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Utilization of Stereoscopic 3D Images in Elementary School Social Studies Classes

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Abstract

We conducted experimental classes in an elementary school to examine how the advantages of stereoscopic 3D images could be utilized in education. More specifically, we selected a unit of the Tumulus period in Japan for sixth-graders as the source of our educational 3D materials. This unit represents part of the coursework for the topic of Japanese history. Educational materials used in our study included stereoscopic 3D images for studying the stone chambers and Haniwa (i.e., terracotta clay figures) of the Tumulus period. Results from our first experimental class showed that educational 3D material helped students focus on specific details and also understand three-dimensional spaces and concavo–convex shapes. Our second experimental class revealed that educational 3D materials also led students to come up with novel questions. These studies suggest the need to understand how to use the essential aspects of stereoscopic 3D images for developing new models in education.

Introduction

In recent years, there have been substantial developments in technology used to present images on displays. Aside from being incorporated into everyday activities, display technologies promote the use of Information and Communication Technology (ICT) in education. As an example, tablets have become increasingly popular in elementary school classrooms as a means of improving educational quality. In Japan, the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) continues to actively promote the use of ICT in education with large-scale projects that investigate the educational effectiveness of tablets and other educational equipment; such projects involve researchers conducting practice classes [1].

In addition to new display technologies, the functionality of new image technologies, such as stereoscopic 3D images, is an active area of research in the field of education. As an example, Aitsiselmi and Holliman reported that stereoscopic viewing on 3D displays was an effective means of completing a mental rotation task, i.e., a cognitive process that involves the mental rotation of objects [2]. Further, Bamford explored the effectiveness of 3D images in the classroom and its potential as a teaching and learning tool [3]. Here, Bamford showed that students responded positively to visual stimuli and suggested 3D images could increase student motivation and engagement. Shibata reported that in school education, students are interested in learning and the use of stereo 3D movies and other such educational materials provides students with a strong sense of depth in their learning [4]. Shibata also showed that approximately 90% of students would like to attend a class using 3D educational content again, suggesting that 3D images could be an effective learning tool for inducing student interest.

In this paper, we describe two studies in which we administered experimental classes in an elementary school and evaluated the educational effects of using 3D content. In particular, we aimed to clarify the differences between the effects of 2D and 3D educational content. We also aimed to describe the advantages of using 3D images to promote education and learning.

Educational 3D Materials

Learning Content

We selected a unit of the Tumulus period in Japan that covers part of the Japanese history coursework from the sixth-grade curriculum. From the third to the seventh century, many tumuli—or *Kofun* in Japanese—were built throughout Japan. Burial mounds of the ruling elite, these *Kofun* were monumental structures indicating powerful political status. The mounds contained large stone chambers with terracotta clay figures called *Haniwa* that were arranged on and around the mounds, as shown in Figure 1.

Key student learning objectives included understanding the features of the Tumulus period by studying the large burial mounds (i.e., *Kofun*), stone chambers, and exquisite terracotta clay figures (i.e., *Haniwa*). We selected this unit because the stone chambers and *Haniwa* have complicated forms and figures; we hypothesized that it would be difficult for students to understand such complicated shapes from conventional textbooks or 2D images. Further, we deemed this unit appropriate for assessing the applicability and effectiveness of 3D images.

Figure 1. Tumulus (i.e., Kofun) and terracotta clay figures called Haniwa.

Human Factors Aspect

Since 2005, when 3D movies and theaters were introduced, public concern regarding potential adverse effects associated with prolonged viewing of 3D images has increased. Although there are many potential causes of visual discomfort when viewing stereoscopic 3D images, the vergence-accommodation conflict is a key problem with stereo 3D displays because it occurs in all conventional stereo 3D displays [5, 6]. Therefore, it is critical to consider how to present 3D images as safely as possible, especially in the classroom.

For use in the sixth-grade social studies class, we considered the fact that movies were viewed at a different size on 3D displays with different viewing distances in the classroom by children with smaller interpupillary distances than those of adults. In creating an educational 3D movie and setting up several 3D displays in the classroom, we considered comfortable 3D viewing [6-8]. More specifically, we set the negative conflict (i.e., stereo images behind the screen) and positive conflict (i.e., stereo images in front of the screen) in the images to be less than one degree in the classroom [9]. In addition, we excluded possible severe adverse factors, such as misalignments of the right and left images and frame violations.

Experimental Class 1

Purpose

The purpose of experimental class 1 was to explore the advantages of 3D images in education as compared to 2D images. Assuming that group work in the classroom is an appropriate use of 3D images, we used three types of 3D displays to actually display the educational 3D materials [10].

Methods

3D Displays Used in Class

As shown in Figure 2, we presented our educational 3D materials on three types of displays: a 3D television with active shutter glasses (KDL-32HX750, Sony), a 3D laptop with the same active shutter glasses (VPCF249FJ, Sony), and an autostereoscopic mobile device (NINTENDO 3DS LL, Nintendo). The resolution and screen size of the 3D television were 1920 × 1080 pixels and 32 inches, respectively. The 3D laptop had the same resolution but a 16-inch screen. The autostereoscopic mobile device had a resolution of 800 × 240 pixels and a 4.88-inch screen size.

3D images were prepared using a side-by-side stereo format. To compare the effects of 2D and 3D images, we also prepared 2D images with the same content to be presented on tablets and worksheets. The left side of the 3D images was used for the 2D presentation.

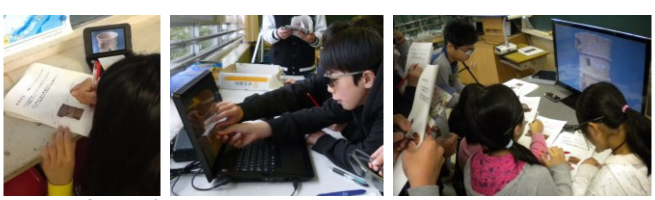

Figure 2. Scenes from our experimental 3D classroom in an elementary school: (left) autostereoscopic mobile device; (center) 3D laptop; and (right) 3D television.

Procedure

An experimental class was conducted with sixth-graders at a public elementary school. The 26 students in the class were divided into three groups of eight or nine students each. All the students had normal stereoacuity, according to self-reported results of a stereo viewing test completed before the class took place.

At the beginning of the experimental class, students were asked questions about *Kofun* and *Haniwa* to measure their level of interest in the learning content. They were asked to respond to the same questions again at the end of the class. During the class, the students filled out three worksheets, evaluating two 3D *Haniwa* images and one 3D image of a spatially arranged *Haniwa* on a burial mound. The three images are shown in Figure 3. The worksheets had enough space for students to write comments.

Figure 3. 3D educational materials used in experimental class 1, including (from left to right) two 3D Haniwa images and one 3D image of a spatially arranged Haniwa.

On each worksheet, images of *Haniwa* were printed as 2D images. First, using a black pencil, students recorded what they had noticed and understood from the 2D image on the worksheet. They marked the places on the image where they had observed items of interest, along with their comments. In addition to using the worksheets, half of the students in each group viewed the 2D images on tablets (iPad mini, Apple). The tablets contained a zoom-in feature accessible via a two-finger movement (i.e., a pinch-out zoom movement). Students then viewed the same content on each of the three types of 3D displays, again recording what they had noticed and understood on the worksheet, this time using a red pencil. The use of two different colors enabled us to distinguish between the comments that the students wrote when viewing 2D and 3D images, respectively, and to analyze the results.

Finally, after completing their worksheets, students answered questions regarding their understanding of the three-dimensional space and concavo–convex shapes (Q1), their interest in *Kofun* and *Haniwa* (Q2, the same question asked at the beginning of the experimental class), and their preference among the 3D display options (Q3). They rated their responses to Q1 and Q2 on a five-point Likert scale and ranked the three 3D displays on Q3.

Results

Figure 4 shows student responses to Q1 after viewing the content; scores are displayed for both groups of 2D image observations (i.e., worksheet only and worksheet plus tablet) and averaged across participants in each group. The y-axis represents their responses, with zero indicating no preference between 2D and 3D images and scores greater than zero indicating a preference for 3D images. Our results demonstrated that three-dimensional spaces and concavo–convex shapes were more easily understood using 3D images. In addition, the preference for 3D images was greater among students who used worksheets alone than among those who used tablets ($p < .05$), indicating that tablets enable a more detailed observation of 2D images than printed educational materials do. This result shows the positive impact of advanced ICTs on educational effectiveness in recent years.

Figure 4. Understandability of three-dimensional spaces and concavo–convex shapes as evaluated by students (Q1).

Figure 5 shows an example of a worksheet after students viewed a 3D television image of spatially arranged *Haniwa* on a burial mound. Black and red ovals indicate the places on the image on which students commented while viewing the 2D and 3D images, respectively. The figure shows the cumulative results for all applicable worksheets, with thicker ovals indicating a greater number of comments, showing that these portions of the image attracted frequent attention.

These results revealed an interesting difference between the 2D and 3D images. More specifically, students were more likely to notice the rolling ground (a burial mound) when viewing the 3D images. Moreover, several students noticed and understood that the *Haniwa* in the image resided on the burial mound. From the perspective of teaching history, it is important to consider the meaning of the arrangement of *Haniwa*. No student noticed the rolling ground in the 2D images under any display condition, suggesting that the 3D images helped students to understand the course content better. More specifically, to acquire this understanding, students focused on the details and thought about the kinds of *Haniwa*, how the *Haniwa* were arranged, and why *Kofun* were constructed. Therefore, exploring 3D images enabled students to develop a deeper understanding of the Tumulus period in Japanese history.

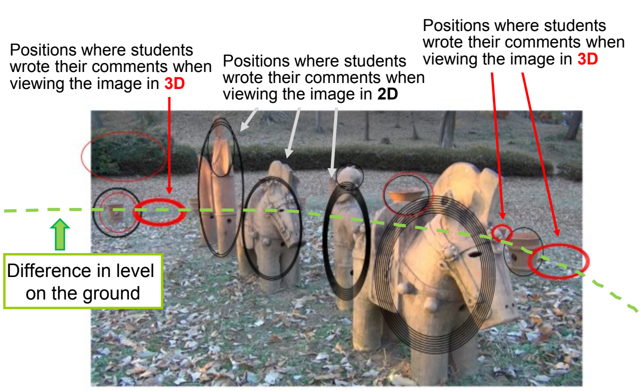

Figure 5. Results of students viewing 2D and 3D educational images, with black and red ovals corresponding to the 2D and 3D images, respectively.

The difference between 2D and 3D was also observed in the use of mobile devices. Figure 6 shows a similar worksheet result after students had viewed a 3D mobile image of the obverse side of a *Haniwa* carved with a human face. Students noticed that the nose had a convex shape, but only when viewing the 3D image. The same results were obtained with both the 3D television and laptop, indicating that the beneficial effect of 3D use was not dependent on display size.

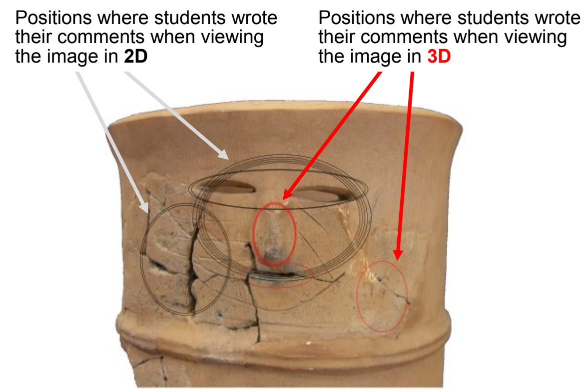

Figure 6. Areas recorded on student worksheets while viewing 2D and 3D images in the mobile condition, with the number of ovals surrounding each area indicating the number of responses.

Next, we focused on differences between the 3D displays. The total number of observations recorded on all three worksheets while students viewed the 3D displays is presented in Figure 7. As noted earlier, the 3D television and 3D laptop had the same resolution but different screen sizes. The larger display prompted more observations, suggesting that information useful for understanding course content should be prominently displayed on a larger screen where feasible. However, the style and content of learning in a particular classroom situation will also affect what 3D display is most appropriate.

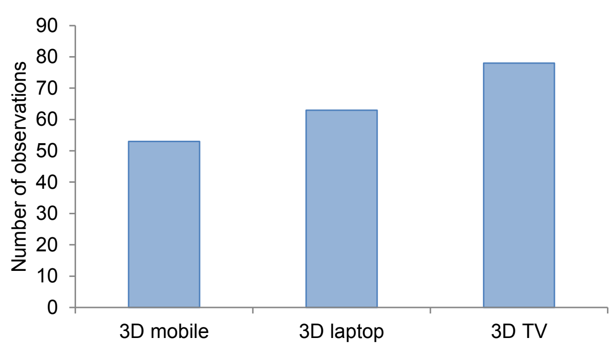

Figure 7. Total number of observations reported on student worksheets while viewing 3D images on various 3D displays.

Figure 8 shows the change in student interest in *Kofun* and *Haniwa* after our experimental class using 3D images. In the figure, scores have been averaged across participants. The y-axis represents the degree of interest, which was measured on a five-point scale with 5 representing the highest interest in the learning content. These results indicate a significant increase in student interest ($p < .05$), strongly suggesting that the class positively affected student learning.

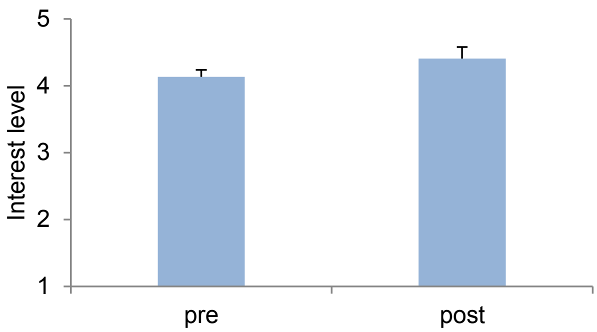

Figure 8. Average level of student interest in Kofun and Haniwa before and after our experimental class using 3D images (Q2).

Finally, as summarized in Table 1, the question regarding student preferences for 3D displays (Q3) revealed that 85% of students preferred viewing images on a 3D television as a way to understand concavo–convex shapes of the *Haniwa*.

Table 1. Preferences for using 3D displays to understand concavo–convex shapes of the *Haniwa*.

Number of responses	3D mobile	3D laptop	3D TV
First-place rankings	1	3	22
Second-place rankings	3	19	4
Third-place rankings	22	4	0

Experimental Class 2

Purpose

The purpose of our experimental class 2 was to evaluate the advantages of 3D images from the perspective of historical learning. We focused on student questions generated from the provided educational materials.

Methods

Historical Learning Aspect

Recent historical learning in social studies classes has focused not only on memorizing historical facts, but also on conducting inquiry-based learning. It is especially important that students generate questions in learning activities involving inquiry-based learning. Owing to the rich information available in educational materials, 3D content and simulation games could be appropriate for generating questions. As an example, McCall reported that junior high school students generated well-considered questions when using a simulation game [11].

Procedure

For this experiment, we conducted an experimental class for sixth-graders at a public elementary school that was not the same class as experimental class 1. Students from two classes—class A with 26 students and class B with 30 students—participated in this study. The experimental class was conducted after students had already attended regular classes on the Tumulus period. In our experimental class, we used two movies on *Kofun*, including stone chambers (depicted in Figure 9), and *Haniwa*. The viewing time of each movie was five minutes. Students in class A viewed the movies in 3D, whereas those in class B viewed them in 2D. The display was a 49-inch 3D television with polarized glasses (KD-49X8500B, Sony); the 3D movies were prepared using a Multiview Video Coding format. The left image of the 3D movie was used to present the 2D observation.

After each viewing of the two movies, students completed a worksheet that encouraged them to develop questions regarding the *Kofun*, the *Haniwa*, and anything else that emerged from the educational materials. Students made a list of as many questions as possible in three minutes. As a pre-test for the study, students were also asked to complete an identical worksheet at the end of their regular classes (i.e., before viewing the videos described above).

In our experimental class, students discussed their hypotheses and questions in small groups after completing the two worksheets. Each group then made a presentation about their respective discussions to share what they came up with during the group work.

Figure 9. Scene captured from the movie showing a stone chamber in a burial mound.

Analysis

For our analysis, we focused on two key evaluation items, i.e., the number of questions and the novelty of the questions derived from the 3D viewing. Regarding the number of questions, we interpret a larger number of questions as indicative of the educational materials being more effective because students were able to generate more questions, which is the first step of conducting inquiry-based learning. Further, student questions were scored for being novel based on how unusual the questions were. A higher score thus indicated that more novel questions were generated. We assigned these scores separately for the two kinds of content.

Results

Figure 10 presents results regarding the number of questions generated for both 2D and 3D observations before and after viewing the educational materials. Scores were averaged for students in each class. Focusing on results of the 3D content, we observe here that the number of questions in the post-test was significantly higher than that of the pre-test ($p < .01$); further, the number of questions generated after viewing the educational 3D materials was slightly higher than that generated after viewing the 2D content.

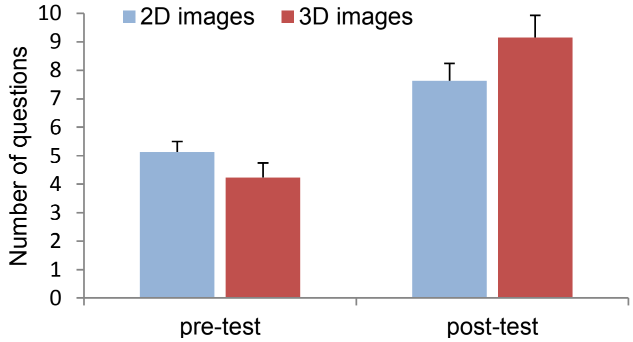

Figure 10. Changes in the number of questions generated before and after viewing the given educational materials.

Figure 11 presents novel question scores for the *Kofun* content for both 2D and 3D observations. The scores were averaged for students in each class. We observe here that scores for viewing the 3D content were significantly higher than those for viewing the 2D content ($p < .01$). As shown in Figure 12, results of the other movie (i.e., including *Haniwa* content) were the same ($p < .01$).

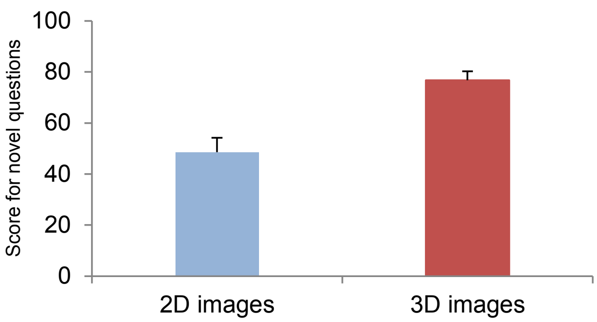

Figure 11. Changes in the number of novel questions generated from the given educational materials covering the Kofun content.

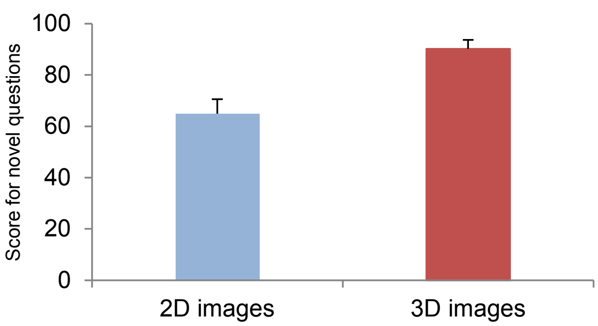

Figure 12. Changes in the number of novel questions generated from the educational materials covering the Haniwa content.

Finally, we present a few examples of the novel questions generated from the 3D observations that were not generated from the 2D observations. First, "Why are the *Haniwa* arranged in a specific order?" Second, "What is the length of the passage that goes from the entrance to the stone chamber?" Third, "Why is the area around the *Kofun* dented?"

Conclusions

In this paper, we report on our work in conducting two experimental classes in an elementary school to evaluate the educational effects of using 3D content.

Our results from the experimental class 1 showed that 3D educational material can help students to focus on details and better understand three-dimensional spaces or concavo–convex shapes. Comparing student understanding acquired from 2D images with that obtained via 3D images, we found that 3D images reveal features frequently overlooked in conventional 2D images. By noticing such features, students enhanced their understanding of the subject content. Furthermore, students preferred a larger display for 3D viewing because it promoted better understanding by highlighting visual content. Nonetheless, in actual practice, other factors may influence decisions as to what 3D display type and screen size are most appropriate in a particular context.

In experimental class 2, results we obtained from worksheets completed by the students revealed that educational 3D content helped them generate novel questions. Comparing two educational materials presented in 2D and 3D, we showed that 3D content enabled students to think in detail about the given content, thus promoting inquiry-based learning.

During these two experimental classes, no student reported visual fatigue or discomfort associated with 3D image viewing. Viewing times were limited to approximately five minutes per image, with sufficient time between viewings; however, in general, some individuals with normal vision in both eyes experience difficulty in viewing stereoscopic 3D images. Additionally, it is important to keep in mind the health issues faced by elementary school students, who are still in their early developmental years. Therefore, despite the strong potential of 3D images as a potential learning tool, their use in schools requires careful consideration.

Future studies are also required to examine the functionality of 3D images in more detail, along with how educational 3D materials can be used to develop new education models. In addition, development of a method to evaluate educational 3D materials is required from the perspective of educational effect.

Acknowledgments

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