Development of Learning Materials on the Diffraction Phenomena of Light Waves and a System for Observing Reproduced Images of Holography Using the Virtual Reality Technology

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Keywords: Virtual Reality, Optics, Holography, Educational Technology.

ABSTRACT

In Japan, the “shift away from science” has been discussed. In addition, the Japanese government has recently been promoting the use of Information and Communications Technology in education. Based on this, we developed learning materials using the virtual reality technology and proposed effectiveness of these learning materials.

1 INTRODUCTION

At present, Japan is facing a challenge in that its students’ “interest in science” is low compared with those in other developed countries. According to the PISA (Programme for International Student Assessment) [1], an international achievement survey of 15-year-olds, Japan is below the average of developed countries in terms of indicators, such as “enjoyment of science,” “instrumental motivation to learn science,” and “students' self-efficac students' self-efficasy in science. y in science.”

This trend becomes more pronounced as students move up through the grades. For example, according to the 2022 National Assessment of Academic Ability conducted by the National Institute for Educational Policy Research, 49.4% of elementary school students answered “Yes” to the question “Do you like studying science?” whereas the proportion of junior high school students was 32.3%, showing a decrease of 17.1%. Furthermore, the percentage of junior high school students who answered “Yes” to the questions “Do you think studying science is important?” and “Do you want to have a career related to science in the future?” was lower than that of elementary school students. As these results indicate, Japanese students’ interest in science declines as they progress through the grades, resulting in a lower level of interest in other developed countries.

We examined the causes of this shift away from science. First, the results of PISA’s “instrumental motivation to learn science” and the National Assessment of Academic Ability’s “Do you want to have a career related to science in the future?” indicate that Japanese students “do not see any future value in science learning.” Next, we examined the results of the question “Do you understand the content of the class well?” in the National Assessment of Academic Ability. The percentages of elementary school students who answered “Yes” were 39.7% for Japanese, 45.7% for math, and 55.0% for science, whereas the percentages of junior high school students were 32.2% for Japanese, 36.2% for math, and 31.1% for science. The elementary school students had the highest level of understanding of science, whereas the junior high school students had the lowest level of understanding. Considering the trend of declining interest in science as students advance through the grades, it is thought that the difficulty of science as a subject is one of the reasons for the shift away from science. From this discussion, the following two items were identified as approaches to prevent students from the “shift away from science”:

① Adding future value to science learning.
② Facilitating understanding by promoting learning through experimentation.

The reason for ② is that we believe experiments are a powerful way to solve the difficulty of understanding in science learning.

Furthermore, the Japanese government launched the “GIGA (Global and Innovation Gateway for All) School Program” [2] in 2019.This is an attempt to provide one computer terminal and high-speed network for each student against the backdrop of Japan lagging behind other developed countries in “the utilization of ICT (Information and Communications Technology) in the educational field”. In addition, the mobile terminal (cell phone/smartphone) ownership rate [3] for Japanese by age group shows that 87.7% of 13–19-year-olds own a mobile terminal; this percentage is expected to continue to grow in the future. Therefore, BYOD (Bring Your Own Device), which allows individuals to use their home terminals in the educational field, is being considered, and opportunities for students to use their personal computer terminals for learning are expected to increase.

Based on the above discussion, our laboratory is developing learning materials using ICT. We are focusing on the XR (extended reality) technology and examining the effectiveness of teaching materials that take advantage of it. The advantages of the XR technology include the ability to simulate experiments that are difficult to prepare and to visualize phenomena that cannot be observed in real space. Therefore, the development of learning materials using the XR technology makes it possible to facilitate virtual performance of experiments and promote understanding of phenomena in the field of optics. In this study, the learning theme is set as "interference and diffraction of light waves." Holography is also learned as an applied technology, which can add future value to science learning. Thus, the two approaches described above can be implemented.

2 PREVIOUS RESEARCH

Nakano is developing "interference of light waves" learning materials using the AR (augmented reality) technology [4]. The contents were developed using Unity (a game engine provided by Unity Technologies), and AR functions were implemented by incorporating Vuforia, a library for AR development. The learning contents include "Principle of superposition of waves," "Young's experiment," and "Recording process of CGH (computer-generated hologram)." The images of learning "Young's experiment" and "Recording process of CGH" are presented in Fig. 1 and Fig. 2, respectively.

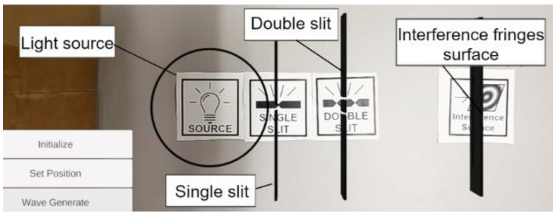

Fig. 1 Young's experiment.

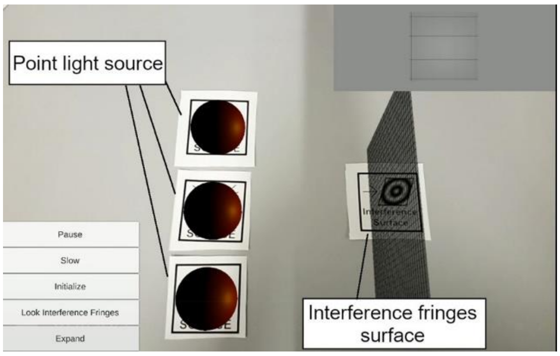

Fig. 2 Recording process of CGH.

The use of the AR technology in this learning material offers three advantages. First, the use of AR markers allows learners to learn interactively. For example, in Young's Experiment and Recording process of CGH, students can manipulate the propagation distance of light waves by moving the AR markers and intuitively experience how this affects the experimental results. Second, in the two aforementioned studies, the light waves can be visualized, enabling the learner to understand the interference of light waves more intuitively. Finally, there is no need to prepare any experimental apparatus, such as an optical system, in all of the studies. Thus, learning materials using the XR technology have advantages for learners.

3 PROPOSED SYSTEM

This chapter describes the proposed system, development environment, and external libraries used.

3.1 OVERVIEW

In this study, we develop a learning material for the "diffraction of light waves" using the VR (virtual reality) technology. This learning material allows students to observe the diffraction of light waves during the reproduction process of holography. A dedicated system for observing the reproduced holography images is also developed. In addition, an external library, WFL (Wave Field Library) [5], can be used to calculate diffracted light.

3.2 LEARNING MATERIALS

The content of this learning material is to learn the "Huygens-Fresnel principle" and "diffraction of light waves in the reproduction process of holography" in a virtual space. Learners wear a VR head-mounted display (HMD) to observe the reproduction process in a three-dimensional manner. The "Huygens-Fresnel principle" is represented by a semicircular object that imitates a wavelet and a linear object that constitutes a wavefront. The image is presented in Fig. 3.

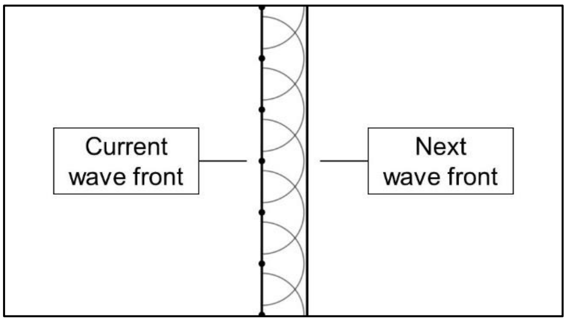

Fig. 3 Image of the "Huygens-Fresnel Principle" represented by objects.

This visualizes the diffraction of waves on a holographic surface. Finally, the point where the diffracted waves cross each other is determined to be the point of constructive interference, and a spherical object is placed to represent the point of high light intensity. The image is presented in Fig. 4. As a result, a reproduced image is created by the spherical object. The learner observes the retrieval of the reproduced image from a hologram recording a single light source.

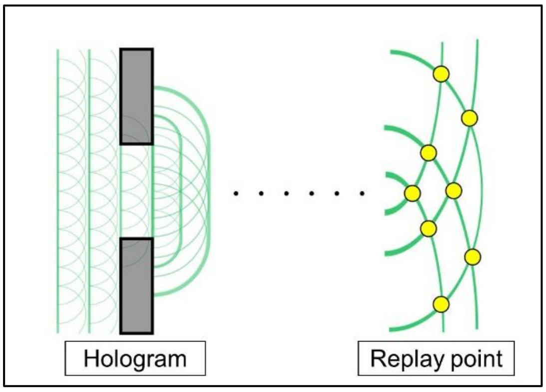

Fig. 4 Image of constructing a reproduced image from diffracted waves.

3.3 HOLOGRAPHIC REPRODUCTION IMAGE OBSERVATION SYSTEM

The diffracted light propagating in the normal direction from the hologram is calculated. The hologram plane is set as the 0-m point, and the spherical object is repeatedly placed at the point where the light intensity is higher than the threshold value on the plane at z' m. This constructs the reproduced image. The image is presented in Fig. 5.

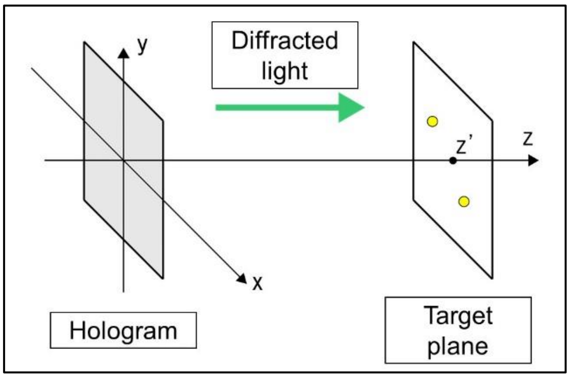

Fig. 5 Image of the construction of a reproduced image via diffraction calculation.

By clicking a button on the interface, the user observes the reproduced image while making one rotation at 45° intervals. This research uses a hologram that records a single light source and a hologram that records 284 light sources that form a cube.

3.4 DEVELOPMENT ENVIRONMENT

The contents in the virtual space are created by Unity. HTC Vive, jointly developed by Valve and HTC, is used for VR HMD.

3.5 WAVE FIELD LIBRARY

WFL, an external library, is used for diffraction calculations in the system described in Section 3.3. WFL is a C++ library for wave optics calculations published by the Optical Information Systems Laboratory, Faculty of Engineering Science, Kansai University, and Kyoji Matsushima. Because the coding environment of Unity is C#, WFL is built as a DLL (dynamic link library) for C# using Visual Studio 2019.

4 DEVELOPMENT RESULT

This chapter describes the results of the actual development of the proposed system.

4.1 LEARNING MATERIALS

We developed a learning material for "diffraction of light waves" using the VR technology. The learning process involves reading a text while observing each phenomenon. The learning progresses by clicking buttons on the interface using an HTC Vive controller. Figure 6 demonstrates how the "Huygens-Fresnel principle" is studied. The object represents how a spherical wave forms the next wavefront.

Next, Fig. 7 demonstrates how the diffraction of light waves is observed. A reference beam is irradiated onto the hologram and observed from the side.

Finally, Fig. 8 demonstrates the observation of a single light source reproduced. By clicking the button, the user can rotate 45 degrees°.

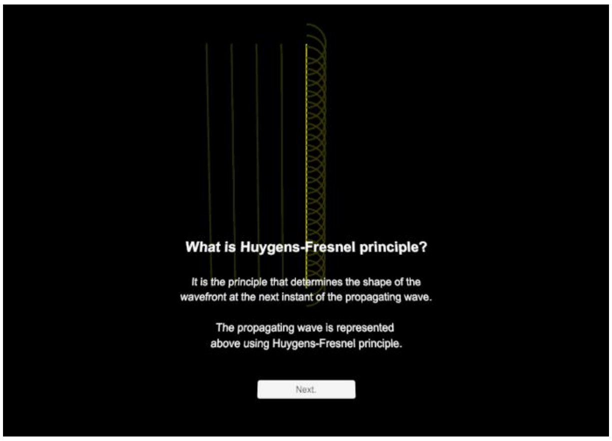

Fig. 6 Learning the Huygens-Fresnel Principle.

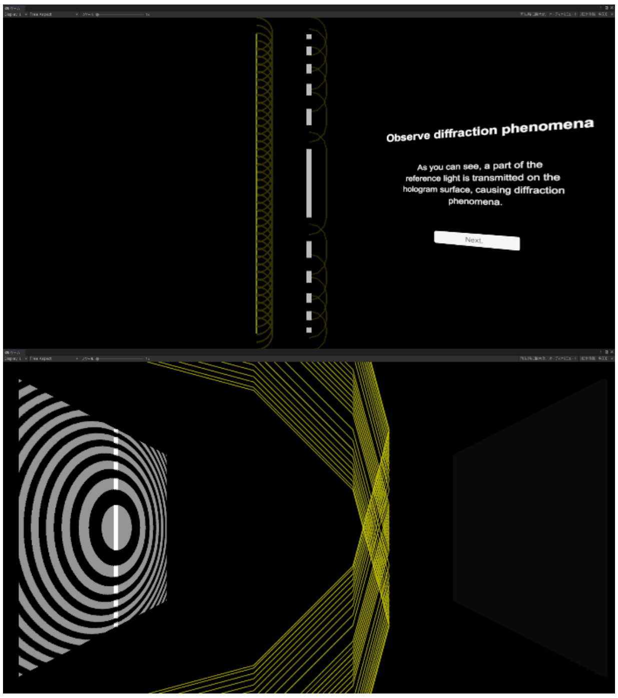

Fig. 7 Observing the diffraction of light waves.

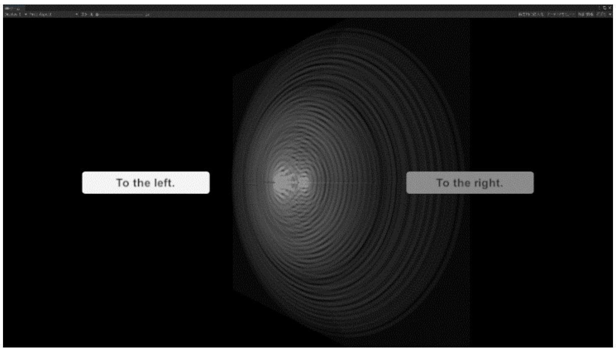

Fig. 8 Observing a single light source reproduced.

4.2 HOLOGRAPHIC REPRODUCTION IMAGE OBSERVATION SYSTEM

A system dedicated to observing reproduced holographic images using the VR technology has been developed. Figure 9 demonstrates how the reproduced cube is observed.

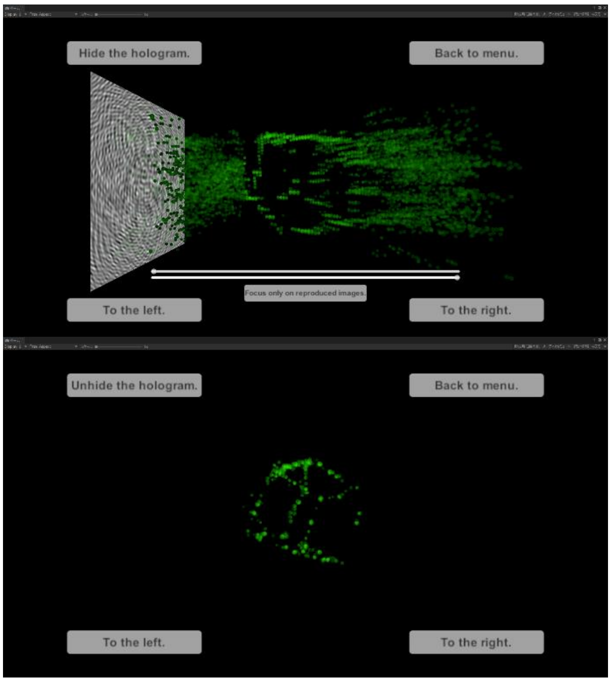

Fig. 9 Observing a reproduced cube.

5 DISCUSSION

The following two approaches were identified as countermeasures against the "shift away from science":

① Adding future value to science learning.

② Facilitating understanding by promoting learning through experimentation

For ①, we propose that this material will be useful. Taking advantage of the VR space, we attempted to demonstrate the relationship between "interference and diffraction of light waves," which students learn in the curriculum, and "holography," an applied technology. When the learning material is executed, the diffracted waves generated on the hologram surface can be observed in a three-dimensional manner as they construct the reproduced image through the VR HMD. This should allow users to intuitively understand how the diffraction of light waves is used in holography technology. This shows that scientific phenomena learned in the curriculum are used in future 3D display technology, and students should be able to recognize the future value of learning science. As for ②, because the VR technology provides a virtual experimental environment, this material should provide students with a new understanding aid. Specifically, this material allows students to easily observe the diffraction of light waves, which should contribute to their understanding. However, from the viewpoint of learning through experiments, it lacks interactivity, such as changes in experimental results by changing the wavelength or slit width. Therefore, in the future, it will be necessary to add more functions to improve students' understanding.

6 CONCLUSIONS AND FUTURE WORK

The final objective of this study is to confirm the effectiveness of learning materials using the VR technology in solving the "shift away from science" problem of students in Japan. We have narrowed down the causes of the "shift away from science" to two points and developed learning materials in the field of optics using VR as an approach to this problem. The content of the learning is "diffraction of light waves," and its relationship to "holography" is also learned. To convey the future value of holography, a dedicated system for observing reproduced images was also developed simultaneously, with specifications that enable the observation of three-dimensional reproduced images using VR. Because this material was developed as a countermeasure against the "shift away from science" among Japanese students, it is essential that students who study science use it and evaluate it in the future. The perspectives of evaluation include "whether or not learning is effective," "whether or not learning motivation is improved," "whether or not students feel that science learning has future value," and "usability of the learning materials". We will conduct a questionnaire survey to confirm the usefulness of the learning materials and, if necessary, improve them.

ACKNOWLEDGEMENT

This work was supported by IAAR Research Support Program, Chiba University, Japan.

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