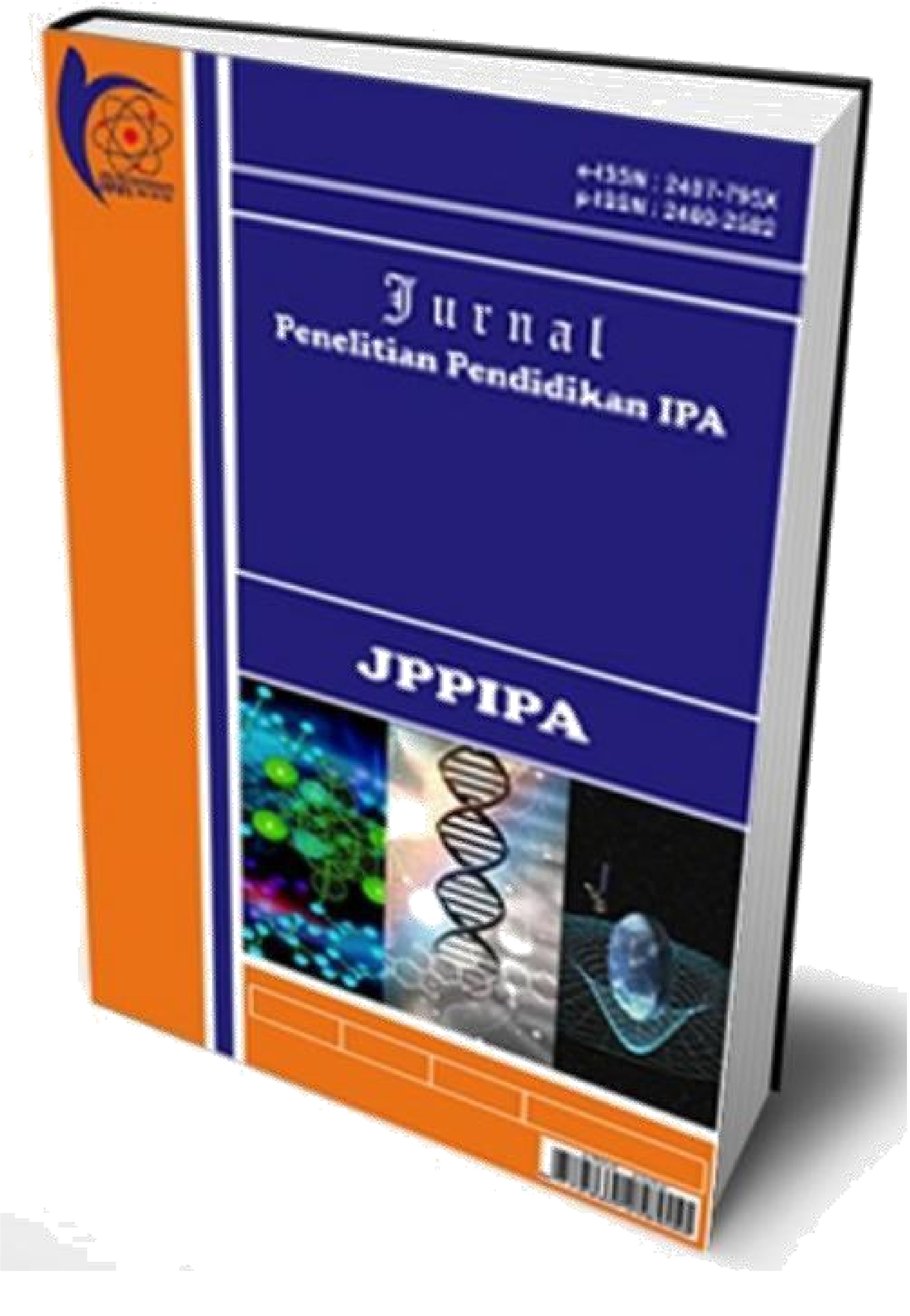
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Development of Virtual Reality Laboratory Integrated with Artificial Intelligence for Acid-Base Titration Practicum

Nova Irawati Simatupang[1*], Elferida Sormin[1], Leony Sanga Lamsari Purba[1], Nelius Harfa[1], Adi Nugroho[2]

[1] Chemistry Education Study Program, Faculty of Teacher Training and Education, Universitas Kristen Indonesia, Jakarta, Indonesia.
[2] School of Business and Economics, Universitas Prasetya Mulya, Jakarta, Indonesia.

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Corresponding Author:
Nova Irawati Simatupang
nova@uki.ac.id

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Abstract: The development of technology-based learning platforms and media has been widely carried out; however, most of efforts primarily focus on increasing student interest, while less attention is given to enhancing skills and scientific thinking processes. The purpose of this research was to develop a technology – based learning media, namely a Virtual Reality (VR) laboratory integrated with Artificial Intelligence (AI) to support students' scientific thinking skills and processes. The AI - integrated VR laboratory was specifically developed for the implementation of acid-base titration practicums. The research followed the ADDIE development model. During the implementation phase, the product was tested on 31 students from Chemistry Education Study Program at UKI, selected using a random sampling technique. Data collection, particularly for product evaluation, was conducted using a non-test instrument in the form of a Likert scale questionnaire. The instrument consisted of indicators of usefulness, efficiency, and interest which were share via Google Form link. Before being distributed to student, the instrument has been validated by an expert validator with a background in chemistry learning media. The results of the analysis indicated that the AI-integrated VR laboratory received positive response from students with a percentage level of 80.79% for the usefulness indicator, 77.06% for the efficiency indicator, and 79,45% for the interest indicator. Therefore, the result of the development of VR laboratory integrated with AI can be considered as a viable alternative learning media for conducting acid-base titration practicum.

Keywords: Acid-base titration; Artificial intelligence; Chemistry; Practicum; Virtual reality laboratory.

Introduction

The integration of technology into education has been progressively advancing, particularly following the widespread adoption of the online learning system during the COVID-19 pandemic. Technology-based learning platforms and media have been extensively developed to facilitate effective online instruction (Simatupang et al., 2020). The utilization of technology in learning media is considered to be able to provide convenience in learning activities, and promote the development students' critical thinking skills (Lestari et al., 2023; Puti et al., 2024).

The application of technology into science education, especially in the field of chemistry, has been consistently, as students are more likely to comprehend and apply scientific concepts effectively when the theoretical knowledge is accompanied by practical experiences. Nevertheless, current development in learning media and the integration of technology in chemistry learning activities have largely emphasized enhancing student engagement, student interest and the production of scientific outcomes, rather than fostering deeper conceptual understanding (Sasmitatias & Kuswanto, 2018).

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Chemistry, as a branch of the natural sciences, inherently requires practical laboratory activities to foster a deeper conceptual understanding. One fundamental area of chemistry that demands experimental validation is acid–base titration(Marzuki & Astuti, 2017). The implementation of laboratory practicums is considered both practical and effective when carried out to teach chemical concepts, particularly in the context of acid-base titration (Reny & Salempa, 2018). This supports the assertion that practical sessions are an integral part of chemistry education are an inseparable component of the learning process and play a crucial role in enabling students to achieve meaningful learning and gain firsthand experience in validating various chemical concepts (Tatli & Ayas, 2010; Widarti et al., 2022). In addition to enhancing students' comprehension of chemical principles, especially those related to acid–base titration, practicum activities help students become familiar and understand the various uses of practicum tools and materials available in the laboratory. Furthermore, beyond improving laboratory skills, practicum activities contribute significantly to the development of students scientific thinking process skills (Listyarini & Nur Pamenang, 2022).

In the implementation of practical laboratory activities at both schools and university levels, financial constraints are unavoidable because such activities incur significant costs. Facilitating laboratory practicums requires funding for facilities and infrastructure, including laboratory instruments and consumable materials, which are relatively expensive (Pradibta & Nurhasan, 2020). Consequently, there is a growing need for alternative learning media that provide cost-effective, safe, and flexible solutions. The development of virtual laboratories through technology innovation offers a promising alternative, especially given the rapid advancement of technology that significantly impacts education, particularly in science learning (Safiatuddin & Asnawi, 2023; Wulandari et al., 2021).

In several developing countries, conventional chemistry laboratories used for practical coursework have increasingly been replaced with virtual laboratories (Fung et al., 2019). Since 2016, the development of virtual laboratories has been implemented across various disciplines, including robotics, information technology, engineering, biology, physics, and chemistry. At the undergraduate level, several virtual laboratory initiatives have been developed to cover topics such as: Cation analysis through flame test, Determination of the mass fraction of fluoride ions in toothpaste, and measurement of sugar content in candy (Alkhaldi et al., 2016; Bortnik et al., 2017; Reeves & Crippen, 2021).

The integration of Virtual Reality (VR)–based laboratories in chemistry learning process has been shown to yield positive outcomes and greater flexibility, as they can be accessed anywhere and anytime. Moreover, the tools and materials in the VR laboratory room can be reused without additional cost (Balsam et al., 2019; Calvert, 2020). The necessity of developing VR laboratories for chemistry practical activities has also been positively received by students from public and private high schools in the Jakarta area (Purba, 2023; Simatupang et al., 2023).

In addition to the advancement of VR-based laboratories, virtual laboratories are also being developed with the integration of Artificial Intelligence (AI) to substitute the role of laboratory supervisors or assistants in the laboratory. Artificial Intelligence (AI) is a branch of computer science concerned with the creation of intelligent machines capable of performing tasks that that typically require human intelligence. AI represents a key technology in the era of the Industrial Revolution 4.0 era that is designed through modelling processes that emulate and, in some cases, replace human functions (Russell & Norvig, 2021; Supriadi et al., 2022). The integration of AI into virtual laboratory environments enables the development of more adaptive, effective, and efficient learning systems (Mondal, 2025; Rawat, 2024). The development of AI – integrated VR laboratories provides an alternative solution for conducting virtual practicums, particularly by enhancing student's conceptual understanding and engagement in science learning activities (Puspita, 2020; Rokhim et al., 2020).

The development of a Virtual Reality laboratory integrated with Artificial Intelligence (AI) is also expected to address the findings of Reeves and Crippen's systematic review, which recommended incorporating elements of social interaction in the form of guidance delivered by an AI laboratory assistant (Reeves & Crippen, 2021). Therefore, the development of VR laboratory integrated AI is anticipated to serve not only as a solution in situations where laboratory equipment is limited, and learning is often confined to observing procedures through demonstration videos. More importantly, this VR laboratory integrated AI developed for Acid-Base Titration is expected to assist students in practicing, enhancing their conceptual understanding, and improving their laboratory skills, particularly in the implementation of acid-base titration practicums.

Method

The research method employed as the framework for developing the VR laboratory integrated AI for the

Acid-Base Titration practicum was the ADDIE development model (Branch, 2019). According to Branch, the stages in this development research consist of five stages: Analysis, Design, Development, Implementation, and Evaluation. The stages undertaken in the development of this the VR laboratory integrated AI for the Acid-Base titration practicum are illustrated in Figure 1.

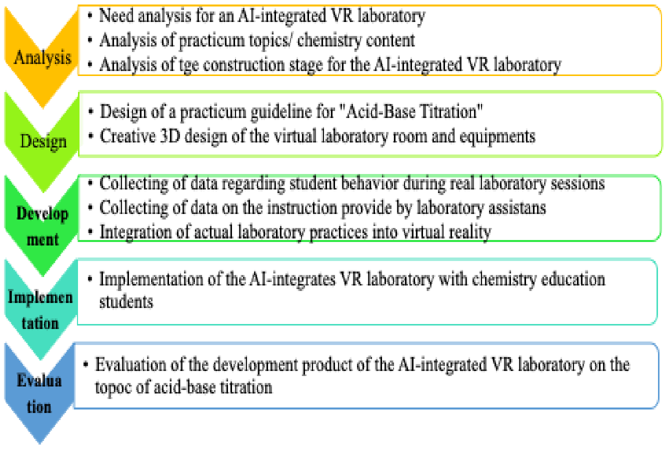

Figure 1. Development Stage of the AI-integrated VR Laboratory on the Topic of Acid-Base Titration

Chemistry Education Study Program at the Christian University of Indonesia. At the end of the implementation stage, a google form link was distributed to the students containing a non-test instrument used for the evaluation phase. The non-test instrument contains 12 statements covering three indicators: usefulness, efficiency, and interest in using the AI-integrated VR laboratory. The instrument was developed using positively worded statements on a five-point Likert scale, consisting of the following categories: (1) very dissatisfied, (2) dissatisfied, (3) somewhat satisfied, (4) satisfied, and (5) very satisfied (Sugiyono, 2015).

Result and Discussion

Analysis Stage

The analysis stage was carried out by analyzing students' perceptions regarding the need for a virtual laboratory for the implementation of chemistry practicum activities. The survey was distributed to 150 high school students from three public schools that already possessed conventional laboratory facilities. The results of the analysis indicated that students expressed a positive response toward the development of a VR laboratory for use in chemistry practicum activities (Simatupang et al., 2023).

Based on the results of the analysis, recommendations were made for the development of VR laboratories utilizing the Oculus Quest platform to enhance operational feasibility. The integration AI in the VR laboratory development process was limited to the implementation of virtual la laboratory assistants, whose primary role is to provide procedural instructions for conducting practicums to the participants. The topic of Acid-Base Titration was selected due to its relevance and applicability not only for high school and vocational school students but also at the university level,

Design Stage

In the second stage, the design process commenced with the preparation of a practical guide for Acid-Base Titration, entitled Determining Acetic Acid Levels in Apple Cider Vinegar. Still within the design stage, following the completion of the experimental guide, the development of the VR laboratory was initiated by creating 3D assets for (a) the laboratory environment, (b) laboratory equipment, and (c) the virtual laboratory assistant, as illustrated in Figure 2.

Figure 2. Creative 3D Design of the VR Laboratory Room and Equipment's

The 3D design of the laboratory space was modelled to replicate the actual layout of the chemistry laboratory at the Universitas Kristen Indonesia. This approach aimed to ensure that, when students use the Oculus Quest to access the virtual laboratory, they experience an immersive environment that closely resembles being in a real laboratory setting (Petrov & Atanasova, 2020).

Development Stage

In the third stage, the development process commenced by collecting data on the experimental activities for Determining Acetic Acid Levels in Apple Cider Vinegar in the real laboratory setting. In addition to collecting data for the practical activities, data were also collected on the actions of the virtual assistant when providing experimental instructions. This activity data was subsequently integrated into the AI-integrated VR laboratory environment, as illustrated in Figure 3.

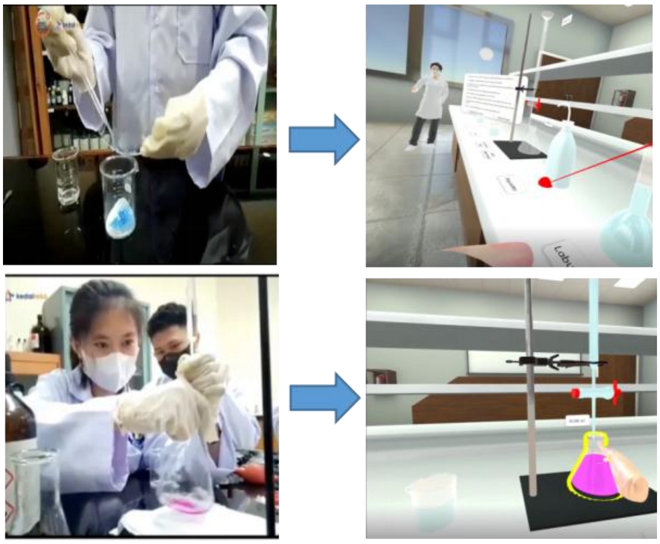

Figure 3. Integration of actual laboratory practices into VR

Several innovations were incorporated into the development of the AI-integrated VR laboratory for the Acid-Base Titration experiment, including:
(1) Prior to conducting the practicum, students (practitioners) are required to complete a pre-test as a prerequisite for accessing the laboratory space or practicum station;
(2) As part of the AI implementation, the VR laboratory includes a virtual assistant (a female laboratory assistant) equipped with audio instructions that convey the experimental procedure. The addition of audio is intended to enhance the sense of realism during practicum sessions conducted in the VR laboratory (Batubara, 2020);
(3) In addition to the audio instructions provided by the virtual assistant, the procedural steps are also displayed as pop-up texts. At the bottom of each pop-up, a component is included that allows users to repeat the procedure in case of any errors in the execution. These innovations were designed to enhance the flexibility and efficiency of chemistry practicum sessions conducted using the AI-integrated VR laboratory.

Implementation Stage

The implementation stage was conducted after the development process had been completed and the product had undergone validation. The validated components included: the suitability of the experiment with the Acid-Base Titration topic, the relevance of the questions used in the pre-test, the accuracy of the names and forms of laboratory equipment, and the availability of necessary materials for conducting the experiment. The implementation was carried out directly with 31 undergraduate students from the Chemistry Education Study Program at Universitas Kristen Indonesia, comprising students from four different cohorts, as shown in Figure 4.

Figure 4. Implementation of AI-integrated VR laboratory

In the final stage, following the implementation of the AI-integrated VR laboratory, a Google Form link containing 12 statements was distributed to the students

Evaluation Stage

The evaluation stage was conducted based on student's responses collected through a Google Form instrument. The questionnaire data were analyzed by calculating the percentage scores for the three indicators included in the instrument. These indicators focused on:
(1) **Usefulness** – assessing students' perceptions of the benefits of using an AI-integrated VR laboratory to conduct experiments on the Acid-Base Titration topic;
(2) **Efficiency** – evaluating whether students experienced ease or difficulty when using the AI-integrated VR laboratory with the aid of Oculus Quest 2;
(3) **Interest** – determining the extent to which students were interested in using the AI-integrated VR laboratory in future practicum activities.

Based on the data obtained from the 31 participants, it was found that 83.87% of the students had previously heard about the use of VR laboratories in chemistry learning. Furthermore, the analysis results indicated that students responded positively to the use of the AI-integrated VR laboratory, with a percentage score exceeding 70% for each indicator (Figure 5). The highest percentage was recorded for the usefulness indicator, reaching 80.97%. Although this percentage does not reach 90%, as reported in the development of a VR laboratory for the reaction rate topic (Rahmi et al., 2023). Overall, the AI-integrated VR laboratory developed in this research can be considered a viable alternative learning media for conducting chemistry practicum activities on the topic of Acid-Base Titration. This finding aligns with the primary objective of developing a virtual laboratory, namely to provide students with a learning media for students that enables risk-free exploration and the ability to independent perform practical activities (Bortnik et al., 2017).

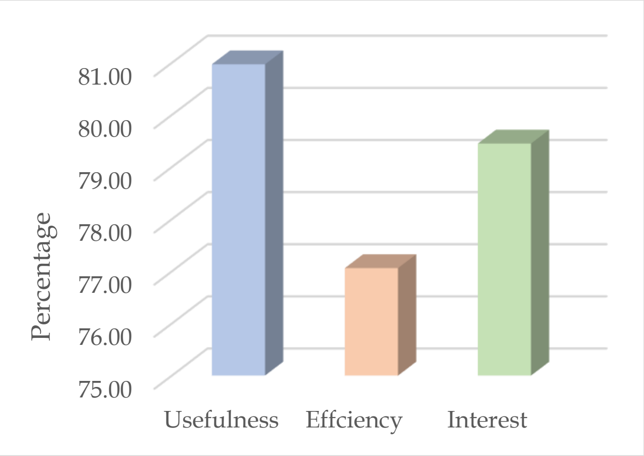

Figure 5. Percentage of student's perceptions on the use of AI-integrated VR laboratories for Acid-Base Titration practicums.

Students responses demonstrated high interest using the AI-integrated VR laboratory in practicum activities, with a percentage of 79.45%. This interest appears to stem from the VR laboratory's capacity to facilitate independent exploration without the procedural limitations often encountered in real laboratory setting (Alkhaldi et al., 2016). One of the most appealing features identified by students was the inclusion of an audio-based virtual assistant (laboratory assistant), which helped reduce the need to repeatedly consult the experimental manual.

The lowest percentage was observes for the efficiency indicator. Several first-semester students, who had never previously used the Oculus Quest, reports difficulties in entering the virtual laboratory room, and confusion regarding the delineation of their work area during experimental activities. This finding supports the observation by (Suherdi, 2019) that, in the initial stages of VR laboratory implementation, preliminary orientation regarding the basic use of the VR environment is essential due to its limited familiarity among student. Additionally, when interacting with certain equipment in the VR laboratory, students frequently dropped the tools. As a result, they recommended the integration of tactile feedback effect, even within the virtual setting, to enhance realism and improve user interaction.

Conclusion

The development of an AI-integrated VR laboratory for the acid-base titration practicum received a positive response from students with details of 80.97% for the usefulness indicator, 77.06% for the efficiency indicator, and 79.45% for the interest indicator. The innovation carried out by adding virtual assistant audio as a form of AI integration in the VR laboratory has enhanced students' interest in using the AI-integrated VR laboratory during practicum activities.

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Author Contributions

Conceptualization: N.I.S.; evaluation: E.S., N.I.S.; design: N.I.S., E.S., L.S.L.P., N.H., A.N.; development: A.N., N.I.S., E.S., L.S.L.P., N.H.; implementation: N.I.S., E.S., L.S.L.P; evaluation: E.S., L.S.L.P.; methodology: L.S.L.P.; validation: N.H.; formal analysis: N.I.S.; resources: E.S., N.H., A.N., data curation: N.I.S., L.S.L.P., writing-review and editing: NIS. All authors have read this article and agreed to the published version of the manuscript.

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Conflicts of Interest

In writing this article, we sincerely declare that no conflict of interest may affect the objectivity and integrity of the results

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