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Nama Penulis : **Nova Irawati Simatupang**, Elferida S., Leony SL Purba, Nelius H., Adi Nugroho

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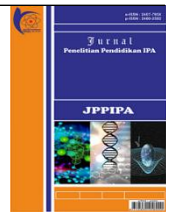

Development of Virtual Reality Laboratory Integrated with Artificial Intelligence for Acid-Base Titration Practicum

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Abstract: The development of technology-based learning platforms and media is widely carried out, but focuses more on efforts to increase interest, and still pays less attention to improving 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) so that it can still accommodate students scientific thinking skills and processes. The Ai integrated VR laboratory was specifically developed for the implementation of acid-base titration practicums. The research was conducted by following the ADDIE development model. The implementation stage was carried out on 31 Chemistry Education Study Program UKI student who were selected by random technique sampling. Data collection, especially on product evaluation, was carried out using a non-test instrument in the form of a Likert scale questionnaire. The instrument consisted of indicators of usefulness, efficiency, and interest which are 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 show that the AI-integrated VR laboratory that was develop received a positive response from students with a percentage level of 80.79% on the usefulness indicator, 77.06% on the

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efficiency indicator, and 79,45% on the interest indicator. So, the result of the development of VR laboratory integrated with AI can be an alternative that can be considered as a learning media for acid-base titration practicum.

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Keywords: Acid-base titration, artificial intelligence, chemistry, virtual reality laboratory, practicum.

Introduction

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

The application of technology in science learning, especially in the field of chemistry, is also something that continues to be done continuously, because students will be able to master and apply scientific concepts if the theory is accompanied by practical implementation. However, so far the development of learning media and the use of technology in chemistry learning activities have primarily focused on increasing student interest and the resulting scientific products (Sasmitatias & Kuswanto, 2018).

Chemistry, as a branch of the natural sciences, requires practical laboratory work to facilitate deeper understanding. One area of chemistry that necessitates experimental verification is acid—base titration (Astuti & Marzuki, 2017). The implementation of practicums is considered more practical and effective when carried out to teach chemical material, especially on the topic of acid-base titration (Reny, 2018). This underscores the assertion that practical sessions in 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, 2010; Widarti et al., 2021). In addition to facilitating students' comprehension of chemical principles, especially the concept of acid—base titration, practicum activities help students become familiar and understand the various uses of practicum tools and materials available in the laboratory. In addition to improving laboratory skills, practicum activities can also help students improve their thinking process skills (Listyarini & Pamenang, 2022).

In the implementation of practical laboratory activities at schools or universities, financial constraints are unavoidable because such activities incur significant costs. Facilitating laboratory practicums requires funding for facilities and infrastructure, including laboratory equipment and consumables, which are relatively expensive (Pradibta & Nurhasan, 2020). Therefore, alternative learning media that offer cost-effective, safe, and flexible solutions are needed. The development of virtual laboratories through technology presents a viable alternative, given the rapid technological advances that heavily influence education, particularly in the sciences (Wulandari et al., 2021; Safiatuddin & Asnawi, 2023). In several developing countries, traditional chemistry laboratories for practical coursework have been replaced by virtual laboratories (Fung et al., 2019). The use 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, even the tools and materials in the VR laboratory room can be used repeatedly (Balsam et al., 2019; Calvert & Abadia, 2020). The need for development of VR laboratories that will be used for the implementation of chemistry practical activities has also received a positive response from students of public and private high schools in the Jakarta area (Simatupang, et al., 2023; Purba, et al., 2023)

In addition to the development of VR-based laboratories, the development of virtual laboratories is also integrated with Artificial Intelligence (AI) so that it can replace the need for laboratory supervisors/laboratories in the laboratory. *Artificial Intelligence* (AI) is a branch of computer science related to building smart machines that are able to do things that usually require human intelligence. AI is one of the technologies in the industrial revolution 4.0 era that is designed with a modeling process that can imitate and replace the role of humans (Russel & Norvig, 2021; Supriadi, et al., 2022). Integrating AI into virtual laboratories enables more adaptive, effective, and efficient learning systems (Rawat, 2024; Mondal, 2025). The development of an AI-integrated VR laboratories offers an alternative solution for conducting virtual practicums, particularly by reinforcing student understanding (Rokhim, 2020; Puspita, 2020).

In educational settings where laboratory equipment is limited, students often observe laboratory procedures via demonstration videos. Consequently, the utilization of AI-enhanced VR laboratories is expected to provide an alternative that not only allows students to observe equipment functionally but also enables them to practice and improve hands-on practicum skills in a virtual environment.

Method

The research method used as a reference in developing an AI-integrated VR laboratory for this Acid-Base Titration practicum adapts the ADDIE development model (Branch, 2019). According to Branch, the stages in this development research consist of Analysis, Design, Development, Implementation, and Evaluation stages.

The stages involved in developing the AI-integrated VR laboratory for the acid-base titration practicum are described 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, 2019).

Result and Discussion

1. 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 3 public schools that already had real laboratory facilities. Based on the results of the analysis, it was found that students responded positively to the development of a VR laboratory for use in chemistry practicum activities (Simatupang, et al., 2023).

Based on the analysis results, recommendations were also obtained for the development of VR laboratories using the Oculus Quest platform to facilitate their operational use. The integration AI in the VR laboratory development process is also limited to the application of virtual assistants (laboratories) whose role is to provide procedural instruction for implementing practicums to practicum participants. The topic of Acid-Base Titration was selected based on its relevance and applicability not only for high school and vocational school students but also at the university level,

2. Design Stage

In the second stage, the design began by compiling a practical guide for Acid-Base Titration with the experimental title Determining Acetic Acid Levels in Apple Cider Vinegar. Still in the design stage, after the experimental guide has been completed, the creation of the VR laboratory begins by cr space, (b) l virtual labora

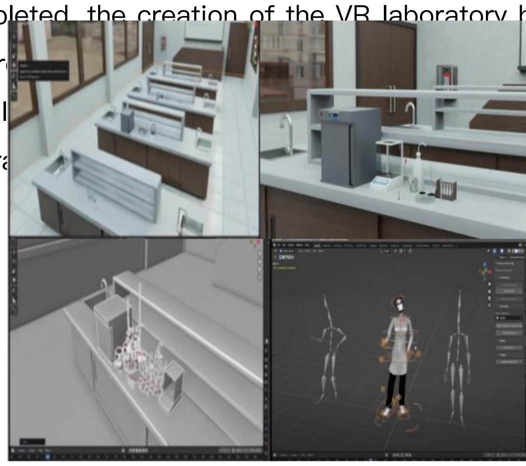

Figure 2. Creative 3D Design of the VR Laboratory Room and Equipment's

The 3D design of the laboratory space is made following the real shape of the chemistry laboratory at the Universitas Kristen Indonesia with the aim that when students use the Oculus Quest and enter the virtual laboratory space, students can feel as if they are entering a real laboratory space (Petrov & Atanasova, 2020).

3. Development Stage

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

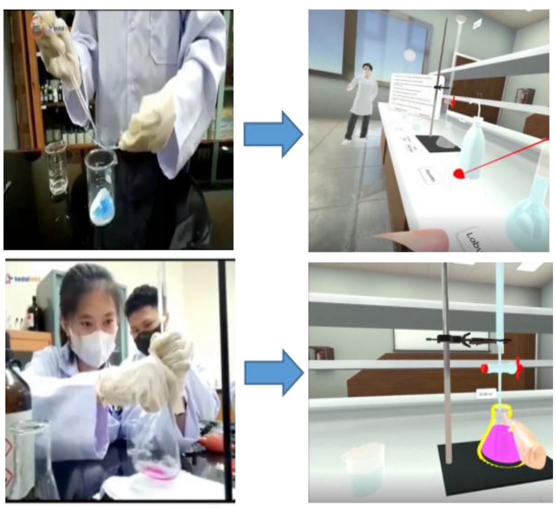

Figure 3. Integration of actual laboratory practices into VR

Several innovations were introduced in the development of the AI-integrated VR laboratory for the Acid-Base Titration experiment, including: (1) Before students (practitioners) are allowed to carry out the practicum, they are required to complete a pre-test as a prerequisite to access the laboratory space or practicum station;

(2) As part of the AI implementation, the VR laboratory features a virtual assistant (a female laboratory assistant) equipped with audio instructions that deliver the experimental procedure. The addition of audio aims to enhance the sense of realism during the practicum conducted in the VR laboratory (Batubara, 2020);

(3) In addition to the audio instructions delivered by the virtual assistant, the procedural steps are also presented in the form of 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 using the AI-integrated VR laboratory.

4. Implementation Stage

The implementation stage was carried out after the development process was completed and the product had undergone validation. The components validated included: the appropriateness 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 shapes of laboratory equipment, and the availability of required materials for conducting the experiment.

The implementation was conducted 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

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

5. Evaluation Stage

The evaluation stage was conducted based on the responses provided by students 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 show that students gave a positive response to the use of the AI-integrated VR laboratory with a percentage above 70% for each indicator (Figure 5). The highest percentage of student responses was recorded in the indicator of the usefulness of the VR laboratory, 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), in general, the AI-integrated VR laboratory developed in this research can be considered a viable alternative learning media for chemistry practicum activities on the topic of acid-base titration.

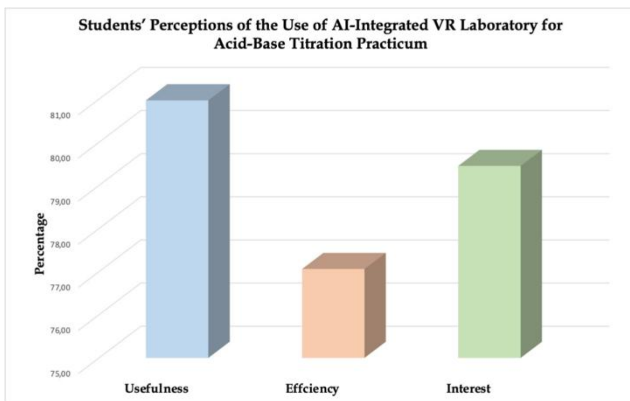

Figure 5. Percentage of student's perceptions on the use of AI-integrated VR laboratories for Acid-Base Titration practicums.

Students also have an interest in using the AI-integrated VR laboratory in practicum activities, with a response rate 79.45%. The addition of a virtual assistant audio component (laboratory assistant) is one of the components that is interesting to students because it makes it easier for students not to have to read the experimental guide repeatedly.

The lowest percentage is in the efficiency indicator. For some 1st semester students who had never used oculus quest, they have difficulty entering the virtual laboratory room, and are confused about limiting the work area when conducting experiments. This finding aligns with Suherdi (2019), that in the early stages of implementing a VR laboratory, it is necessary to first socialize the basics of the VR laboratory because its use is still very limited. In addition, when using some of the equipment in the VR laboratory, students often dropped the tools, leading them to recommend the addition of a tactile feedback effect, even in 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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(5 Agustus 2025)

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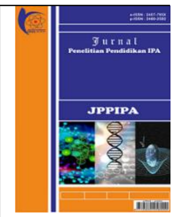

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The integration of technology into education has been progressively advancing, particularly since the implementation of the online learning system during the COVID-19 pandemic. Technology-based learning platforms and media have been widely developed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

The application of technology in science learning, especially in the field of chemistry, is also something that continues to be done continuously, because students will be able to master and apply scientific concepts if the theory is accompanied by practical implementation. However, so far the development of learning media and the use of technology in chemistry learning activities have primarily focused on increasing student interest and the resulting scientific products (Sasmitatias & Kuswanto, 2018).

Chemistry, as a branch of the natural sciences, requires practical laboratory work to facilitate deeper understanding. One area of chemistry that necessitates experimental verification is acid—base titration (Astuti & Marzuki, 2017). The implementation of practicums is considered more practical and effective when carried out to teach chemical material, especially on the topic of acid–base titration (Reny, 2018). This underscores the assertion that practical sessions in 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, 2010; Widarti et al., 2021). In addition to facilitating students' comprehension of chemical principles, especially the concept of acid—base titration, practicum activities help students become familiar and understand the various uses of practicum tools and materials available in the laboratory. In addition to improving laboratory skills, practicum activities can also help students improve their thinking process skills (Listyarini & Pamenang, 2022).

In the implementation of practical laboratory activities at schools or universities, financial constraints are unavoidable because such activities incur significant costs. Facilitating laboratory practicums requires funding for facilities and infrastructure, including laboratory equipment and consumables, which are relatively expensive (Pradibta & Nurhasan, 2020). Therefore, alternative learning media that offer cost-effective, safe, and flexible solutions are needed. The development of virtual laboratories through technology presents a viable alternative, given the rapid technological advances that heavily influence education, particularly in the sciences (Wulandari et al., 2021; Safiatuddin & Asnawi, 2023). In several developing countries, traditional chemistry laboratories for practical coursework have been replaced by virtual laboratories (Fung et al., 2019). The use 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, even the tools and materials in the VR laboratory room can be used repeatedly (Balsam et al., 2019; Calvert & Abadia, 2020). The need for development of VR laboratories that will be used for the implementation of chemistry practical activities has also received a positive response from students of public and private high schools in the Jakarta area (Simatupang, et al., 2023; Purba, et al., 2023)

In addition to the development of VR-based laboratories, the development of virtual laboratories is also integrated with Artificial Intelligence (AI) so that it can replace the need for laboratory supervisors/laboratories in the laboratory. *Artificial Intelligence* (AI) is a branch of computer science related to building smart machines that are able to do things that usually require human intelligence. AI is one of the technologies in the industrial revolution 4.0 era that is designed with a modeling process that can imitate and replace the role of humans (Russel & Norvig, 2021; Supriadi, et al., 2022). Integrating AI into virtual laboratories enables more adaptive, effective, and efficient learning systems (Rawat, 2024; Mondal, 2025). The development of an AI-integrated VR laboratories offers an alternative solution for conducting virtual practicums, particularly by reinforcing student understanding (Rokhim, 2020; Puspita, 2020).

In educational settings where laboratory equipment is limited, students often observe laboratory procedures via demonstration videos. Consequently, the utilization of AI-enhanced VR laboratories is expected to provide an alternative that not only allows students to observe equipment functionally but also enables them to practice and improve hands-on practicum skills in a virtual environment.

Method

The research method used as a reference in developing an AI-integrated VR laboratory for this Acid-Base Titration practicum adapts the ADDIE development model (Branch, 2019). According to Branch, the stages in this development research consist of Analysis, Design, Development, Implementation, and Evaluation stages.

The stages involved in developing the AI-integrated VR laboratory for the acid-base titration practicum are described 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, 2019).

Result and Discussion

1. 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 3 public schools that already had real laboratory facilities. Based on the results of the analysis, it was found that students responded positively to the development of a VR laboratory for use in chemistry practicum activities (Simatupang, et al., 2023).

Based on the analysis results, recommendations were also obtained for the development of VR laboratories using the Oculus Quest platform to facilitate their operational use. The integration AI in the VR laboratory development process is also limited to the application of virtual assistants (laboratories) whose role is to provide procedural instruction for implementing practicums to practicum participants. The topic of Acid-Base Titration was selected based on its relevance and applicability not only for high school and vocational school students but also at the university level,

2. Design Stage

In the second stage, the design began by compiling a practical guide for Acid-Base Titration with the experimental title Determining Acetic Acid Levels in Apple Cider Vinegar. Still in the design stage, after the experimental guide has been completed, the creation of the VR laboratory begins by cr space, (b) l virtual labora

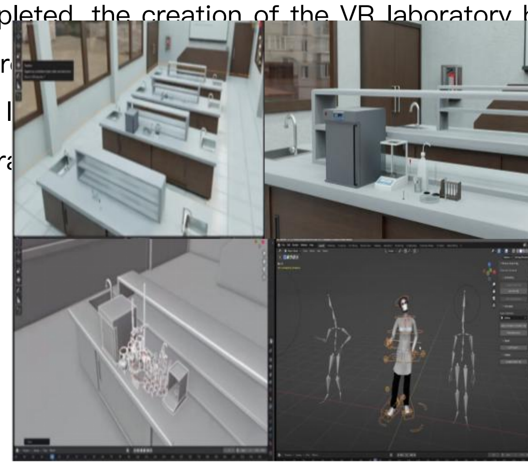

Figure 2. Creative 3D Design of the VR Laboratory Room and Equipment's

The 3D design of the laboratory space is made following the real shape of the chemistry laboratory at the Universitas Kristen Indonesia with the aim that when students use the Oculus Quest and enter the virtual laboratory space, students can feel as if they are entering a real laboratory space (Petrov & Atanasova, 2020).

3. Development Stage

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

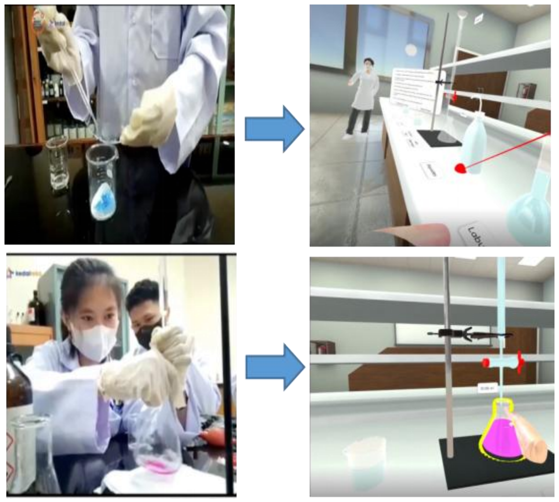

Figure 3. Integration of actual laboratory practices into VR

Several innovations were introduced in the development of the AI-integrated VR laboratory for the Acid-Base Titration experiment, including: (1) Before students (practitioners) are allowed to carry out the practicum, they are required to complete a pre-test as a prerequisite to access the laboratory space or practicum station;

(2) As part of the AI implementation, the VR laboratory features a virtual assistant (a female laboratory assistant) equipped with audio instructions that deliver the experimental procedure. The addition of audio aims to enhance the sense of realism during the practicum conducted in the VR laboratory (Batubara, 2020);

(3) In addition to the audio instructions delivered by the virtual assistant, the procedural steps are also presented in the form of 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 using the AI-integrated VR laboratory.

4. Implementation Stage

The implementation stage was carried out after the development process was completed and the product had undergone validation. The components validated included: the appropriateness 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 shapes of laboratory equipment, and the availability of required materials for conducting the experiment.

The implementation was conducted 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

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

5. Evaluation Stage

The evaluation stage was conducted based on the responses provided by students 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 show that students gave a positive response to the use of the AI-integrated VR laboratory with a percentage above 70% for each indicator (Figure 5). The highest percentage of student responses was recorded in the indicator of the usefulness of the VR laboratory, 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), in general, the AI-integrated VR laboratory developed in this research can be considered a viable alternative learning media for chemistry practicum activities on the topic of acid-base titration.

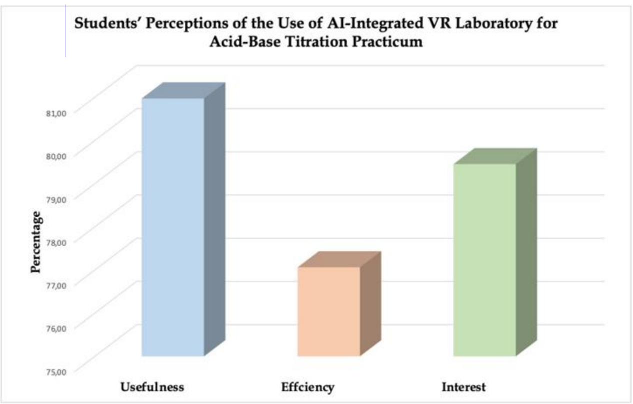

Figure 5. Percentage of student's perceptions on the use of AI-integrated VR laboratories for Acid-Base Titration practicums.

Students also have an interest in using the AI-integrated VR laboratory in practicum activities, with a response rate 79.45%. The addition of a virtual assistant audio component (laboratory assistant) is one of the components that is interesting to students because it makes it easier for students not to have to read the experimental guide repeatedly.

The lowest percentage is in the efficiency indicator. For some 1st semester students who had never used oculus quest, they have difficulty entering the virtual laboratory room, and are confused about limiting the work area when conducting experiments. This finding aligns with Suherdi (2019), that in the early stages of implementing a VR laboratory, it is necessary to first socialize the basics of the VR laboratory because its use is still very limited. In addition, when using some of the equipment in the VR laboratory, students often dropped the tools, leading them to recommend the addition of a tactile feedback effect, even in 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.

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

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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, virtual reality laboratory, practicum.

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(N. I. , S. S. R. I. , S. A. P. , & S. I. M. Simatupang, 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

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Example: Susilawati, S., Doyan, A., Muliyadi, L., & Hakim, S. (2019). Growth of tin oxide thin film by aluminum and fluorine doping using spin coating Sol-Gel techniques. *Jurnal Penelitian Pendidikan IPA, 1*(1), 1-4. https://doi.org/10.29303/jjppipa.v1i1.264

production of scientific outcomes, rather than fostering deeper conceptual understanding (Sasmitatias & Kuswanto, 2018).

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; N. I. 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.

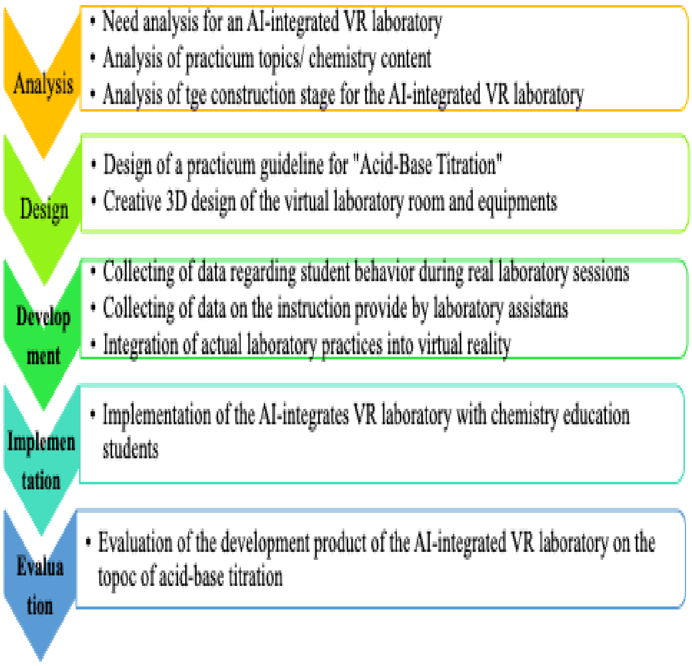

Figure 1. Development Stage of the AI-integrated VR Laboratory on the Topic of Acid-Base Titration

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

1. 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(N. I. 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,

2. 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).

3. 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.

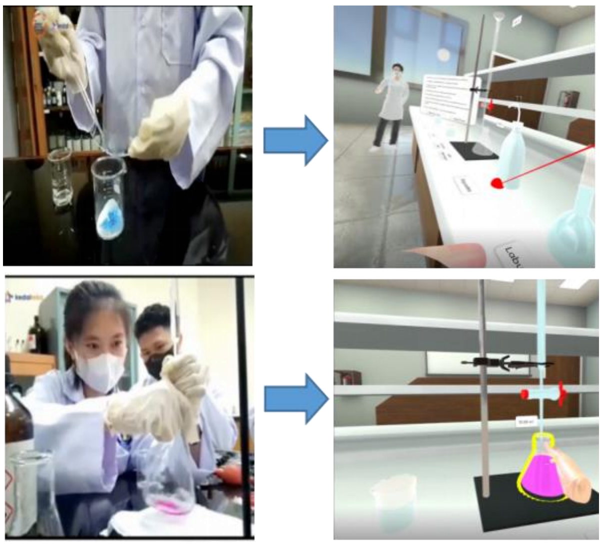

Figure 3. Integration of actual laboratory practices into VR

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.

4. 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

5. 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).

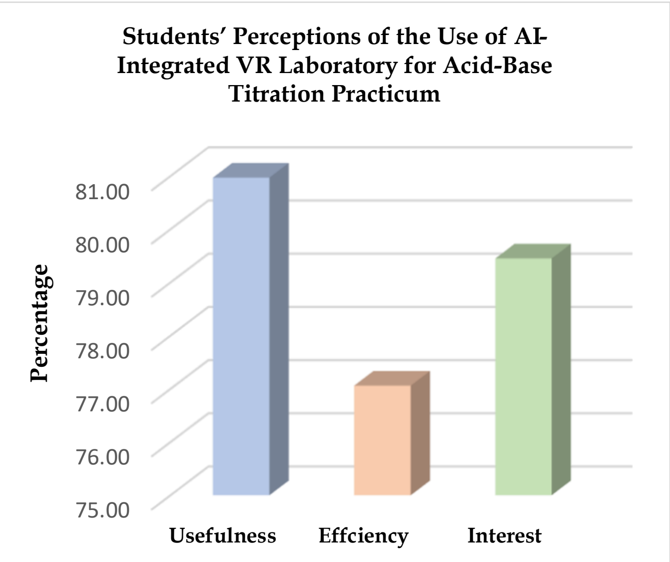

Figure 5. Percentage of student's perceptions on the use of AI-integrated VR laboratories for Acid-Base Titration practicums.

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

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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

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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).

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.

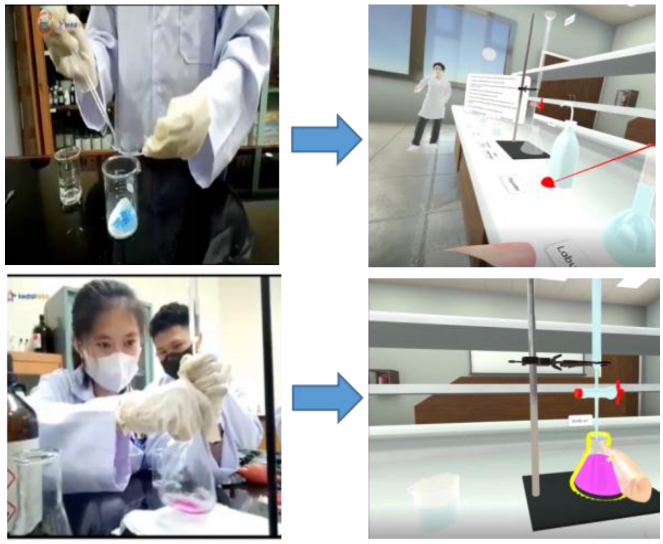

Figure 3. Integration of actual laboratory practices into VR

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).

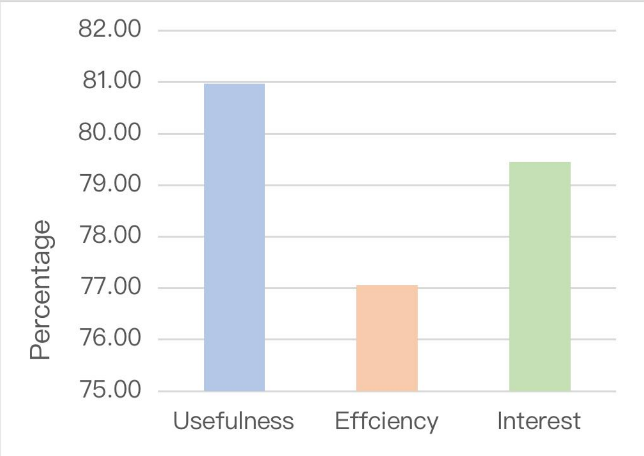

Figure 5. Percentage of student's perceptions on the use of AI-integrated VR laboratories for Acid-Base Titration practicums.

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

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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.

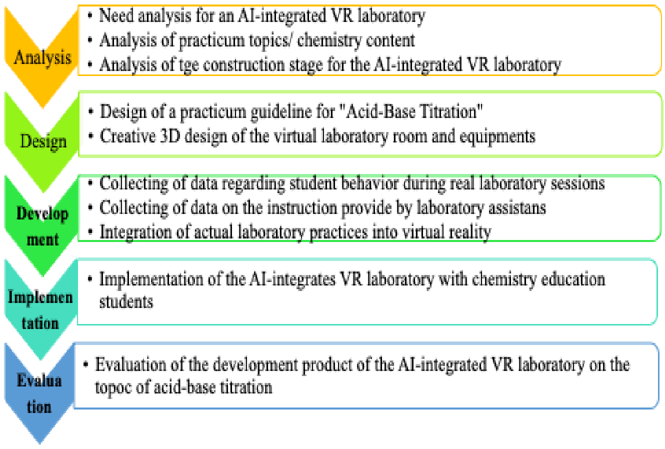

Figure 1. Development Stage of the AI-integrated VR Laboratory on the Topic of Acid-Base Titration

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.

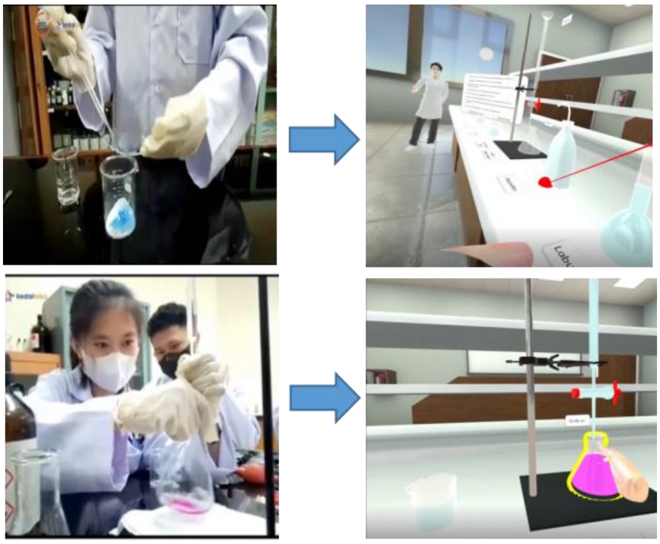

Figure 3. Integration of actual laboratory practices into VR

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).

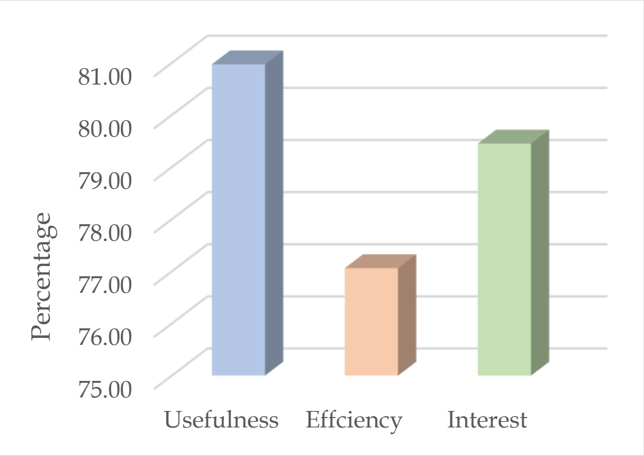

Figure 5. Percentage of student's perceptions on the use of AI-integrated VR laboratories for Acid-Base Titration practicums.

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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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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