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Comparison of 2D and 3D Views on Educational Virtual Reality Content

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Virtual reality (VR) techniques are being applied in education. However, there are issues to consider when using VR in schools, such as active student participation without any difficulties. In this study, we conducted an experimental class using a desktop-style VR system in a school and focused on the viewing methods of the co-learners in a group work. We examined whether there were differences in educational outcomes between a learner operating with VR and a co-learner viewing in 2D or 3D. Results showed that 2D observations can allow students to learn essential classroom concepts whereas 3D observations could allow students to learn more comprehensively. We concluded that group work activities using VR techniques are highly effective for viewing in 3D and has positive effects even for students who view in 2D; however, it requires consideration to certain health impacts such as visual fatigue.

Keywords: Education, School, Stereopsis, Stereoscopic 3D images, Virtual reality

Introduction

The use of information and communication technology is being promoted in education, and new devices and media are actively being used for learning in schools. Recent advances in display technology have caused changes in teaching methods. The Google Expeditions Program, for example, provides students with virtual field trips using 360° images (Google Inc., 2020). Students can position themselves in the center of 360° photos and panorama scenes and thereby learn the historical importance of the locations that are represented by such images. Students can take advantage of the benefits of virtual reality (VR) technology because they can tour virtual social studies that are difficult to physically attend and can have a virtual experience in a time-slip manner.

It has been shown that using VR techniques can bring benefits to education. For example, Dede (2009) showed that immersion in a digital environment can enhance learning through situational experiences and thus result in immersive interfaces producing positive effects for education. Also, Jackson and Fagan (2000) reported that collaborative immersive-VR learning experiences can be integrated into existing school curricula by showing their effectiveness. In particular, research on education using VR has been increasing recently, and positive effects and user experience improvements have been reported. However, a recent review of immersive VR in education reported that the majority of the studies focused on the description and evaluation of the appropriateness or the effectiveness of applied teaching practices with VR support (Pellas et al., 2020). Conversely, fewer studies were conducted to measure students' learning performance, the review pointed out.

In addition, there have been several studies conducted in schools on stereoscopic vision, which is the core element in VR technology. Bamford (2011) explored the effectiveness of stereoscopic 3D images in the classroom and their potential as teaching and learning tools. Bamford suggested that 3D images could increase student motivation and engagement. Shibata et al. (2017) showed the positive educational effect by creating novel comments and questions using stereoscopic 3D images in elementary school classes by comparing the differences in learning with 2D or 3D content. Shibata et al. also reported that 3D educational materials helped students focus on specific parts of images when a 3D television and stereoscopic 3D movies were used. Therefore, it was expected that students would be able to observe areas of interest in more detail through interactive operations using VR technology. In research using a desktop-based VR environment with 3D images, Hite et al. (2019) evaluated several tasks related to the spatial acuity of sixth grade and ninth grade students and indicated that there were no reported differences between grade levels in perceptions of virtual presence and that the spatial acuity of younger learners played an important role when using VR technologies for science learning. The study suggests the importance of considering VR technology use in terms of which unit of education, and for whom. Moreover, there are few studies comparing the effects of 2D and 3D in education by using VR technology compared with still images and movies.

Although VR educational materials exhibit benefits that are not available with conventional educational materials, most such materials are often adopted for personal use using a head-mounted display (HMD). However, in schools, in addition to individual learning, it is important to collaboratively understand the educational content and to resolve issues in groups. Monk-Turner and Payne (2005), for example, showed the importance of group work and that small groups of students work more effectively together than larger groups. Moreover, it is important that teachers interact directly with students to obtain reliable feedback about their learning status because they have a very important role in the classroom by facilitating learning activities.

Another important consideration is that schools have a wide variety of children and should provide fair high-quality education. Although binocular vision and VR can be expected to have positive effects, in school education, consideration must be given so that all students can use VR educational materials. It has been reported that there are individual differences in the ability to detect horizontal retinal disparities. It is said that about 5% of the population cannot use binocular retinal disparities for depth perception (Richards, 1970), which is also known as stereo blindness. If 30 students are in a class, one or two students may not be good at stereopsis. Furthermore, it has been stated that up to 30% of all people have some kind of stereo anomaly. As a result, some students may experience discomfort or visual fatigue when using VR for long periods, for example. Therefore, while taking advantage of VR, it is necessary to pay attention to students who have difficulties viewing in 3D.

In this study, to examine the advantages of VR use and to clarify the effects of 2D and 3D views using VR in group work on learning, we conducted an experimental class in a school and analyzed the state of student learning. By comparing the effects of 2D and 3D views, we examined whether there is a positive effect of using VR even for students who are not good at stereoscopic viewing. The purpose of the study was to examine whether there are differences in educational effects between a learner operating the VR educational materials and a co-learner viewing in 2D or 3D.

Methods

Participants and VR System

An experimental class was conducted for eighth graders at a junior high school. There were 16 students in the class. They were divided into four groups and a VR system was used in each group. To promote collaboration in a group work setting, we chose a desktop-style VR system (zSpace 300, zSpace, Inc.) instead of an HMD. This is because desktop-style VR systems allow students to view the same display, share the same 3D model in a real space, and write down their comments on a paper worksheet as they usually do in the classroom. In addition, they can naturally discuss what can be learned from the VR educational materials.

The VR system has a 24-inch stereoscopic 3D display with a resolution of 1,920 × 1,080 pixels (Figure 1). The students viewed the stereoscopic 3D images using circularly polarized 3D glasses. The 3D display used spatial interlacing to present different images to the left and right eyes by a film-type patterned retarder attached to the display. In most implementations of this method, even-numbered pixel rows on the screen are used for one eye and odd rows for the other (Tanabe et al., 2015). Thus, using polarized 3D glasses, the left eye views only the left image and the right eye views only the right image. To create the 2D view in this study, we used 2D glasses which used the same polarizing film for the right and left eyes. Therefore, the 3D view or 2D view was controlled by using the 3D or 2D glasses without changing anything on the display. In the 2D view, the resolution of the image was halved in a precise sense; however, it was practical enough for learning.

The students held a dedicated stylus like a pen which provided 6 degrees of freedom and were able to naturally rotate their wrists to move and examine the 3D objects present in the educational materials (zSpace Inc., 2020). The VR system contained two tracking sensors for tracking the user 3D glasses and stylus on the display. Therefore, when a student with tracked 3D glasses tilted his or her head to look around an object, the VR system was dynamically updated to display an accurate perspective of the images. It follows, however, that the other three students in the group viewed the images as slightly geometrically distorted regardless of whether they were viewing in 3D or 2D. When viewed in 3D, the 3D models are distorted in a 3D space whereas when viewed in 2D, the figures on the display screen appear distorted. However, the students were able to understand what was displayed during learning without great difficulty, thus indicating that the distortion was not especially severe.

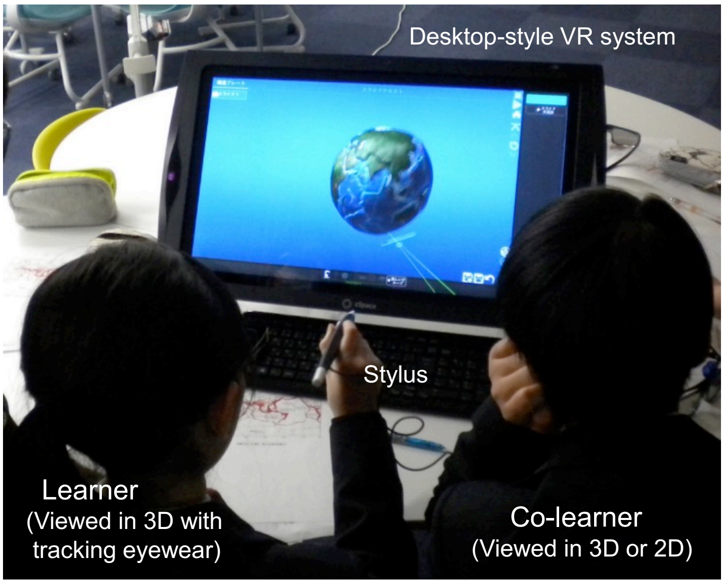

Figure 1. Desktop-style VR system used in the experimental class.

Learning Content

We aimed to explore the usage of VR in education through actual classroom situations instead of laboratory experiments. Therefore, we selected appropriate educational materials before conducting an experimental class. We, including a school teacher who is one of the authors, discussed the educational unit and criteria for evaluating the effects of the VR techniques and then selected plate tectonics and earthquake mechanisms as the learning content. Earth science content from the VIVED Science module (VIVED, 2020) was installed in the VR system and was used to conduct the experimental class session. The students were able to split the tectonic plates and observe their overlap in addition to moving the 3D objects (Figure 2). The educational material reproduced the three-dimensional structure of the tectonic plates, that is, the overlap.

The VR educational material itself did not have specific learning objectives and tutorials. Students were able to explore the causes of earthquakes by associating the location of epicenters printed on the paper with the plate locations. The reason we chose this unit and this educational material was that students could conduct exploratory group activities and it was expected that it would be relatively easy to understand the concept of overlapping tectonic plates due to the stereoscopic vision and interactivity of VR technology. Also, it was considered that using this content would lead to promotion of the collaborative learning experience because students can share and observe objects (i.e., tectonic plates) with their groupmates instead of entering the virtual world. The educational effect in this study was that the students had a deep understanding of what they were learning and were able to express it using specific terms. It was necessary for the students to be able to explain verbally to confirm their deep understanding.

VR systems were suitable for individual learning and group activities; however, it was difficult to explain the 3D representation on the screen to the whole class. Thus, an augmented reality (AR) presentation tool (zSpace Inc., 2020) describing the VR system was used during instruction and for students' presentations after the group activity; this approach allowed the remaining students and teacher to observe the object that was displayed in the VR system, as depicted in the right image of Figure 2. The AR mode image was displayed on the classroom screen by a projector.

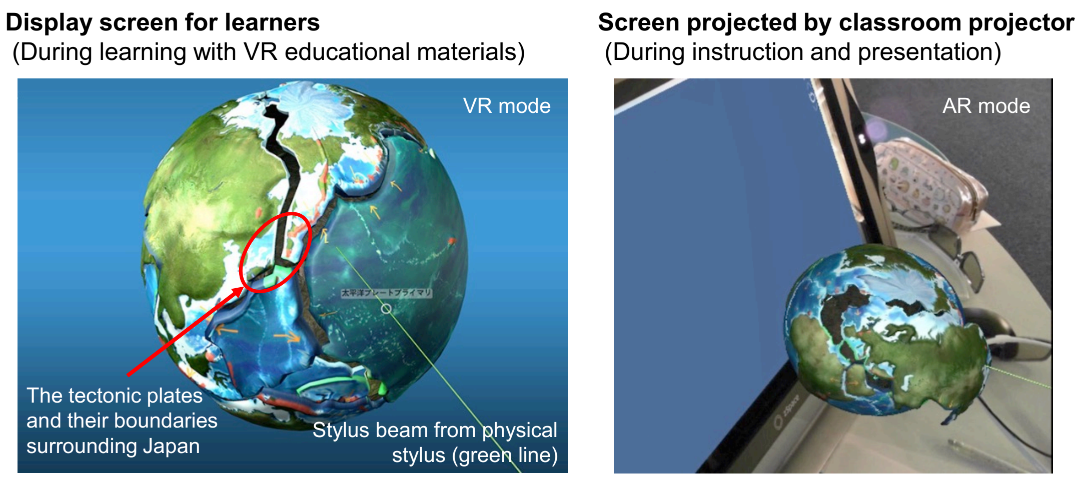

Figure 2. VR educational materials related to plate tectonics and the mechanisms by which earthquakes occur.

Procedure

The experimental class was conducted based on a lesson plan created in advance. At the beginning of the class, based on the lecture style of instruction, the students understood that the surface of the earth is composed of several plates and that an earthquake occurs due to the movements of these plates. After completion of the lecture, the students understood the positions and names of the plates by using the VR system and practicing stylus operations. They wrote the names of the plates on paper worksheets with figures showing the plate divisions for a thorough understanding. When explaining the use of the VR system, students were instructed to take off their glasses if their eyes felt tired or uncomfortable during the class.

After the practice session using the VR system, the students performed two tasks using the VR system in each group. The first task was to consider the relationship between the plates and earthquakes that occurred near Japan. The second task was to consider the relationship between the plates and earthquakes that occurred at several places around the world. The two tasks included the same activities except for the learning content.

To investigate the manner in which students, other than those who wore tracked 3D glasses, referred to as co-learners in this study, shared 3D objects to conduct their discussion, we defined two experimental conditions. In two groups, the co-learners wore 3D glasses without tracking to collaborate and share nearly the same experience as that experienced by a learner who used a stylus and wore tracked 3D glasses. In the remaining two groups, the co-learners wore 2D glasses which did not perform any tracking during the task and which used the same polarizing film for the right and left eyes. Using the 2D glasses, the students were able to view only a single image of the stereoscopic 3D image that was displayed on the screen. Furthermore, in the two tasks, we switched the groups of 2D and 3D glasses; therefore, all students underwent learning under both types of conditions. Table 1 shows the student groups and lists the conditions and settings used for learners and co-learners.

Table 1

Conditions and settings used for learners and co-learners.

Group		View	Stylus	Eyewear tracking
3D group	Learner	3D	Yes	Yes
	Co-learner	3D	No	No
2D group	Learner	3D	Yes	Yes
	Co-learner	2D	No	No

Group work activities proceeded with the teacher providing instruction on two tasks. At the beginning of each task, the teacher instructed the students to think about the characteristics of earthquakes near Japan in task 1 and around the world in task 2, respectively. Students performed the tasks in their groups, with two students participating as learners in task 1 and the other two students as learners in task 2. Thus, all students participated as both learners and co-learners through the two tasks. Learners operated the VR educational materials for 3 min. The order of learners was decided by the students at the beginning of group work. While performing their tasks, the students were instructed to write comments regarding what they thought or noticed on the worksheet based on the perspectives of the learner and co-learners. Additionally, the students wrote their reflections of the group work on their worksheets for 3 min at the end of the group work. Each group work activity (the two tasks) took about 10 min, including the time to change learners. However, as described above, students did not view the screen of the VR system for the entire group work time. The time spent viewing 3D images continuously, including the practice before group work, was 5 min at the longest, and the cumulative time in class was about 15 min. After completing the two tasks, the students discussed the things they had thought of in each group as an additional learning activity, which was further presented in class using the AR presentation tool on the VR system.

At the end of the class, the students completed a questionnaire that asked them to answer two questions. These questions were designed to directly ask students about comprehensibility of 3D viewing. The first question was "When you used the stylus with the VR system, did you easily understand the structure of the plates by viewing in 3D?" The students answered with yes or no. The second question was "Viewing the screen when your friend was operating the VR system, which was easier to observe through the plates, the material about the first Japanese earthquake or the material about the later world earthquake?" Students rated their responses on a 5-point bipolar scale, including an even-point scale. In the analysis, it was converted to the viewpoint that it was easier to understand whether they viewed it in 3D or 2D. Additionally, the students commented regarding their impressions of the classes that used the VR system to perform learning. This study was performed in such a way that it was easy for students to understand and was also performed with the consent of the students to participate in addition to the permission of the school.

Analysis of Comments in Tasks

In an analysis of the comments described in the worksheet, text mining was performed to organize text type data and capture the features of learners and co-learners. Because the text written by the students was in Japanese, text analysis was performed in Japanese using KH Coder software (Higuchi, 2016; Higuchi, 2017) and the results were interpreted. First, the entire text was corrected for typos and spelling. Second, a compound word was defined with reference to the original text of the comments. For example, the proper noun "Philippine Sea Plate" was no longer split into the three words "Philippine," "Sea," and "Plate." This distinguished it from the case where the general term "plate" was used. Moreover, the four types of learners were defined as external variables. Then, a co-occurrence network was created and the co-occurrences between the extracted words and each external variable were analyzed. The network was generated by connecting pairs of terms using a set of criteria defining the co-occurrences and the differences and relevance of comments made by the different learners were analyzed. In addition, the frequencies of terms and the coefficients of the pairs of terms were calculated.

Results

Learning Behavior in Group Work

The behavior of the students during group work can be characterized as follows. At first, learners moved the plates of the area they were interested in, and then talked with co-learners to consider the positional relationships of multiple plates. In addition, observed learning behaviors using the VR system were different depending on whether the co-learner viewed in 3D or 2D. Learners whose co-learners viewed in 3D tended to have a little longer viewing distances and wider ranges of stylus movements. A characteristic scene to show the difference between 3D and 2D groups was when the co-learner pointed to an object and talked. The co-learners viewing in 3D pointed to a location in real space in front of the screen, while the co-learners viewing in 2D pointed to the screen of the display.

Comments from Learners and Co-learners

The comments from the learners who used tracked 3D glasses and a stylus in the groups that used either 3D or 2D viewing for the co-learners exhibited similar tendencies. They focused on the shape of the plate structure and the overlapping plates. For example, a student wrote that the Pacific Plate is located under the Philippine Sea Plate and the North American Plate, while another student commented that the positional relationships were easy to understand when compared with the printed material because the earth and the plate were both observed to be round. On the other hand, comments from the co-learners were seen to differ by observing the comments of the group who viewed in 3D and the group who viewed in 2D. The 3D observation group clearly provided more comments on the stereoscopic effect than were provided by the 2D observation group. Specifically, the students who viewed in 3D focused on the shape of the plate structure and overlapping plates, which is similar to that focused on by learners who used a stylus and moved the objects of the educational materials.

From the analysis of the text mining, the total number of extracted terms was 299 and included 91 types. Figure 3 shows the co-occurrence network analyzed by the text mining by using 41 different terms and four external variables. In the figure, the four types of learners (defined as external variables) are displayed as squares and the terms are circled with larger circles indicating that more were used in the comments. The most frequent frequently used words were "plate" (45 times), followed by "arrow" (18 times), and "bumpy" and "surround" (10 times), and "Pacific Plate" (8 times). Here, the "arrow" indicates the direction in which the plate moves, and is drawn at the edge of the plate in the VR educational material. In the co-occurrence network, the term connection relationships are indicated by lines and the coefficients of the pairs are indicated by the line thicknesses. The numbers displayed on the lines indicate the Jaccard similarity coefficient. Focusing on those terms that appeared frequently, "plate" was highly relevant to all four learners and especially to co-learners viewing in 3D. The term "surround" was also relevant to all four learners. "Pacific Plate" and "bumpy" were associated with both learners and co-learners when viewed in 3D. In other words, these terms had no relevance to the students who viewed in 2D but only for the students viewing in 3D. "Arrow" was related to the co-learners viewing in 3D and to both learners and co-learners in the 2D group. Furthermore, when focusing on terms that were only relevant to each of the four learners, for co-learners viewing in 2D, unlike the other three learners, there was only one single term, namely "small."

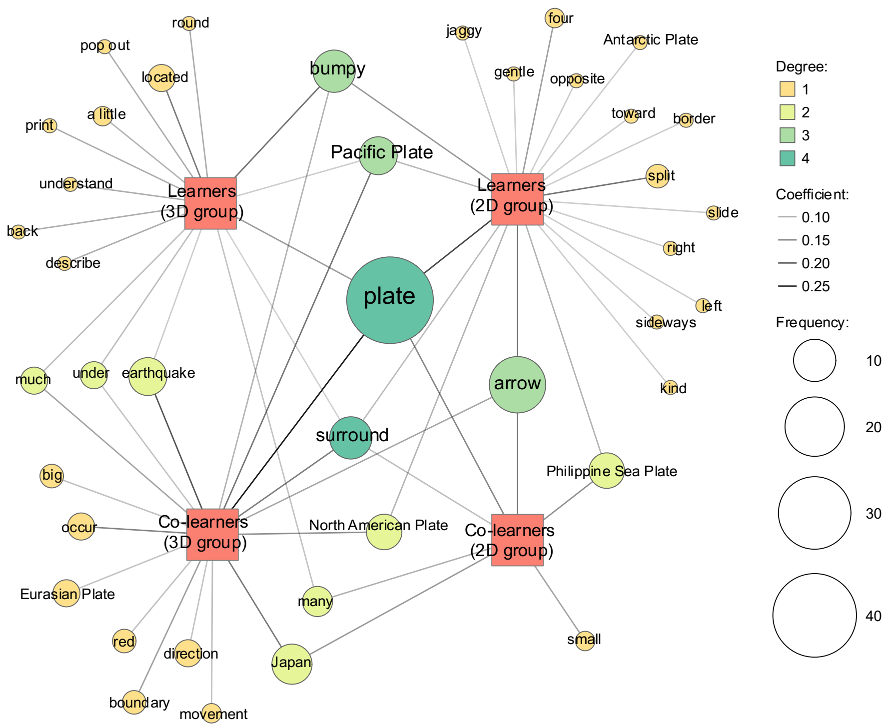

Figure 3. Results of co-occurrence network analyzing comments and focusing on learner differences. Note that the learners in the 2D group viewed the images in 3D but their partners viewed in 2D.

Questionnaire

From the results of the questionnaire completed at the end of class, the answer to the first question about student understanding of the plate structure by viewing in 3D was given as follows: All students except one who answered that a decision could not be made responded positively. Therefore, students easily understood the structure of the plates by viewing in 3D. The comments for the positive responses demonstrated that the plate structure was clearly understood mainly because the overlapping of plates and the thickness were easily visualized; also, the plate boundaries that were not seen on the paper map were also observed. Additionally, some students commented that the ability to disassemble and enlarge the object could be the reason for the topic to be easily understood.

The answers to the second question regarding the ease of observation from the viewpoint of the co-learners were provided as follows: Nine students preferred viewing in 3D (three students much preferred and six a little), six students preferred viewing in 2D (two students much preferred and four a little), and one student answered that a decision could not be made. There was no significant difference in preference for viewing in 3D or 2D. From the comments that contained student impressions for the class in which the VR system was used, most students commented on their interest and understanding of VR. However, there was a comment by one student that mentioned the visual fatigue that was associated with viewing a 3D image; another student reported light-motion sickness related to the usage of VR. The symptoms of both students were minimal and temporary and were better by the end of class. As far as the teachers and experimenters could see, none of the students who used the VR system as learners took off their glasses.

Discussion

The results from the experimental class showed that, when considering the relationship between plates and earthquakes, all four types of learners were able to focus on the fact that the place where earthquakes occurred was surrounded by plates. Therefore, the students under all conditions were able to learn that earthquakes occur due to plate movements and it was determined that the learning goal had been achieved. However, the term "Pacific Plate," which is very important for considering the recent large earthquakes in Japan, was not mentioned only by the co-learners who viewed in 2D. In addition, the co-learners who viewed in 2D did not use the description of "bumpy," which is an advantage of VR using stereoscopic vision, and mentioned a small number of terms not shared with other learners. Larger numbers of terms can be interpreted to indicate that the educational methodology was effective because the students were able to generate thoughts and comments related to the learning topic. From the results obtained, it was determined that 2D observations can provide important concepts that need to be learned but that 3D observations can more deeply facilitate learning.

A difference in learning behavior was observed for each learning group. The co-learners viewing in 3D pointed to a location in real space in front of the screen, while the co-learners viewing in 2D pointed to the screen of the display. This is quite reasonable because the images that the co-learners viewed in 2D were displayed on the screen. However, importantly, there was a gap in image position between learners viewing in 3D and co-learners viewing in 2D. This suggests that 3D observations and discussions may be affected when there are students viewing in 2D in the group. From the result of text analysis, there were more term connections in the 3D group than in 2D group, indicating that information was shared through 3D group work and there may have been lively discussions. However, from the perspective of sharing space in VR use, detailed examination will be necessary in the future.

Two students reported visual fatigue and motion sickness even though both of them exhibited only mild symptoms. The students responded in the second question of the questionnaire that they preferred viewing in 2D, which was considered to be due to visual discomfort when viewed in 3D. Generally, the visual fatigue and discomfort that are associated with stereo viewing are attributed to vergence–accommodation conflict (Hoffman et al., 2008; Shibata et al., 2011). The conflict is observed to be present for all conventional stereoscopic 3D displays, including HMDs. Moreover, the motion sickness that was reported during the study may also be related to the representation of the images (e.g., image distortion) in addition to image movement. These indicate that it is important to consider the manner in which VR educational materials should be used in class and also the manner in which images should be presented from the aspects of distortion and vergence–accommodation conflict. In addition to designing VR content, it may be effective to limit usage time and learning scenes in classrooms to reduce visual fatigue and discomfort.

Conclusions

For the use of VR content in schools, practical issues such as the technical problems of equipment and learning challenges remain. Nevertheless, this study concluded that group work with viewing in 3D is highly effective for learning but requires attention to health impacts such as visual fatigue. The following are findings from this study.

1) By viewing VR educational materials in 3D, students can easily understand the concavo-convex shapes and structures of objects and learn deeply about the learning content. Moreover, it can be expected not only for learners who operate VR educational materials in group work but also for co-learners who are viewing in 3D.

2) While using VR educational materials, viewing in 3D has an advantage for observing 3D objects, but students can learn important concepts even when they are viewed in 2D.

3) To provide fair high-quality education, it is suggested that when using VR techniques at school, it would be good to have an option to view in 2D for students who are not good at viewing in 3D. In that case, it would be effective to form a group with students to view in 3D to utilize the advantages of VR educational materials and to share the information in the group.

Although this study demonstrated the positive effects of using VR techniques for education with practical classes in school, it has limitations that require further work. Even if the learning theme and VR device are different, it is expected that more objective knowledge supporting the results of this research could be obtained by conducting similar practical classes. In addition, it is necessary to perform detailed examinations to clarify the functionalities of using VR techniques as well as to observe methods that can use VR educational materials to develop new methodological models in education.

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