

Design Principles and Production of HMD-Applied Virtual Science Laboratory for High School Students

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This study has shown the potential of Virtual Science Laboratories (VSL) to improve students' conceptual mastery, creative thinking, scientific problem-solving skills, and Information Communication Technology skills. VSL offers many advantages over traditional laboratory setups, such as reducing time constraints, improving the quality of experiments, and increasing efficiency of learning. However, VSLs also have limitations, such as the need for an internet connection and the lack of real-world experience. To address these limitations, this study aimed to develop and evaluate a Head-Mounted Display (HMD)-based VSL for teaching the neutralization reaction of acids and bases in chemistry to high school students. The study used the ADDIE model for the design and development process, with the VSL developed using Unity and Oculus Quest 2. The HMD-based VSL was structured around a six-stage learning process, including stimulation, problem statement, data collection, data processing, verification, and generalization. The study also examined the advantages and disadvantages of using HMD VR technology in education and learning, highlighting the potential for increased motivation, effective communication and evaluation, and better understanding of complex phenomena with visualization and repetition training. However, HMD-based VSL can also lead to physical reactions such as dizziness or 'cybersickness.' Therefore, careful consideration is needed when using HMD VR technology in education. Overall, this study provides valuable insights into the design and development of VSL and the use of HMD VR technology in education. It highlights the need for well-established learning theories and rigorous educational design to support effective learning experiences and enhance students' scientific capabilities. The developed VSL for the neutralization reaction of acids and bases provides a safe and realistic experimental environment for high school students, expanding their learning experiences with specific manipulation experiences.

Keywords: Virtual Science Laboratory, VSL, HMD, ADDIE model, Chemical Education

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1. Necessity and purpose of the study

In the past, the practice of conducting experiments in the laboratory had a very high educational value, but it was necessary to consider complex matters concerning cost issues, space, instructors, schedules, and safety (Bretz, 2019). From this point of view, various online tools such as several e-learning platforms have been used as alternatives to lab experiments, among which Virtual Science Laboratory (VSL) cannot completely replace lab experiments in class, but their value is increasing as a complementary educational tool (Chan et al., 2021).

VSL, a computer simulation learning environment that can be leveraged from a simple 2D visualization of laboratory experiments, low immersion VR based on a computer display to a level that replicates real-world laboratory environments, has long been developed (Jones, 2018; Kim et al., 2019; Reeves & Crippen, 2021). VSL may have advantages such as economics, accessibility, safety, and flexibility, but may have less presence and interaction (Ali & Ullah, 2020; Faulconer & Gruss, 2018; Lynch & Ghergulescu, 2017; Trijayanti et al., 2021).

VSLs are expected to continue to develop, but designing and developing these complex virtual learning environments is challenging. Expertise is required for an effective learning experience (Mikropoulos & Natsis, 2011), and well-established learning theories and rigorous educational design should reduce the disruption of cognitive learning processes (Makransky et al., 2019).

The purpose of this study is to identify the necessary components and improvements in the HMD-based VSL developed for the purpose of common science (chemistry) for high school students in Korea to reveal educational usability. If this study can increase the understanding of the virtual science laboratory's educational experience and understand whether it is helpful for learners, it will be beneficial for both the students and the VSL development process in the future. Therefore, the purpose of this study is to explore the components and improvements necessary for VSLs for high school students.

The research question is to find out what the components of the developed VSL are, what are the improvements, and what are the possibilities for use in the curriculum.

Virtual Science Laboratory

VSL is a method consisting of a structure in which you can experience real experiments using tools implemented virtually in the same structure as a real laboratory (Babaie, 2017; Chan et al., 2021). Through this virtual laboratory, you can understand the process or procedure that takes place in the actual laboratory. You will also be able to learn how to use the equipment in practice.

The advantages of virtual laboratories are that they can improve the students' conceptual mastery, improve creative thinking and scientific problem-solving skills, and develop Information Communication Technology skills without neglecting laboratory knowledge.

The following are the advantages of a VSL:

1. Reduces time constraints if there is not enough time to teach all students in the laboratory until all students understand.
2. Helpful if there are students who live far away from school regardless of the geographical boundaries.
3. Economical and does not require laboratory buildings, vehicles, and materials as traditional laboratories do.
4. Improves the quality of the experiment because it allows repetition of the experiment and clarifies the uncertainty of laboratory measurements.
5. Improves the efficiency of learning because students frequently study in the laboratory.
6. Does not interact with real, dangerous tools and materials, ensuring security and safety (Ali & Ullah, 2020; Faulconer & Gruss, 2018; Trijayanti et al., 2021).

The weakness of VSL is that students need to connect to the Internet or use computers to simulate real laboratories, and because they lack experience in real laboratories, students are confused about assembling or manipulating tools in VSL and thus do not get the real experience (Lynch & Ghergulescu, 2017).

VSL has a long history and varies in usage from desktop display (PC) base to immersive VSL wearing HMD (Reeves & Crippen, 2021). Recently, it was reported that the effect would be high in terms of learning due to the issue of VSL, but there were rather opposite results. Jensen and Konradson (2018) reported the positive effects of immersion and realism on learning outcomes. It was found that learners using immersive HMD participated more, spent more time on learning tasks, and acquired cognitive, psychomotor, and emotional skills. However, the sense of presence may decrease according to the quality of graphics and the level of perception when used, and there may be differences in VR technology acquisition depending on the personality characteristics of the individual. Similarly, Makransky et al. (2019) discovered that wearing an HMD in VSLs increased presence but decreased learning effects due to cognitive load, as measured by EEG. Consequently, it is essential to investigate the conditions of immersive VSLs that can enhance learning effects.

Education in VR Learning

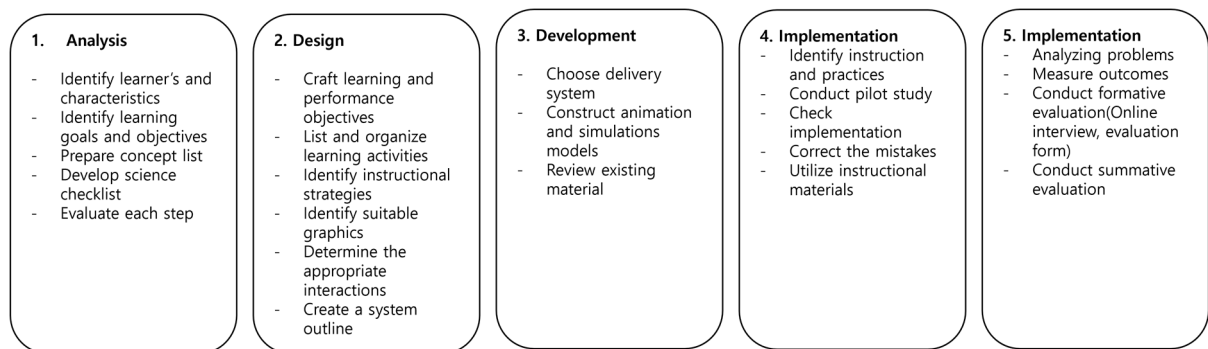
VR learning has several advantages in education. For example, in education, VR can provide experiences in a new context and can be utilized to provide risk-reduced education and realistic and immersive experiences (Jensen & Konradsen, 2018). Using VR in education or learning also has several advantages such as increased motivation, effective communication and evaluation, a better understanding of complex phenomena with visualization and repetition training, adaptability and flexibility, increased safety and health, reduced simulation environmental friendliness and resource consumption, reduced training preparation and execution time, and cost-effectiveness (Häfner et al., 2018). In particular, students experiencing immersive VR using HMD are more likely to learn using a controller to promote visual, auditory, and haptic functions simultaneously than through the provision of simple visual and auditory (Kwon, 2019). However, the HMD VR's effects are not always positive. Physical reactions such as dizziness (Oak, 2018) or 'cyber motion sickness' can be experienced as nausea and headaches due to sensory mismatches (Kawai & Häkkinen, 2018). Taken together, various considerations are needed for conducting education using HMD for K-12 students.

Method

1. Research Design

This study adopted the ANALYZING, DESIGNING, DEVELOPMENT, IMPLEMENTING, and EVALUATING (ADDIE) model to develop HMD-based VSL. The ADDIE model is an educational model widely used by many educators to develop educational and training programs (Spatioti et al., 2022). In particular, there are cases in which VSL was built using the actual ADDIE model (Manyilizu, 2022). Figure 1 is the basic step of the ADDIE model for the design and development of the learning process.

Figure 1. ADDIE model for design and development of the VSL (Manyilizu, 2002)



For development, the VSL development process was applied according to the ADDIE model used by Manyilizu (2022).

1. Analyzing

Analyze target groups and requirements

Identify topics for chemistry class

Identify chemical concepts and activities required for the experiment

Develop VSL objectives for the selected topic

2. Designing

Select and configure the appropriate hardware and software tools

Design an HMD-based VSL structure

Design an evaluation plan

Identify and design content types, formats, and delivery

Create a detailed HMD guidance overview

Determine the content and appropriate student interaction

3. Development

Develop based on HMD-based VSL structural design

Content development

System Development with Unity

Feedback from experts on selected topics

4. Implementing

On-site testing and evaluation

How-to workshops and infrastructure preparation for students and teachers

Deploy HMD-based VSL to selected schools

Receive feedback and correct mistakes

Test students' impact on chemistry topics

Experimental Treatment: Assess the Impact and Usefulness of HMD-Based VSL

5) Evaluating

Analyze system problems

Measure the results of an HMD-based VSL

Conduct formation and general assessment of systems and students

2. VSL Content Description

The main objective of this VSL development is to experience the same scientific functions as experiments through the experience of real-world manipulation in a similar environment to existing laboratory experiments (three-dimensional space implemented by Lidar photography) or in a Unity-based virtual laboratory. This VSL, where possible, aims to replace real-world experiments and enhance students' scientific capabilities by allowing them to learn safe and accurate procedures in the process of conducting experiments.

3. VSL Development purpose

The main objective of this VSL development is to experience the same scientific functions as experiments through the experience of real-world manipulation in a similar environment to existing laboratory experiments (three-dimensional space implemented by Lidar photography) or in a Unity-based virtual laboratory. This VSL, where possible, aims to replace real-world experiments and enhance students' scientific capabilities by allowing them to learn safe and accurate procedures in the process of conducting experiments.

Figure 2. VSL implemented through LIDAR



Figure 3. VSL implemented Unity Asset store



HMD-Based VSL Description

The developed content is a single content. The learning process consists of six main stages.

1. Stimulation: Provide a different volume of dilute hydrochloric acid and sodium hydroxide aqueous solution with the same temperature and concentration
2. Problem Statement: What will change when acids and bases react?
3. Data collection: Experiment under various conditions (temperature, indicator)

4. Data processing: Maximum temperature measurement, indicator change measurement
5. Verification (certification): Prepare a result table based on the experimental results
6. Generalization (Conclusion Derivation): It consists of a structure that derives the condition with the highest temperature of the mixed solution and the color change

Before entering the learning process, guidance on learning content is conducted.

1. When a student wears an HMD and drives the content, basic information about the class is presented.

The basic information presents the course name and description of the experiment.

The following is an explanation of the experiment.

- The neutralization reaction of acid and base can be confirmed by a color and temperature change of the indicator.

- You can manipulate the actual experimental tool and observe the color change of the indicator at the neutralization point.

- Learn safety rules for dangerous reagents to handle in the laboratory.

2. When you read the content and press the start button, a tutorial on the content and operation method is presented. It is the interaction of basic manipulation methods and experimental tools.

3. Subsequently, the method of use, experiments, and class goals are presented.

What this experiment shows: Neutralize the dilute hydrochloric acid with the same concentration as the temperature and volume of the aqueous sodium hydroxide solution, and measure the maximum temperature of the mixed solution.

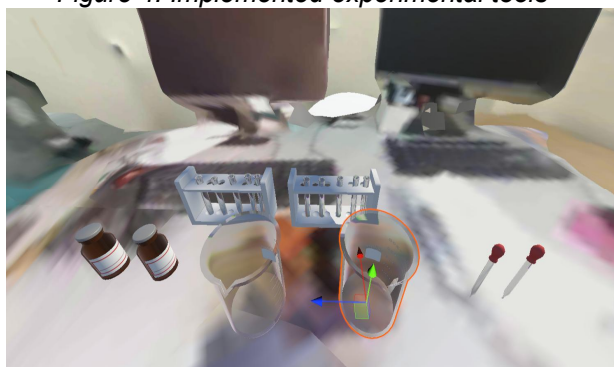
- You can find out the tools and usage required for the neutralization reaction experiment.
- It is possible to explain why the temperature due to the neutralization reaction is the highest in a mixed solution of a certain concentration.
- By observing the color change of the indicator, it is possible to know under what conditions the mixed solution is neutral.

4. Then, you will be guided on the experimental tools.

- Two beakers
- Sodium hydroxide (NaOH) reagent bottle: 30 ml
- Hydrochloric acid (HCL) reagent bottle: 30 ml

- BTB reagent bottle: 30ml
- 3 pipette
- 10 calibration tubes
- 2 test tube rack
- 1 thermometer

Figure 4. Implemented experimental tools



After the guidance of the experimental tools is completed, it is carried out as a full-fledged learning procedure.

1. Stimulation: Provide a different volume of dilute hydrochloric acid and aqueous sodium hydroxide solution with the same temperature and concentration. The table below is presented as experimental conditions and implemented on the same test tube pedestal inside the VSL.

Table 1. Experimental conditions

Test Tube Rack	A	B	C	D	E
Volume of hydrochloric acid (mL)	2	4	6	8	10
Volume of aqueous sodium hydroxide solution (mL)	10	8	6	4	2

2. Question statement: What will be the change when acids and bases react? The corresponding screen is presented as a pop-up.

- Under what conditions does controlling the concentration with a spade generate the most heat?
- Under what conditions does the color change of the BTB solution not occur when the concentration is adjusted with a Pipette?

3. For data collection, observe the color change by dropping the BTB solution on A~E in order. Next, measure the temperature of the mixed solution in A to E. As described above, the student directly manipulates the spade and thermometer through the controller and interacts with the virtual experimental tool.

4. Data processing is based on data collected

- Let A~E organize the liquid properties.
- Arrange the mixed solutions of A to E in the order of highest temperature.

5. For verification, organize the results of the experiment and fill them out in the summary table.

6. Generalization derivation explains what changes occur when acids and bases react to the experimental results based on the contents of the summary table. Currently, the HMD releases the wear.

- When the acid and base react in the same amount, each acid and base disappear, and the mixed solution becomes neutral. In addition, when the acid and the base react, heat is generated and the temperature of the mixed solution increases.

After that, the formation evaluation is conducted, and the learning is terminated.

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