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Usage of Stereoscopic Visualization in the Learning Contents of Rotational Motion*

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***Abstract*—Rotational motion plays an essential role in physics even at an introductory level. In addition, the stereoscopic display of three-dimensional graphics includes is advantageous for the presentation of rotational motions, particularly for depth recognition. However, the immersive visualization of rotational motion has been known to lead to dizziness and even nausea for some viewers. Therefore, the purpose of this study is to examine the onset of nausea and visual fatigue when learning rotational motion through the use of a stereoscopic display. The findings show that an instruction method with intermittent exposure of the stereoscopic display and a simplification of its visual components reduced the onset of nausea and visual fatigue for the viewers, which maintained the overall effect of instantaneous spatial recognition.**

I. Introduction

The stereoscopic display of three dimensional (3D) graphics is advantageous for educational purposes on account of following reasons: (1) the depth recognition stabilizes the perception of the 3D structure; (2) the 3D image of the moving object is easily recognizable; and (3) real-time manipulation of the virtual camera enhances intuitive exploration [1]. The physical phenomena related to the rotational motion of objects are not easy for beginners to understand. In this case, use of a stereoscopic display is an intriguing and effective method for addressing this problem.

However, nausea and visual from viewing the stereoscopic presentation has become an issue for the introduction of 3D stereoscopic materials into classrooms [2]. Therefore, an appropriate instruction method must be developed in order to effectively use such stereoscopic displays.

In our previous study on an application of Fleming's left-hand rule for direct current (DC) electric motors, we found that only 30% of students who lacked confidence in their understanding of two-dimensional (2D) materials felt more confident when using 3D stereoscopic material [3]. It was thought that 2D materials were important for the effective use of stereoscopic images.

This study first examines the onset of nausea and visual fatigue for those viewing stereoscopic presentation of rotating motors in classrooms. Then, the intermittent use of a stereoscopic display is considered for instructional procedures, in order to avoid such nausea and visual fatigue.

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II. Method

A. A DC Electric Motor Model

A model of a DC electric motor, created by using Adobe Flash CS5 with Papervision3D library, rendered a side-by-side 3D stereoscopic image with a resolution of 1000 ×600 pixels for each viewport, and a maximum of six types of vectors were exhibited in the model space. On the basis of instructions in this study, the following three vectors were chosen: the magnetic field of fixed magnets, the electric current that provided by a battery, and the magnetic force exerted on the current-carrying wire (figure 1). The vectors exhibiting electric current and magnetic force were drawn on the wire in rotational motion. In addition, the moving objects along the wires and a commutator expressed the flow of electrons.

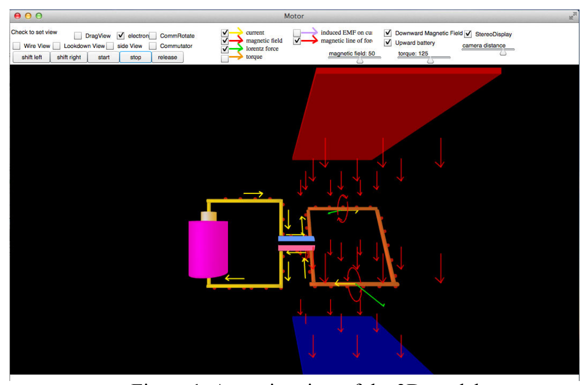

Figure 1. An entire view of the 3D model.

B. Demonstration

Lectures using a 3D stereoscopic model were conducted in three different classes in the Faculty of Education at Tokyo Gakugei University. For the first two classes, majorly consisted of second-year students, the stereoscopic images were continuously exposed to the students during the instructions. One of these classes consisted of 35 natural science students in the Faculty of Education (hereafter referred to as "science class") while the other one consisted of 27 humanities students (hereafter referred to as "humanities classes"). This type of exposure of 3D stereoscopic images to the students is hereafter referred to as "continuous exposure."

For the third class, which consisted of 30 third-year students from both natural science and humanities, 3D stereoscopic images were shown during the explanation of the first scene and just before the transition to the following scene. This type of exposure is hereafter referred to as "intermittent exposure".

All three classes began with a demonstration of an experiment based on Fleming's left hand rule in which two parallel conducting rails were placed on both sides of a long magnet. Lead from a mechanical pencil was placed on the rails perpendicularly and then a voltage of 3 V was applied between the rails. As a result, the lead moved along the rails as a result of the magnetic force exerted on the electric current.

To display the motor model, a dual projector with linear polarization (portable 3D projector 3DP-TX04, T&TS CO., Ltd.) was used to project superimposed side-by-side images (1024×768 pixels) onto an 80-inch polarization-preserving screen. The students viewed the images through linearly polarized glasses, and they were asked to move to appropriate positions in front of the screen.

After a demonstration of the experiment, the motor model viewings were conducted in the following manner.

a) View 1: First, an entire view of the 3D stereoscopic model was shown (figure 1).

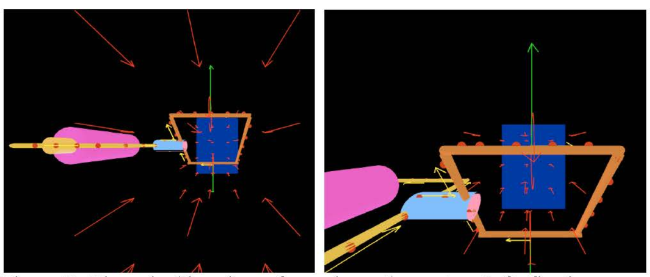

Figure 2. Views looking down from above the motor. Left: fixed cameras. Right: cameras move with a side of wire.

b) View 2 : Second, the view was switched to one from above the rotating wire. This is a view looking down from above the rotating wire (figure. 2 left). The motion of the wire viewed from this position is directly comparable to the first demonstration experiment. In this case, the change of direction of the electric current at every turn of the wire and the role of the commutator for such change was mentioned.

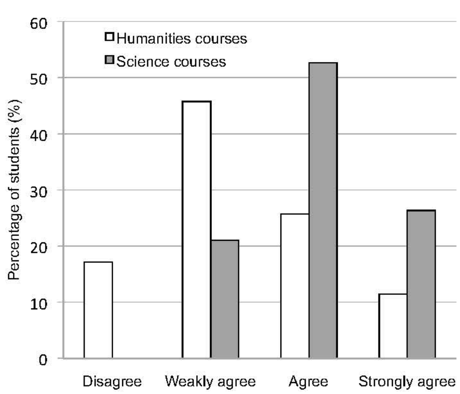

Figure 3. Students' self-confidence when explaining the mechanisms of the demonstration experiment based on Fleming's left-hand rule. a) Unfilled bar; humanities courses students. b) Filled bar; natural science courses students. The equality of distributions for a) and b) was rejected at the significance level of 0.05 by the Kolmogorov-Smirnov test.

c) View 3: in order to continue observing one side of the rotating wire, the camera positions moved along the side of the wire, and the observed side always remained in the center (figure. 2, right).

Finally a questionnaire regarding experiences of nausea and fatigue was presented to the students.

C. 3D Eyeglasses Removal Comparison

Students were allowed to remove their 3D glasses at any time during the instruction. The act of removing the glasses was influenced by two overall reasons: (1) students were interested in how the images appeared on the screen compared to how they appeared through the 3D glasses, and (2) students felt temporal nausea or visual fatigue. In the first case, students compared the images by briefly removing their glasses; while in the second case, students removed their glasses for a relatively long amount of time.

In this study, the lectures were videotaped in order to estimate the onset of nausea and fatigue in the instructional processes, and count the number of students who removed their glasses every 30 seconds. To eliminate the number of students who removed their glasses for the first reason mentioned above, only the number of students who completely removed their glasses was counted.

III. Results and Discussion

A. Continuous Exposure

Questionnaires, given to the students immediately after the demonstration experiment, inquired how confident they felt when explaining the experiment by themselves. Figure 3 includes a comparison of the histograms between the science and the humanities students. A Kolmogorov-Smirnov test at the significance level of 0.05 shows that the hypothesis of equality of the distributions for these classes is rejected, since the value D (=0.371) was grater than the Critical value (=0.308). Although the knowledge of Fleming's left-hand rule is included in junior high school curriculums, humanities students had lower confidence levels when applying this knowledge to the experiment.

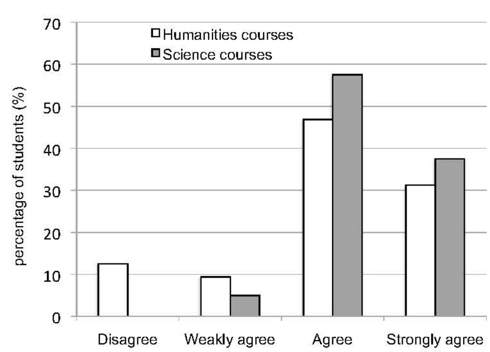

Figure 4. Students' responses regarding the effectiveness of the 3D stereoscopic display for understanding the entire spatial structure of the motor model (View1).

Figure 4 shows the distribution of the students' response to the question of whether the 3D stereoscopic display was effective for understanding the entire structure as well as its relationships of magnetic fields, the current along the wire, and the magnetic force exerted on the rotation wire. Before the questionnaire was given, the non-stereoscopic image was shown followed by the stereo display. The majority of students in both classes responded positively to this change in effect. Only one student responded with "disagree." for both figures 3 and 4. From those who responded "disagree" or "weakly agree" in figure 3, 86% chose "agree" or "strongly agree" in figure 4.

The instruction was switched from View 1 (the fixed view of the entire model) to Views 2 and 3 (views focused on the rotating wires). After viewing and explaining each particular view for approximately 5 min, the questionnaires regarding experiences of nausea and fatigue were given to each student. The results of Views 1 and 2 are compared in figure 5. Although approximately 20% of students did not feel nausea during View 1, almost all of them felt some nausea during View2. Based on the Wilcoxon signed-rank test at the significance level of 0.05%, the hypothesis that the two distributions were equivalent was rejected, because the value of P_two_tail (=0.018) was smaller than the significance level (=0.05). This figure implies that the observation of rotational motion from the rotating frame induces more nausea and fatigue compared to that of the fixed frame.

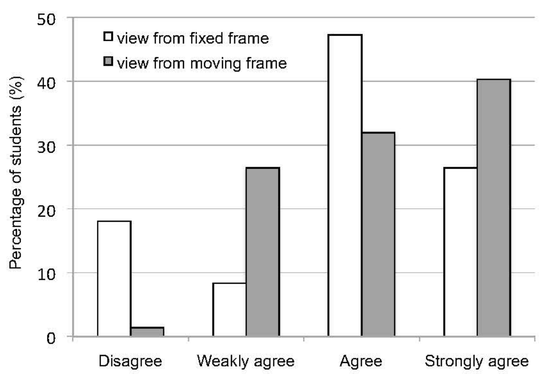

Figure 5. Students' response on the feeling of nausea or fatigue when viewing the rotational motion from the fixed frame (View 2) and the rotating frame (View 3).

During View 3, an animation of the rotating wire without vector presentation was first shown in order to allow students to recognize the location of the viewpoint. Then, the students were questioned regarding whether they felt sick or fatigued when viewing the rotating frame without vector presentation.

Figure 6 shows the comparison of View 3 with and without vectors of the magnetic field, the electric current and the magnetic force. Figure 7 shows a comparison of students' response regarding nausea and fatigue with and without vectors. The results imply that a simpler image without vectors was a more effective approach to viewing the display.

B. *Intermittent Exposure*

During the intermittent exposure instruction, 3D stereoscopic images were shown at the beginning of each scene in order to recognize spatial structures of the model. The most important aspects were provided, which included non-stereoscopic images created on the screen with a virtual camera distance of zero.

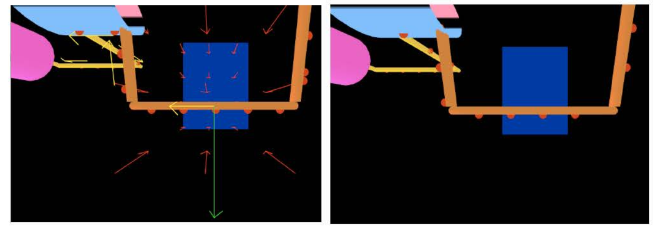

Figure 6. View 3 (rotating frame) with vectors (left) and without vectors (right).

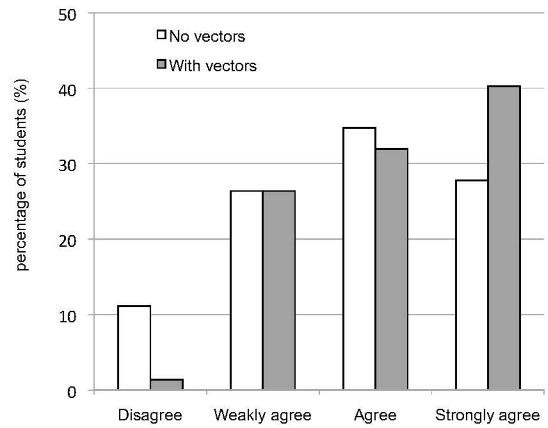

Figure 7. Students' response regarding their feelings of nausea or fatigue during View 3, with and without vector presentations. Data for the view with vectors are equivalent to those in figure 5.

Furthermore, when the stereoscopic display was exposed, the vector presentation in the rotating scene was substantially shortened. The stereoscopic display was only used to recognize the spatial configuration of the vectors.

Figure 8 shows the comparison of students' responses in regard to any nausea felt during View 3 under continuous and intermittent exposure, as previously shown in figures 5 and 7, respectively. The sum of the rates of "disagree" and "weakly agree" to the feeling of nausea during intermittent exposure was 50%, which was a 22.2% increase from the continuous exposure.

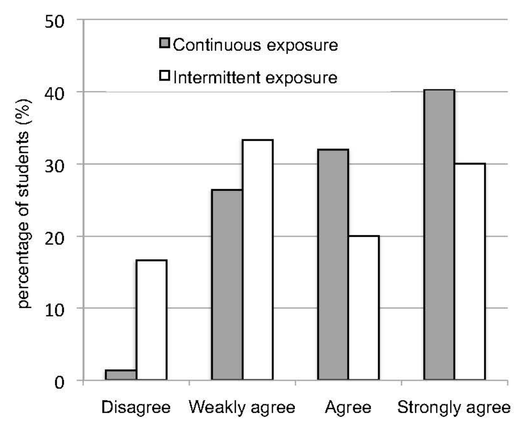

Figure 8. Students' responses regarding their feeling of nausea or fatigue during View 3 under continuous and intermittent exposure of 3D stereoscopic images.

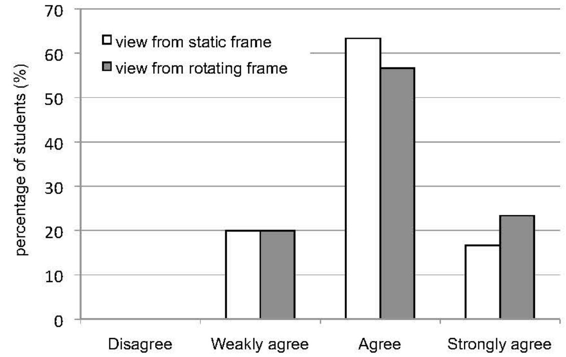

Figure 9. Students' responses regarding the effectiveness of the stereoscopic display during View 2 (static frame) and View 3 (rotational frame) under intermittent exposure.

Figure 9 shows the results of the questionnaire on the effectiveness of the stereoscopic display in helping with understanding of the rotational motion mechanism. Although the exposure time of the 3D stereoscopic view was restricted to only 1 min for each step of explanation, the students' positive responses imply that it was sufficient for learning.

Figure 10 shows the results of removing the 3D glasses. During continuous exposure instruction, approximately 50% of students removed their glasses within 3 min. From 10 to 15 min, 46±7 % (average±standard deviation) students removed their glasses. The majority of the students were seen repeatedly removing their glasses during the instruction.

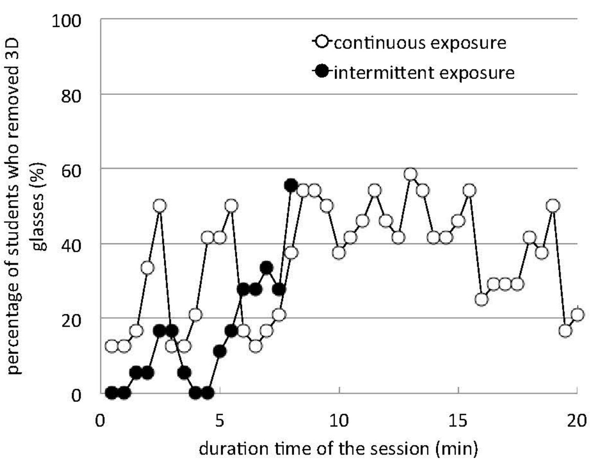

Figure 10. Percentage of students who removed their 3D glasses during the instruction sessions under continuous and intermittent exposure of the 3D stereoscopic images.

On the other hand, the percentage of students who removed their glasses did not immediately increase during intermittent exposure. In face, it reached a level of 56% only by the end of instruction. This finding is desirable for lecture-style instructions (in which the instructor explains the material step by step and the students learn in a synchronous manner) since the learners obtain enhanced recognition from viewing the stereoscopic display.

Table 1 summarizes the students' remarks regarding instruction using the 3D stereoscopic display. 63% of the students remarked that the 3D stereoscopy helped them understand the material whereas 58% mentioned the issues of nausea. A majority of the latter students claimed that resolving this problem was particularly important for the purpose of education. Several students mentioned that using a 3D stereoscopic display was useful since spatial structure could be instantaneously perceived. In addition, some students remarked that they could not pay full attention to the physical mechanisms since the 3D stereoscopic animation was fascinating and stimulating. Likewise, there were comments that the colors should be simpler and the number of visual components in the scene should be minimized in order to allow learners to concentrate on the motion or the components in question.

TABLE I. SUMMARY OF STUDENTS' REMARKS

Remark	*Number*	*Remark*	*Number*
Helps understanding.	58	Feel nauseous, or fatigue.	53
Attract interest.	27	No difference in understanding.	13
Realistic feeling.	3	Cannot concentrate on the mechanism.	3
Instantaneous spatial recognition.	3	Anxious about the complexity of preparation	1

IV. CONCLUDING REMARKS

This paper showed that the stereoscopic display of rotational motion provided a better presentation even though it induced nausea for some viewers. By reducing the time of exposure of stereoscopic images, the onset of nausea and fatigue decreased without seriously hindering the spatial perception. Even a short inspection of the stereoscopic display appeared to sustain 3D perception while viewing the non-stereoscopic images. In addition, due to the reduction of the coplicated visual components, step-by-step introduction of important visual components proved to be effective for overall instruction. Nausea and visual fatigue rather hindered the students' concentration and systematic learning. Therefore, we considered an intermittent exposure method in which the 3D images were briefly displayed in stereoscopic form in order to create a concept of structure and motion. Through careful explanation of the non-stereoscopic 3D images, this approach reduced nausea caused by excessive stimuli of the stereocopic display as well as visual fatigue.

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