Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 6, 7559-7569
2024
Publisher: Learning Gate
DOI: 10.55214/25768484.v8i6.3638

Impact of augmented reality on high school students' motivation and understanding of acid-base titration concepts

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Abstract: The integration of Augmented Reality (AR) in chemistry education, particularly in acid-base titration, offers an interactive approach that can improve students' understanding. This study aimed to assess the effectiveness of AR in enhancing learning outcomes for tenth-grade students at SMA Negeri 4 Denpasar, while also evaluating the user experience through the System Usability Scale (SUS) and User Experience Questionnaire (UEQ). A total of 60 students participated in AR-based learning, and the evaluation focused on changes in learning outcomes before and after using AR. The SUS was used to measure system usability, while the UEQ assessed user experience in terms of attractiveness, Perspicuity, efficiency, stimulation, and novelty. Results showed a significant improvement in student understanding, with an average test score increase of 25%. The SUS yielded a high usability score of 85, indicating that the AR system was easy to use. Additionally, the UEQ highlighted a positive user experience, particularly in stimulation and attractiveness, both rated "excellent." These findings suggest that AR not only improves learning outcomes but also provides an engaging and motivating learning experience.
Keywords: *Augmented reality education technology, Chemistry education learning, User experience questionnaire*.

1. Introduction

Technological advancements in education have opened up significant opportunities for the development of more interactive and innovative learning methods(Mazzuco et al., 2023)(Sarifah et al., 2025). One such emerging technology with recognized potential in the educational sector is Augmented Reality (AR)(Naidu et al., 2023)(Puggioni et al., 2021). AR technology allows for the integration of real-world environments with virtual elements in a single display, creating a more dynamic and interactive learning experience for students(Kartini, 2024). It is particularly effective in enhancing the understanding of complex concepts by visualizing objects or processes that are difficult to grasp through conventional media, such as textbooks or whiteboards(Ripsam & Nerdel, 2022).

In the context of chemistry education, especially in acid-base titration, many students struggle to comprehend abstract concepts like pH changes, acid-base reactions, and equivalence points(Putra et al., 2021). Titration processes are often taught theoretically, but students require a deeper visual understanding to fully grasp the mechanisms involved. AR offers a solution to this gap by providing realistic visualizations that bring students closer to a virtual practical experience.

Several studies have shown that the implementation of AR in education can improve students' learning outcomes and make the material more engaging(Wen et al., 2023). However, it is equally important to assess the extent to which this technology is accepted and effectively used by students(Cheng et al., 2024). Therefore, in addition to evaluating AR's effectiveness in enhancing students' understanding, it is crucial to assess usability and user experience(Astari & Putra,

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2021)(Sudipa, Wiguna, et al., 2022). The System Usability Scale (SUS) and User Experience Questionnaire (UEQ) are standard evaluation tools that can be used for this purpose(Viberg et al., 2021)(Hadiwiyanti et al., 2022). The SUS method enables researchers to evaluate system usability from the user's perspective, while the UEQ provides insights into user experience across dimensions such as attractiveness, Perspicuity, efficiency, stimulation, and novelty(Kadek Risma Juniantari & Tri Anindia Putra, 2021)(Maulana et al., 2022).

This study focuses on the implementation of AR technology in acid-base titration for tenth-grade students at SMA Negeri 4 Denpasar. Its objective is to measure how effectively AR enhances students' understanding of titration concepts and to evaluate the system in terms of usability and user experience using the SUS and UEQ methods. The research aims to contribute to the development of more effective and enjoyable interactive technology-based learning methods in the field of chemistry education.

2. Literature Review

The integration of Augmented Reality (AR) in educational settings, particularly in the context of high school students learning about acid-base titration concepts, has shown promising effects on both motivation and understanding. Research indicates that AR can significantly enhance student engagement and motivation, which are critical factors in the learning process. For instance, Herwin's study provides empirical evidence that AR technology can improve student motivation in classroom settings, suggesting that it effectively arouses enthusiasm and participation among learners (Aditama et al., 2023; Herwin et al., 2023; Yanti et al., 2024). This aligns with findings from Khan et al., who explore the potential of AR to foster improved academic achievement through heightened motivation, although they note that further research is needed to fully understand its impact (Khan et al., 2019).

Moreover, the interactive nature of AR allows students to visualize complex scientific concepts, such as acid-base titration, in a more tangible manner. Immersive learning technologies, including AR, enhance students' understanding and retention of knowledge by simulating real-world experiences (Rahmadina et al., 2024; Viberg et al., 2021) . This is particularly relevant for abstract concepts in chemistry, where visual representation can bridge the gap between theoretical knowledge and practical application. Similarly, Apriyani notes that AR facilitates a more engaging learning environment, leading to increased comprehension and motivation among students (Apriyani et al., 2023).

The motivational constructs identified by Anuar et al. further support the notion that AR can positively influence student learning experiences. Their research outlines four key dimensions of motivation, attention, relevance, confidence, and satisfaction, which are enhanced through the use of AR in educational materials (Anuar et al., 2021; Sudipa, Aditama, et al., 2022). This is echoed by Yıldız, who argues that AR applications attract students' attention and foster creativity, which is essential for deep learning, especially for digital natives who thrive in multimedia environments (Yildiz, 2021).

In the context of science education, studies have shown that AR can lead to significant improvements in student motivation and understanding. For example, Kul and Berber found that AR technologies positively impacted students' academic achievement and motivation in science courses, specifically focusing on elements and compounds (Kul & Berbe, 2022). Furthermore, Gopalan et al. developed a mobile AR application aimed at enhancing learning motivation in science experiments, demonstrating the effectiveness of AR in practical learning scenarios (Gopalan et al., 2020). This is particularly relevant for acid-base titration, where hands-on experimentation is crucial for grasping the underlying concepts.

In summary, the integration of Augmented Reality in high school education, particularly in teaching acid-base titration concepts, has the potential to significantly enhance student motivation and understanding. The interactive and engaging nature of AR not only makes learning more enjoyable but also facilitates a deeper comprehension of complex scientific principles.

3. Methods

This study aims to evaluate the effectiveness of applying Augmented Reality (AR) technology in teaching acid-base titration, as well as to assess usability and user experience through the System

Edelweiss Applied Science and Technology
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Usability Scale (SUS) and User Experience Questionnaire (UEQ) methods. A quantitative approach with a quasi-experimental design was employed for this research. The following outlines the methodology utilized in the study:

3.1. Research Design

This study employs a pre-test and post-test design with a single group of students(Ketut Sepdyana Kartini1*, 2022). Prior to the AR-based learning session, students will complete a pre-test to assess their initial understanding of acid-base titration concepts using the AR application(Lampropoulos et al., 2022). Following this, students will engage in interactive learning through the AR application, which simulates the titration process. After the learning session, a post-test will be administered to evaluate the improvement in their understanding, also using the AR application. Additionally, the usability and user experience of the AR system will be assessed through the SUS and UEQ questionnaires. The following is the main menu display of the AR application which can be seen in figure.1

Figure 1.
AR app main menu.

3.2. Participants

The participants consist of 60 tenth-grade students from SMA Negeri 4 Denpasar. The participants were randomly selected from different classes to ensure a representative sample of the student population. All participants had access to smartphones or tablets compatible with AR technology.

3.3. Research Instruments

The instruments used in this study include (a) Pre-test and Post-test: Multiple-choice tests with 15 questions measuring students' understanding of acid-base titration concepts, such as acid-base reactions, pH, equivalence points, and titration graph interpretation. Examples of practice questions in the AR application can be seen in Figure 2.

Figure 2.
Examples of practice questions in the AR application.

(b) AR Application: A custom AR app developed for this study that visually simulates the acid-base titration process, including acid-base reactions, color changes of indicators, and equivalence points. an example of Augmented Reality in AR applications can be seen in the figure 3

Figure 3.
an example of augmented reality in AR.

(c) System Usability Scale (SUS)(Tri et al., 2023)(Hidayat et al., 2022): A 10-item standard questionnaire used to measure the usability of the AR system, with scores calculated to assess the perceived ease of use. System Usability Scale (SUS) is a widely used tool for measuring the usability of a product or system. It consists of 10 items, each rated on a Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree). The SUS provides a quick and reliable measure of the overall usability of a system, including factors like ease of use, complexity, and satisfaction. SUS Scoring Formula: (1) For odd-numbered questions (1, 3, 5, 7, 9), subtract 1 from the user's response; (2) For even-numbered questions (2, 4, 6, 8, 10), subtract the user's response from 5; (3) Add the adjusted values for all 10 items; (4) Multiply the total by 2.5 to convert the score to a range from 0 to 100.

$$SUS\ Score\ Average\ \bar{x} = \frac{\Sigma x}{n} \qquad (1)$$

$\bar{x}$ = SUS Score Average
Σx = Total Score SUS
n = Number of Respondents

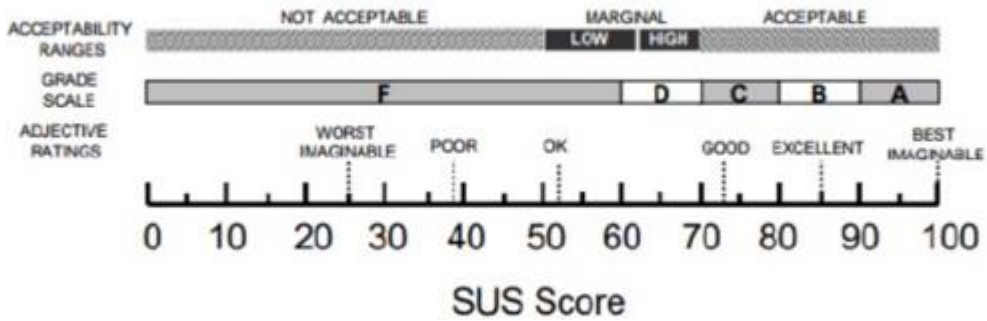

Figure 4.
System usability scale (SUS) acceptability ranges and grading(Tri et al., 2023).

The image illustrates a grading scale for the System Usability Scale (SUS) scores, which is used to evaluate the usability of various systems and interfaces. This scale categorizes SUS scores into several ranges that correspond to different levels of acceptability and descriptive adjectives. From left to right, the scale identifies scores under 20 as "Not Acceptable," with a grade of F and described as the "Worst Imaginable." Scores between 20 to 40 are considered "Poor," and scores from 40 to 60 are regarded as "OK," both of which fall under "Marginal" acceptability. The "Acceptable" range starts from scores over 60, where 60 to 70 is labeled "Good," 70 to 80 as "Excellent," and 80 to 100 as the "Best Imaginable" with a grade of A. This visual representation, referred to as Figure 4, serves as a quick reference for interpreting SUS scores within the context of usability research.

(d) The User Experience Questionnaire (UEQ) (Putra et al., 2023)is a widely recognized tool for assessing the quality of user experience in interacting with software products. It covers six essential dimensions: Attractiveness, Perspicuity (ease of understanding), Efficiency, Dependability, Stimulation, and Novelty. Each dimension is evaluated through a series of statements rated on a scale from -3 to +3, capturing users' immediate reactions to the product. The UEQ allows for quick, standardized user experience evaluation and is particularly useful in comparing the performance of different products or iterations of a product over time. The results from a UEQ can provide developers and designers with actionable insights into how a product is perceived, where it excels, and what areas might require improvement.

3.4. Research Procedure

Preparation Stage: The AR application was developed and tested to ensure it functioned properly for students. Pre-test, post-test, SUS, and UEQ instruments were also prepared. Pre-test Administration: Before using AR, students took the pre-test to assess their initial understanding of the titration material. AR-Based Learning: Students then engaged in learning with the AR application, observing the interactive titration simulation and following the instructions provided(Yıldırım & Seçkin Kapucu, 2021). Post-test Administration: After the learning session, the same post-test was administered to measure their improvement in understanding. SUS and UEQ Administration: Students completed the SUS and UEQ questionnaires to evaluate the system's usability and their experience using the AR application.

3.5. Data Analysis

The results from the pre-test and post-test will be analyzed using paired t-tests to determine if there is a significant improvement in students' understanding after using AR(Kartini & Setiawan, 2019). SUS questionnaire results will be calculated and compared to SUS interpretation standards to assess the usability of the AR application. UEQ results will be analyzed using UEQ software to generate average

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 6: 7559-7569, 2024
DOI: 10.55214/25768484.v8i6.3638

scores for each dimension (attractiveness, Perspicuity, efficiency, dependability, stimulation, and novelty). These scores will be analyzed to evaluate the overall user experience.

4. Process and Results

This study examines the implementation of Augmented Reality (AR) technology in teaching acid-base titration and evaluates its usability and user experience through the System Usability Scale (SUS) and User Experience Questionnaire (UEQ) methods. The findings are presented in two primary sections: the improvement in students' understanding (measured through pre-test and post-test) and the evaluation of the system's usability and user experience.

4.1. Pre-test and Post-test Results

Pre-test and post-test assessments were conducted to evaluate students' understanding of acid-base titration concepts before and after the implementation of AR technology. The results are summarized as follows: the average pre-test score was 58.2, while the average post-test score increased to 82.5. A paired t-test analysis revealed a statistically significant improvement in students' understanding following AR-based learning ($t = 8.73$, $p < 0.01$). The 24.3-point increase in average scores demonstrates that AR technology effectively enhances students' comprehension of acid-base titration. Additionally, most students reported that the interactive visualizations provided by the AR application helped them better grasp the acid-base reaction process and the changes in pH during titration.

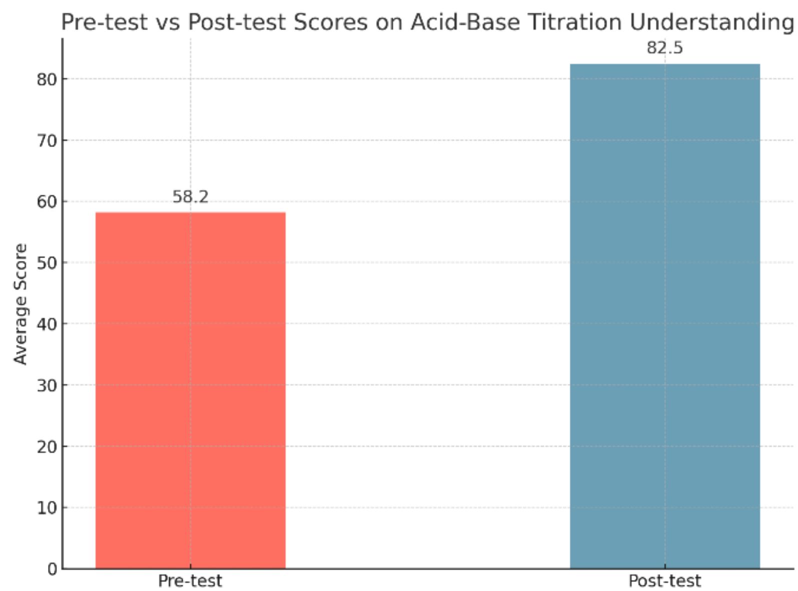

Figure 5.
Comparison of pre-test and post-test scores on acid-base titration understanding.

4.2. Usability Evaluation Results (SUS)

The usability evaluation of the AR application was conducted using the System Usability Scale (SUS) questionnaire. The average SUS score obtained from the students was 85, which, according to the SUS scale, falls within the "excellent" category. This indicates that the students found the application highly user-friendly. Most participants reported that they were able to quickly understand how the application functioned, and they found the navigation to be clear and intuitive.

ISSN: 2576-8484
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Table 1.
Summarizes the SUS scores from all participants.

No	SUS item indicator	Average score
1	Ease to use	86
2	Perspicuity of instruction	84
3	Simplicity of interface	84
4	Ease of navigation	87
5	Willingness to reuse	88

The table presents the average SUS scores for various usability aspects of the AR application, as reported by the participants. The highest score, 8.8, reflects a strong willingness among students to reuse the application, indicating a high level of user satisfaction. Ease of navigation scored 8.7, suggesting that students found the application intuitive to navigate. Ease of use and interface simplicity received scores of 8.6 and 8.4, respectively, demonstrating the system's user-friendly design. Perspicuity of instructions, with an average score of 8.4, also performed well, further reinforcing the application's overall usability. These scores collectively indicate that the AR system was highly accessible and easy to use.

4.3. Experience Questionnaire (UEQ) Results

User experience was evaluated using the User Experience Questionnaire (UEQ), which encompasses six key dimensions: Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, and Novelty. The following is a summary of the average scores for each UEQ dimension:

Table 2.
Summarizes the UEQ scores from all participants.

No	UEQ dimension	Average score	Category
1	Attractiveness	2.1	Excellent
2	Perspicuity	2.2	Excellent
3	Efficiency	2.0	Good
4	Dependability	1.8	Good
5	Stimulation	2.2	Excellent
6	Novelty	2.0	Excellent

The table presents the User Experience Questionnaire (UEQ) results for the AR application used in acid-base titration learning. It evaluates six key dimensions of user experience. Attractiveness received an average score of 2.1, categorized as "Excellent," indicating that students found the application visually appealing and enjoyable to use. Perspicuity scored 2.2, also rated "Excellent," showing that the instructions and overall interface were easy to understand and navigate. For Efficiency, the score was 2.0, falling into the "Good" category, meaning the application was effective in achieving tasks, though there may be minor areas for improvement. Dependability had a slightly lower score of 1.8, categorized as "Good," suggesting that while the system was reliable, students perceived some room for increased consistency in performance. Both Stimulation and Novelty scored 2.2 and 2.0, respectively, and were rated as "Excellent." This reflects that student found the AR experience engaging and innovative, making the learning process more dynamic and enjoyable. Overall, the scores indicate a highly positive user experience, with most dimensions receiving an "Excellent" rating, highlighting the AR application's effectiveness in enhancing the learning environment. The graph of the user experience questionnaire results can be seen in Figure 6.

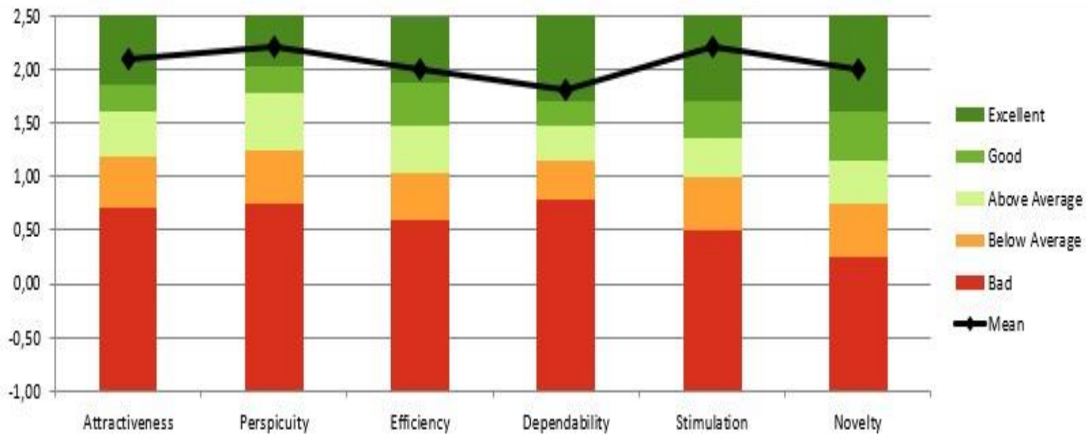

Figure 6.
The graph of the user experience questionnaire results.

4.3. Discussions

The results showed that the use of Augmented Reality (AR) technology on acid-base titration material had a positive impact on student understanding and user experience. The significant increase in post-test results compared to the pre-test (average increase of 24.3 points) shows that AR is able to present abstract chemical materials, such as acid-base titration, in a more visual and easy-to-understand way in line with research conducted (Lai & Cheong, 2022) that AR technology is able to assist students in the learning comprehension process. This finding is in line with previous research(Kibat et al., 2023)(Tarng et al., 2022) which shows that AR technology increases student engagement and understanding of scientific concepts through interactive visualisation that cannot be obtained from conventional learning methods.

Usability evaluation through the System Usability Scale (SUS) shows that the AR application used is very easy to operate by students, with an average score of 85, which is in the "excellent" category. This shows that the application is well designed in terms of interface and navigation, so that students do not experience difficulties when using it in the learning process. This is in accordance with research conducted by (Wen et al., 2023)(Jones & Sharma, 2021)(Almaguer et al., 2023)(Martono et al., 2022) which states that the role of technology provides convenience, especially in the field of education in increasing the ease of getting subject matter. Research (Choudhury & Chechi, 2024)(Ahmed & Lataifeh, 2023) also states that ease of use is an important factor in the successful integration of new technology in the classroom, especially to ensure that technology does not become a barrier to learning.

Furthermore, the user experience evaluation, conducted via the User Experience Questionnaire (UEQ), yielded highly positive results, particularly in the dimensions of Stimulation and Novelty. Students reported that AR provided an engaging and innovative learning experience, which motivated them to better understand the material. High scores in dimensions such as Attractiveness and Perspicuity also indicate that students felt comfortable using AR in their learning. This is an important factor for enhancing student engagement, which may have a positive impact on long-term learning outcomes.

However, despite the positive results, there are several limitations that should be noted. First, this study involved only 60 students from a single school, making the generalizability of the findings to a broader population a point of consideration. Second, the use of AR was limited to a single learning session, meaning that the long-term effects of this technology have not yet been evaluated.

5. Conclusion

Based on the findings of this study, it can be concluded that the implementation of Augmented Reality (AR) technology in the teaching of acid-base titration at SMA Negeri 4 Denpasar significantly enhanced students' understanding of the concepts presented. The AR application demonstrated a high level of usability, with a System Usability Scale (SUS) score categorized as "excellent," and provided a positive user experience, particularly in terms of stimulation and novelty. These results underscore the considerable potential of AR technology as an interactive and engaging visual aid in science education, particularly in the field of chemistry.

Acknowledgement:

The authors would like to express their sincere gratitude to the *Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi* of the Republic of Indonesia for their generous financial support through the Fundamental Research Grant Scheme. This funding has been instrumental in facilitating the successful completion of this study. We are deeply appreciative of the Ministry's commitment to advancing scientific research and innovation in education, which has enabled us to explore the potential of Augmented Reality technology in enhancing chemistry learning. Furthermore, we would like to extend our thanks to the participating students and faculty at SMA Negeri 4 Denpasar for their invaluable cooperation and contribution to this research. Without their involvement, this study would not have been possible.

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