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Understanding the Effect of Input devices for Virtual Magnet Laboratory in Science Education for Third Grade Elementary Students

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ABSTRACT

Due to COVID-19, a number of students are excluded from receiving proper education. Classes that require certain environments for the most effective learning, such as science courses, received the biggest impact since students were not able to learn through conducting experiments. We introduce a virtual reality-based system to resolve this problem, which is the replica of the traditional science lab but without requiring any real-life equipment. We specified the experiment to a third grade elementary school magnetism related experiment, as this is the first lab-based science curriculum students encounter in South Korea. Our system was designed to be compatible with three input devices (a keyboard, a hand-held controller, and a device that detects bare hand gestures) that vary in its immersion and usability, since it can affect one's learning performance differently. Through conducting a user study, we evaluated the system's potential in its usefulness and effectiveness in teaching students the basic magnetism properties, and distinguished the most compatible input device in conducting science experiments with the system. This revealed that even though the keyboard showed the best usability, the device that detects bare hand gestures was chosen to be the most compatible.

Keywords: Elementary physics experiment, virtual laboratory, magnetism, input device

I. Introduction

Throughout the recent years, the COVID-19 pandemic impacted the field of education significantly. A number of countries went through quarantine for a long period of time, excluding students from attending schools and receiving proper education. The duration of time for students to study at schools and be educated diminished, interfering with their academic performance in a negative way [1]. This is particularly a great problem with science education, because conducting experiments has been proven to be an effective learning method for students in studying science [2]. While many students are forced to turn to e-learning courses as an alternative way of attending school, regular e-learning courses are unable to instruct proper skills and knowledge needed for laboratory experiments [3]. In contrast, virtual labs are just as effective as real-life labs in instructing the suitable skills for students, and has an additional advantage of being more accessible [4].

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We introduce a virtual science lab for magnet experiments for 3rd grade students in elementary schools to conduct science experiments without needing real-life lab equipment in a remote environment. We designed the system to work with three different types of input (1) a typical QWERTY keyboard (2) a handheld controller (i.e., Vive Pro Eye Controller) (3) a device that detects bare hand mid-air gestures (i.e., Leap Motion), because various input devices influence the users' immersion and experiences in a different way and it is important to select the appropriate device [5]. To demonstrate each input device's usefulness and suitability, we designed three experiment scenarios that can evaluate such criteria. We recruited 6 participants and conducted a user study, where they were introduced to the three input devices randomly. We conducted a short interview after the participants finished the three scenarios with an input device. After they finished the scenarios with all three input devices, we conducted an additional interview to evaluate the input devices, scenarios and the usefulness of virtual lab applying to science education. The study reveals the potential of our virtual science lab and which input device is the most suitable in using the system.

II. Related Work

2.a Science Education Platform for VR and AR

Many studies focused on creating a reproduction of a traditional science lab through virtual-reality. For instance, Yair et al. [6] introduced a 3D dynamic solar system model based on virtual reality, which uses powerful scientific visualization techniques, to be utilized as an effective learning aid for instructors in teaching astronomy to primary and secondary school students. Similarly, Aoki et al. [7] agreed that virtual reality (VR) and augmented reality (AR) has become an important tool in education and created VR and AR-based learning aids for middle school science education in each grade. Furthermore, Weng et al. [8] applied AR to biology education by introducing an AR system, which allows students to learn the process of meiosis and cell respiration through individualized interaction and social communication.

Multiple research investigated the effect of VR when used for educational purposes. As an example, Pyatt et al. [9] analyzed the difference in students' attitudes when conducting experiments in physical and virtual science labs and distinguished that the virtual lab showed better equipment usability and a higher degree of open-endedness than the physical lab. Moreover, Park et al. [10] designed a VR-based system, which visualized the magnetic fields in 3D, to be applied in elementary school science experiments and concluded that utilizing the system enhanced students' ability to present the magnetic fields significantly. As such, much prior research revealed the effectiveness of VR in enhancing students' understanding and showing better academic performances.

Furthermore, several research utilized VR and AR to improve the visualization effects, to support students' clear understanding of certain concepts. As an example, Matsutomo et al. [11] presented an AR-based visualization system for education, which visibly depicts the magnetic fields of both a single magnet and the line currents. Additionally, Mannuβ et al. [12] introduced a learning aid AR system that tracks and calculates the magnetic field of a real-life magnet in real-time, while visualizing its magnetic lines.

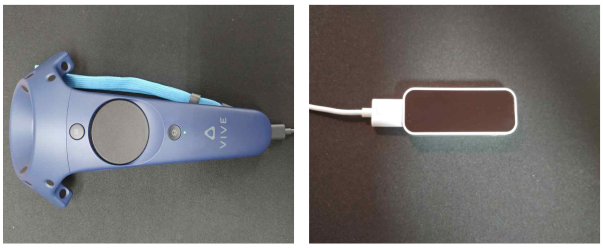
2.b Application of VR/AR in Science Classrooms

Much research has been conducted to identify what effect VR and AR systems have when used in real-life classrooms. Cai et al. [13] combined AR and motion-sensing technique to allow students' natural interactions in learning magnetic fields and explored its effect by comparing students' attitudes and test scores between the experimental and the control group, which revealed that the AR-based motion-sensing system improved students' learning attitude and academic performance. Similarly, Fidan et al. [14] presented an AR-based education platform called FenAR that supports Problem Based Learning (PBL) activities in classrooms and utilized a quasi-experimental design with two experimental groups and a control group, and concluded that combining AR with PBL activities both increased students' learning achievements and encouraged their positive attitude towards physics. Aoki et al. [15] developed an AR teaching aid, that visualized the magnetic lines in 3D using conventional tablet PCs, and investigated the difference in students' explanation of the principle of electromagnetic induction before and after using the teaching aid. The results revealed that the number of students who were able to provide a scientific explanation about the concept significantly increased after using the teaching aid and demonstrated the usefulness of AR in science education. Furthermore, Chenrai et al. [16] applied VR technology in a geoscience classroom to allow students to experience the processes of Earth in an immersive environment, and identified that the students' learning gain increased significantly after using the VR teaching aid. Similarly, Liou et al. [17] presented a virtual reality classroom and evaluated its effectiveness by examining the difference in students' learning achievements and learning motivation between the experimental group and the control group, which revealed that the experimental group showed significantly better learning motivation and achievements, effectively demonstrating the positive impacts of virtual reality application in education.

Ⅲ. Virtual Magnet Lab System

3.a Implementation

The virtual magnet lab was developed and using Unity Game Engine 2020.3.7.f1 running on Desktop PC with an Intel Xeon Bronze 3106 CPU, 64.0GB RAM and NVIDIA Quadro P40000. We used a computer keyboard, Vive Pro Eye Controller (Fig. 1a) and Leap Motion (Fig. 1b) as input devices and a computer monitor as an output device. The magnet assets in the system was downloaded from the Unity assets store. There are three magnet experiment scenarios to conduct with all three devices. The virtual magnet bar has the real magnet bar properties, for example, attracting magnetic objects. Moreover, the magnet's movement is limited to move on the two-dimensional surface.



(a) (b)

Fig. 1 (a) Vive Pro Eye Controller, (b) Leap Motion

3.b Experiment Scenario

We designed three experiment scenarios based on elementary science curriculum in South Korea. Fig 2 shows the overview of three scenarios.

1) Scenario 1

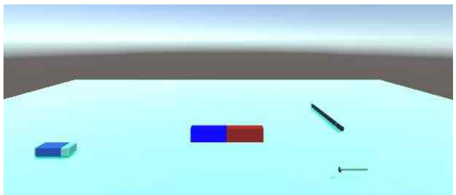
The aim of this scenario(Fig. 2a) is to identify the magnetic objects in real life. Various objects are put in the plane and the users are asked to move the magnet to find out which objects are attracted and stick to the magnet. The types of objects are different depending on the input devices. For magnetic object example, there were a nail, a steel can and a fire extinguisher at keyboard, controller and Leap Motion version respectively.

2) Scenario 2

The goal of this scenario(Fig. 2b) is to learn the relationship between the mass of the magnetic object and the magnetic force. A ball having magnetic property and the magnet are placed in a row while the ball is on the left side and the magnet is on the right side. The participants are instructed to move the magnet to the left slowly and observe when the ball starts to move. This scenario is repeated twice with different ball mass and after finishing, the participants are required to find out which ball is heavier. The answer is the heavy ball starts to move when the magnet bar comes closer than the light ball.

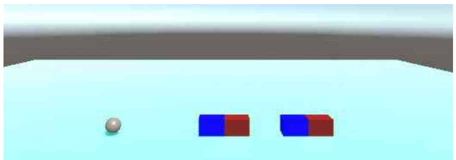
3) Scenario 3

The purpose of this scenario(Fig. 2c) is to learn the relationship between the number of magnets and the magnetic force. This scenario is similar to Scenario 2, however, the difference is an extra magnet on the right side. When starting the scenario, the participants are instructed to wait for 5 seconds and observe the ball movement. After that, they move the extra magnet and connect two magnets, then compare the magnetic force between two cases. The answer is connected two magnets have bigger strength.



(a) Scenario 1

(b) Scenario 2

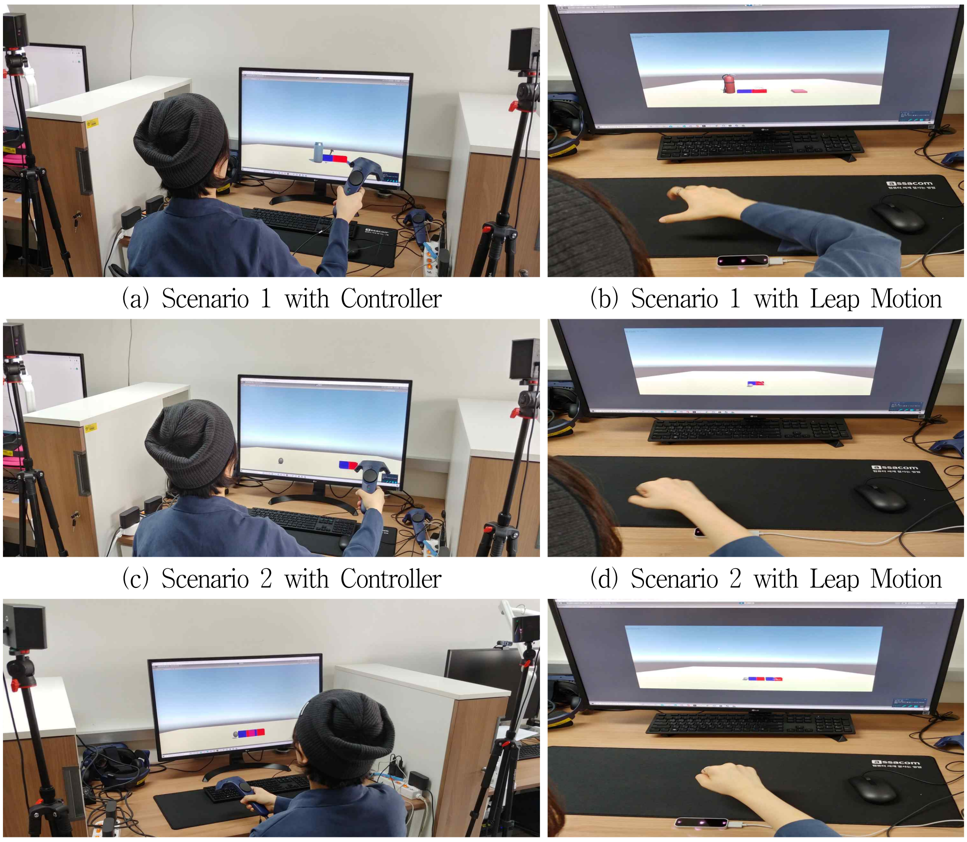


(c) Scenario 3

Fig. 2 Experiment Scenario

3.c Apparatus

The primary objective of the main study is to evaluate the system's potential in helping students understand magnetism related concepts and achieve proper laboratory



(a) Scenario 1 with Controller (b) Scenario 1 with Leap Motion

(c) Scenario 2 with Controller (d) Scenario 2 with Leap Motion

(e) Scenario 3 with Controller (f) Scenario 3 with Leap Motion

Fig. 3 Implementing each scenario with Vive Pro Eye Controller and Leap Motion

experiment skills and knowledge. We also aim to identify which input device is the most suitable for users to conduct science experiments in virtual reality. The implementation with Vive Pro Eye Controller and Leap Motion can be found in Fig. 3.

1) Computer Keyboard

Used a standard QWERTY keyboard of a desktop computer. The participants moved the magnets using the up, down, left and right arrow keys which make the magnets move in the direction of front, back, left and right.

2) Vive Pro Eye Controller

Used only the one controller of a virtual reality device, Vive Pro Eye. The controller model is on the screen and the magnet bar is connected to it. The participants were to move the controller to move the magnet and limited any other interactions such as pushing the controller's button.

3) Leap Motion

Used a device, created by Ultraleap, that tracks and captures bare hand movements and gestures. The participants could see their hand model on the screen which copies the hand movement and gesture. They could either hold or let go of the magnet by clenching their fists or opening their hands and could also move the magnet by moving their hands around while holding it. We limited the participants to only using their right-hands.

Ⅳ. Main Study

4.a Participants

We conducted the main study with 6 participants(all females), and their average age was 23.67. The purpose of this study is identifying the potential of system focusing on learning effectiveness in educating science, we recruited only adults.

4.b Procedure

We explained the purpose of this study and asked the participants to sign the consent form. Then, we described the overall process and the devices they will use. The three input devices, a keyboard, right-hand side controller of Vive Pro Eye, and Leap Motion were presented to the participants randomly. After having a short lesson about using the first type of device, the participants had time to practice it. Then, we explained how to perform each scenario and made them conduct it. There were short quizzes between the scenarios. For example, which objects have magnetic property, which ball is heavier and which case has stronger force. After finishing all scenarios with the first device, they had a short interview about the device. The second and the third device were performed in the same process. When finishing three scenarios with all devices, they were asked their opinions about device preference, most appropriate device in virtual science laboratory, the suitability of scenarios for learning objectives and whether virtual science experiment could assist science education or not. The entire process took 30 minutes.

V. Finding

5.a A computer keyboard received the highest usability score.

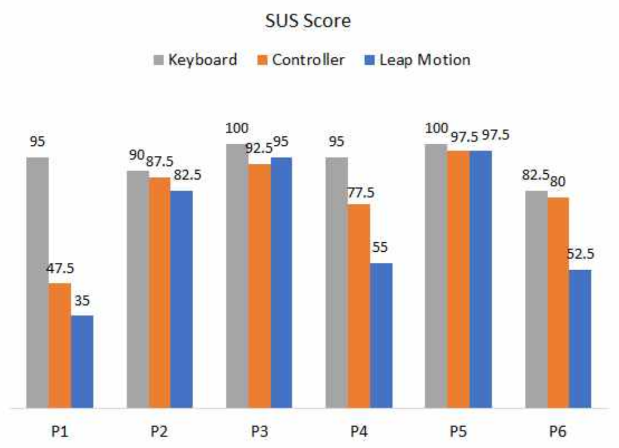


Fig. 4 SUS Score of each device

We measured each input device's usability by asking the participants to answer the System Usability Scale (SUS) Questionnaire. As shown in Fig. 4, the participants chose the keyboard as the most usable device, by giving the score of 93.75. The Vive Pro Eye Controller and the Leap Motion device received a score of 80.42 and 69.58. The participants claimed that the keyboard was the easiest in learning how to use when performing the experiment scenarios and preferred it the most due to already being familiar and only requiring simple interactions. On the other hand, the participants perceived the Vive Pro Eye Controller to be too difficult to learn and preferred it the least. Several participants (P1, 3, 4) mentioned that the controller caused them to perform bigger movements than they expected in order to move the magnet, causing fatigue.

5.b Leap Motion was the most realistic and provided the best immersion

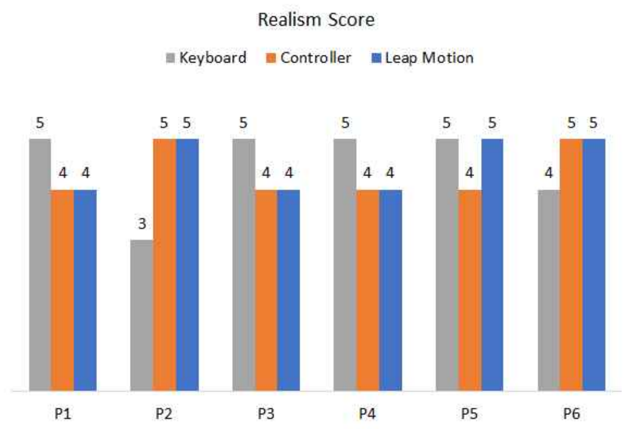


Fig. 5 Realism Score of each device

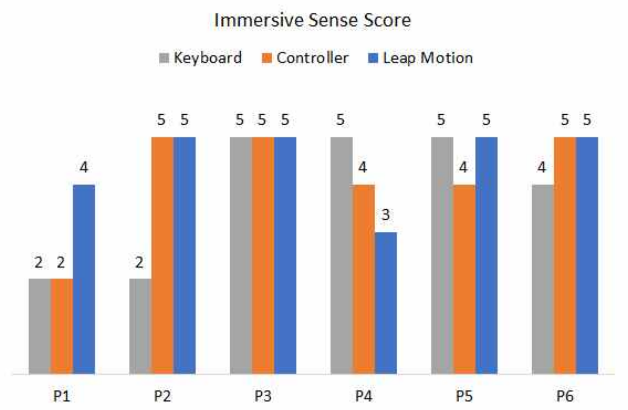


Fig. 6 Immersive Sense Score of each device

To identify which input device provided the best realism and immersion, we first had the participants evaluate each input device's ability to provide realism on a 5-point Likert scale. As a result, as depicted in Fig. 5, the participants chose the keyboard and the Leap Motion to have the best realism with a score of 4.50. In particular, P5 mentioned :

"The Leap Motion device allows me to interact with the magnet as if in real life."

We also had the participants measure how immersive each input device is on a 5-point Likert scale and the result is shown in Fig. 6. They answered that the Leap Motion provided the best immersion and gave a score of 4.50, while the keyboard provided the least immersion and gave a score of 3.83.

5.c Leap Motion is chosen as the most suitable to use

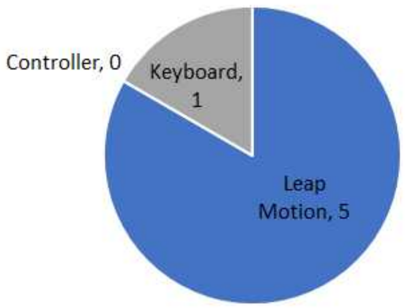


Fig. 7 The number of votes for the most suitable device (N=6)

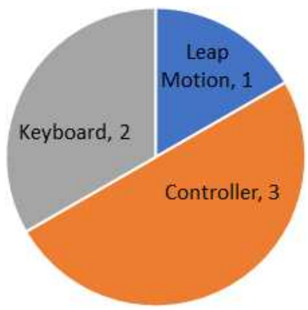


Fig. 8 The number of votes for the least suitable device (N=6)

To evaluate the compatibility of each input device with the virtual science lab system, we asked the participants which input device they found it the most appropriate to use to conduct virtual science experiments. In consequence, the majority of the participants (all but P4) chose the Leap Motion device as the most suitable since it provides the best realism and immersion. In contrast, the Vive Pro Eye Controller was chosen to be the least suitable. Half of the participants (P1, 3, 4) reasoned that it is too difficult to use and is unrealistic compared to the other input devices. For more specific details of the result, please refer to Fig. 7 and Fig. 8.

5.d Experiment scenarios are suitable for their learning objectives

We measured each experiment scenarios' suitability in each learning objective by asking participant to give a score in a 5-point Likert scale. As a result, Scenario 1, 2, 3 got scores of 4.83, 4.5, 4.83 respectively.

In case of Scenario 1, they commonly answered the reason that they easily classified which objects had magnetic property by approaching the magnet bar. P4 mentioned :

"The difference among the magnetic objects and non-magnetic objects was clear and it was appropriate to set those object as real life ones"

Scenario 2 got the worse score among three. The participants were able to check the magnetic force range by discovering when the ball starts to move. However, some participants (P2, 4) mentioned that comparing the mass of ball was difficult. P2 commented :

"It would have been better if there was a grid pattern to check the relative distance"

Scenario 3 got the good score because there was visible difference between one magnet and two magnets. The all participants claimed that it was easy to compare the difference of magnetic force by observing the ball movement and infer the relationship between the number of the magnet bar and the magnetic force.

5.e Virtual science lab can help science classes

We asked the participants to rate on a 5-point Likert scale whether virtual science lab would be helpful for science class. Several participants(P1, 2, 3, 4) gave the 5 score. They mentioned the virtual lab is more accessible than the traditional one and with proper devices, virtual environment would be very similar to the real one. P4 commented :

"The virtual lab was good to conduct the simple science experiments and understand the concepts. It is not that different from the real lab and I hope to conduct other experiments"

On the other hand, some participants(P5, 6) claimed virtual labs could not replace real labs. P6 mentioned :

"I agree to the virtual lab has good accessibility but in my opinion, conducting experiments in the real environment is the best"

Ⅵ. Discussion

6.a The difference between the most usable device and the most suitable device

Keyboard was regarded as the most usable device because it has been used for a long time and is already familiar to the participants. However, it was not chosen as the most suitable device in virtual science experiment. Although Leap Motion was considered as the least usable device due to its unfamiliarity, it was chosen as the most suitable device. The reason of this result came from how to move the magnet bar. In the case of the keyboard, the participants must press the keypads on the keyboard, as it does not support direct manipulation of the magnet bar. On the other hand, the participants can grab and move the magnet bar while holding it with Leap Motion. This intuitive way in moving the object affected the realism and immersion. These factors played a key role in choosing the suitable device because the results of realism, immersion and suitability are similar. This means that the participants considered the realism and immersion more important than usability when choosing the most suitable device.

6.b The low score of the widely used VR device

Even though Vive Pro Eye is one of the widely used VR devices, the participants perceived Vive Pro Eye Controller as the least suitable device and providing the least realism. We expected Vive Pro Eye Controller might get the high preference and suitability but the result was opposite. It is originally used with Head Mounted Display(HMD) of Vive Pro Eye. In this study, we used the computer monitor as the output device, and this could affect the result of it. If the HMD is used as the output device, the result could be changed.

6.c The significance of conducting science experiments in virtual reality

Conducting science experiment in VR environment has many advantages. First, it is more accessible than the traditional laboratory. Due to COVID-19 pandemic, it is hard to learn science through experiments. Virtual lab is one of the solutions of this problem because students are able to participate the lab class at home. The safety which is very important in lab classes is a benefit. There are lots of dangerous but essential experiments in the science curriculums. In VR environment, those are less dangerous because of not using real harmful chemicals and the lack of accidents such as explosion. The possibility of various environments is also a strength. One example is the weightlessness environment which is almost impossible in the normal classes. In this study, we presented the only basic magnet experiments. However based on these advantages and our result, it is able to develop more advanced experiments and this would be the future work.

Ⅶ. Limitation

First, this system is designed for third grade students but we conducted the study with adults. The participants already know the concepts about magnet so it is hard to investigate they can learn from this experiment. Second, in the current state, the computer monitor was used as the output device. This could affect the result of Vive Pro Eye which is developed to use with HMD. Moreover, this system was presented only for right-handed and there was some recognition problems when using Leap Motion.

Ⅷ. Conclusion

We developed a virtual laboratory system with magnet experiments based on elementary third grade science curriculum and investigated this system could help students effectively in science classes focusing on the effect of input devices. It has three experiment scenarios related with basic magnet concepts and these are able to be conducted with three input devices. Through user studies, the participants considered the keyboard as the most usable device and Leap Motion as the most suitable for the system. In addition, they agreed conducting science experiment in virtual reality helps students to learn science.

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