VR content did not have a greater effect on knowledge memory than expected. Moreover, in terms of cost, constructing an immersive VR learning environment requires a lot more than a PPT slide.

However, in the four-weeks-delayed test, the performance of the immersive VR group rose significantly compared with the PPT slideshow group. This can be interpreted with a positive evaluation of students' immersive VR media. In particular, students in the immersive VR group showed little negative feelings after learning. As mentioned above, it was not efficient for immersive VR to acquire knowledge, but it succeeded in effectively generating students' motivations and positive emotions. Motivated students conducted additional learning after immersive VR media lessons, which resulted in improved test scores four weeks later. As a result, immersive VR media developed with clear learning goals and the multimedia theory led to higher learning performance compared with the PPT slideshow media.

From this experiment, it is confirmed that educational immersive VR can lay considerable learning outcomes. In particular, learning by immersive VR has the effect of inducing motivation for learning contents and continuous learning. The following implications should be noted when developing educational virtual reality derived from this study.

First, it is important to make the operation method very simple when developing educational immersive VR content for middle school students. According to Freina and Ott (2015), educational effectiveness can be seen through immersive VR from middle school age. However, according to this experiment, some students struggled to adapt to having only two buttons on the VR console. Most of the students who usually enjoyed the game did not have much difficulty, but students who were not familiar with the game showed awkwardness in manipulating the console. In light of this, it is necessary to make educational content easy to learn through simple operation methods so that the learner can concentrate fully on the learning content.

Second, providing a lot of words as learning material in an immersive VR environment can reduce the learner's motivation. Many learning materials were provided in letter form in the content developed in this study. However, depending on the individual differences of the students, the size of the letters was small, and they were blurry. According to the redundant principle of the multimedia theory, it is necessary to consider various alternative methods, such as replacing the content of the visual channel (e.g., letters) with narration, and providing only important parts in letter form.

Third, immersive VR is still difficult to wear for a long time due to technical problems, such as nausea. Therefore, the number of learning materials should be significantly lower than that of normal classroom lectures. The content developed for this study was also developed by extracting only the core content of the solar system unit. In other words, it is difficult to learn all of the learning content using only immersive VR media. For immersive VR to actually be used in the educational field, it is necessary to connect with the existing instruction forms.

Meanwhile, this study has following limitations. Immersive VR cannot experiment with multiple people at once. However, many VR-related studies are studied based on an experimental group consisting of about 15 people. This study also had 15 students in the experimental group and in the control group, respectively. I used interviews to help to address this shortfall, but this limitation still exists. Next, the population was recruited from the international middle school. Because most of the international middle school students are taught by student-led classes, students' self-directed learning ability is likely to be higher than that of typical middle school students. The reason why no significant difference existed in the evaluation of the participation category in the post-surface questionnaire may be that international middle school students habitually participate in most classes themselves. Therefore, it is not enough to generalize the results of this experiment to all general middle school students. Finally, questionnaires and interviews were used to prevent learners' cognitive overloads from being pointed out as existing disadvantages of immersive VR. However, to verify this more clearly, subsequent research using scientific measurement methods such as the electroencephalogram test is needed.

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