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Practicality and Effectiveness of Markerless Augmented Reality Integrated Learning Media on Buffer Solution Material on Phase F Learners' Learning Outcomes

Praktikalitas dan Efektivitas Media Pembelajaran Terintegrasi *Markerless Augmented Reality* pada Materi Larutan Penyangga terhadap Hasil Belajar Peserta Didik Fase F

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Abstract

This study aims to develop and measure the practicality and effectiveness of markerless augmented reality integrated learning media on buffer solution material for phase F students. The development of this media is based on improving students' ability to understand abstract chemical concepts through three-dimensional visualization (macroscopic, sub-microscopic, and symbolic representations) without the need for physical markers (markerless). This research uses the Educational Design Research (EDR) approach with the Plomp model and a pre-experimental one-group pretest-posttest design. The sample in this study was 31 students of class XI IPA 2 in one of the schools in Padang city. The practicality stage was tested through questionnaires distributed to teachers and students. In contrast, the effectiveness stage was measured through student learning outcomes in the cognitive domain based on pretest and posttest scores. The results showed that the learning media was classified as practical, with an average score of 83.13% from students (practical category) and 89.55% from teachers (convenient category). The effectiveness was classified as moderate, with an average N-Gain score of 0.61. The analysis using the Wilcoxon Signed Ranks Test yielded an Asymp. Sig. value of less than 0.05, indicating that the posttest scores were higher than the pretest scores. Furthermore, the calculated W_{stat} *of 0.00 <* W_{table} *of 163, resulting in the acceptance of* H_1 *and the rejection of* H_0*. This confirms that there was an improvement in students' cognitive learning outcomes after using the markerless augmented reality media. In conclusion, this media is effectively used as a chemistry learning tool because it can improve students' conceptual understanding.*

Keywords: *Practicality, effectiveness, markerless augmented reality, buffer solution, learning outcomes.*

Abstrak

Penelitian ini bertujuan untuk mengembangkan serta mengukur tingkat kepraktisan dan efektivitas media pembelajaran berbasis *augmented reality* tanpa penanda (*markerless*) yang terintegrasi pada materi larutan penyangga untuk peserta didik fase F. Pengembangan media ini didasarkan pada upaya meningkatkan kemampuan peserta didik dalam memahami konsep kimia yang bersifat abstrak melalui visualisasi tiga dimensi (representasi makroskopik, submikroskopik, dan simbolik) tanpa memerlukan penanda fisik (markerless). Penelitian ini menggunakan pendekatan *Educational Design Research* (EDR) dengan model Plomp serta desain pra-eksperimen *one-group pretest-posttest*. Sampel dalam penelitian ini adalah 31 siswa kelas XI IPA 2 di salah satu sekolah di Kota Padang. Tahap kepraktisan diuji melalui angket yang dibagikan kepada guru dan peserta didik. Sementara itu, tahap efektivitas diukur melalui hasil belajar peserta didik pada ranah kognitif berdasarkan skor *pretest* dan *posttest*. Hasil penelitian menunjukkan bahwa media pembelajaran ini tergolong praktis, dengan skor rata-rata sebesar 83,13% dari peserta didik (kategori praktis) dan 89,55% dari guru (kategori sangat praktis). Adapun efektivitas media tergolong sedang, dengan nilai rata-rata N-Gain sebesar 0,61. Analisis menggunakan uji Wilcoxon Signed Ranks Test didapati Asymp Sig. < 0,05, yang berarti nilai pretest lebih besar dari posttest, serta diperoleh nilai W_{hitung} = 0,00 < W_{tabel} = 163, maka H_1 diterima dan H_0 ditolak yang menyatakan bahwa terdapat peningkatan hasil belajar peserta didik pada ranah kognitif setelah menggunakan media markerless augmented reality. Dengan demikian, media ini efektif digunakan sebagai sarana pembelajaran kimia karena mampu meningkatkan pemahaman konsep peserta didik.

Kata Kunci: Praktikalitas, efektivitas, *markerless augmented reality*, larutan penyangga, hasil belajar.

1. Introduction

Chemistry is one of the scientific disciplines that studies matter and its changes (Chang, 2010). As a "central science", chemistry plays an important role in bridging various other fields of science such as biology, physics, and engineering (Brown et al., 2012). Among the urgent topics in chemistry learning is buffer solutions, which can maintain pH stability despite small additions of acids/bases (Chang & Overby, 2022). This concept involves understanding the dynamic balance between a weak acid and its conjugate base, which is material that is important not only in understanding chemical reactions but also requires in-depth understanding from students, both conceptually and applicatively.

However, learning buffer solutions in secondary schools often faces various obstacles. Previous research indicates that the level of understanding of concepts in this material is still low, where only 45.53% fall into the category of understanding. In comparison, 12.96% of students experience misconceptions, and another 10.46% do not understand (Alighiri et al., 2018). Previously in this study, a baseline questionnaire was distributed in one of the schools in Padang city, where the results showed that as many as 86.7% of students considered the topic of buffer solution difficult, and only 43.4% of them felt they understood the material.

This finding aligns with previous studies that have more thoroughly identified the misconceptions in students related to this topic. Based on the results of previous studies, it was revealed that the most significant misconceptions that occurred in the topic of buffer solutions were related to the mechanism of action of buffer solutions, with a percentage reaching 51%, while the lowest misconception of 31% was in the part of understanding the nature of buffer solutions (Nurhujaimah et al., 2016). Similar results were also obtained using a diagnostic assessment, which revealed that among the problems experienced by students were difficulties in understanding the mechanism of action of buffer solutions, calculating pH, and interpreting the principle of equilibrium (Mapada et al., 2022). On the other hand, previous research also states that the difficulties experienced by students include analyzing buffer solutions and non-buffer solutions, calculating pH, analyzing the impact of adding acids and bases, and understanding the working principles and functions of buffer solutions (Pramesti, 2023). These misconceptions can lead to incorrect understanding and interpretation of concepts, impacting students' learning outcomes (Afifah, 2020).

These problems require innovative solutions, one of which is through learning media based on a multi-level representation approach. This approach is applied to the chemistry learning process to reduce concept errors, as explained by Suparwati (2022), who states that misconceptions occur due to the inequality of students' understanding of scientific concepts, especially at the sub-microscopic level. Therefore, visualization that touches the macroscopic, submicroscopic, and symbolic levels is needed. In addition, the use of learning aids can also help students in capturing abstract concepts, thereby increasing interest in learning (Kosim et al., 2024), improving the quality of student learning outcomes (Utami, 2017), and making the learning process more enjoyable, interactive, efficient, and practical, which ultimately increases their involvement and motivation (Naffi'an et al., 2024). However, in practice, the available learning aids are still limited to the symbolic level. It is not optimal to bring up the three levels of representation as a whole that are needed in learning buffer solutions, even though the material is abstract and contextual. Therefore, various forms of representation are needed to visualize the intended material so students can observe the phenomena, analyze them, and draw conclusions more deeply (Alighiri et al., 2018).

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Along with technology development, Augmented Reality can be one option to be applied in the chemistry learning process. Interactive experiences with augmented reality have shown potential in providing multi-level visualization of chemical representations, thus helping students gain a deeper understanding of concepts (Olim et al., 2024). Augmented reality technology also supports the learning process of chemistry, especially on the topic of buffer solution (Afifah, 2020), because it can enrich the learning experience by presenting digital visualizations that are integrated with the real world, making it easier for students to understand the working process of buffer solution interactively (Sirakaya & Sirakaya, 2022). By integrating augmented reality into chemistry learning media, teachers have the opportunity to reduce misconceptions that occur and support student learning outcomes (Anwar et al., 2024).

Based on the explanation above, augmented reality has been applied in various learning media in the field of chemistry, especially on the topic of buffer solutions, as researched by Aini (2022), Salsabila (2022), and Almubarak et al. (2021). However, these studies still have several limitations, including modules that are less efficient to carry to various places, dependence on internet data speed, use of marker-based augmented reality, and no effectiveness test. Meanwhile, the markerless augmented reality integrated learning media developed by Abshari & Guspatni (2024) has been tested for validity, but not in terms of its practicality and effectiveness on learning outcomes.

From this explanation, this study aims to fill the research gap from previous studies by testing the practicality and effectiveness of markerless augmented reality integrated learning media on buffer solution material on the learning outcomes of Phase F students in class XI IPA. Hopefully, this research will provide innovations and contributions in digital technology-based chemistry learning media that are more practical, effective, & follow 21^{st}-century learning needs.

2. Literature Review

2.1. Practicality

Practicality refers to the extent to which an intervention or product can be used realistically and effectively in a real learning environment (Plomp & Nieveen, 2013). In education, this aspect is essential because it determines the applicability and sustainability of using a medium, device, or learning strategy by end users, namely teachers and Students (Nieveen, 1999). An intervention is considered practical if it is easy to use, suits users' needs, and aligns with real conditions in the classroom. Practicality can be assessed through two perspectives: expected practicality, which is assessed before implementation, and actual practicality, which is observed during use in the field (Plomp & Nieveen, 2013). In this study, the expected practicality aspect was studied, with the aspects assessed in the practicality test of augmented reality media integrated with markerless augmented reality on buffer solution material, namely ease of use, efficiency, and media benefits.

2.2. Effectiveness

Effectiveness can be interpreted as the level of usefulness of an intervention in achieving the target that has been designed before. In the realm of learning activities, effectiveness shows the extent to which the media or innovation can encourage improving student learning outcomes (Plomp & Nieveen, 2013). Evaluation of effectiveness is usually done by comparing scores before and after the intervention, namely pretest and posttest, to see if there is a significant improvement. Although a medium is considered practical, without sufficient effectiveness, its application will not provide optimal benefits. Therefore, effectiveness is often the primary focus in educational research to determine the feasibility of using a medium more broadly (Surya & Moramowati, 2023). Practicality and effectiveness complement each other; practicality ensures implementation, while effectiveness ensures the usefulness of the intervention for achieving learning outcomes. In this study, the effectiveness test was measured from students' learning outcomes before (pretest) and after (posttest) learning in the cognitive domain.

2.3. Media and Learning

Learning media is used during the learning process to effectively and accurately convey the lesson's content from the source to the Students (Latuheru in Basri & Sumargono, 2018; Pagarra et al., 2022). This media includes software (message content) and hardware (tools or technology) that functions not only as a teacher's support, but also as the main learning media (Kristanto, 2016). In its selection, educators must consider the media's suitability to stimulate students' cognitive, affective, and psychomotor aspects (Daniyati et al., 2023; Wulandari et al., 2023). Learning media are divided into visual and audiovisual media, each having a strategic role in supporting understanding and learning experiences. According to Levie & Lents (1982), media have four main functions: attention function, affective function, cognitive function, and compensatory function. Thus, learning media is not only a means of delivering information, but also a vehicle for organizing interactions, uniform learning processes, and collaborative improvement of learning outcomes (Hasan et al., 2021).

2.4. Augmented Reality

Technology development at this time has encouraged using Augmented Reality (AR) as a means of creative and interactive learning. Augmented reality technology is a system that unites virtual elements with the real world directly, in real-time, and registered in three-dimensional form (Azuma et al., 2001). Augmented reality can be used for various educational purposes, such as visualization of abstract concepts, interactive simulations, and presentation of information in an interesting way. Based on the method, augmented reality is divided into marker-based and markerless, where markerless augmented reality allows users to display digital objects without printing markers, but rather through the recognition of the location or position of the device (Brito & Stoyanova, 2018). In learning, markerless augmented reality offers flexibility of access, real and virtual world interaction, and visualization of microscopic entities such as atoms and molecules, making it very suitable to be applied to abstract chemical materials. In addition, augmented reality can stimulate various senses of Students, strengthen conceptual understanding, and increase engagement in the learning process (Munawir et al., 2024), making it a practical and relevant medium to support 21st-century learning goals.

Previous studies have shown that Augmented Reality-based learning media are efficient and effective in learning chemistry, especially in abstract materials such as buffer solutions. Aini (2022) found that the augmented reality integrated chemistry module was feasible and received positive student responses, although there were still technical limitations. Salsabila (2022) also shows that augmented reality applications for practicum of buffer solution are valid, practical, and very feasible to be used by students. Similar findings were revealed by Almubarak et al. (2021), which showed high practicality and validity values on the AR-Sparkol integrated wetland-based module. Regarding effectiveness, Hoai et al. (2024) and Amirbekova et al. (2024) confirmed that using augmented reality significantly improved students' understanding of chemical concepts, learning motivation, and learning outcomes in a modern learning context.

Research by Damayanti & Guspatni (2024) and Santika & Guspatni (2024) also confirmed that augmented reality-based media in chemistry can significantly improve learning outcomes

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based on N-Gain and t-test values. These results become an important foothold in this study, which aims to develop a markerless Augmented Reality integrated buffer solution learning media that is not only materially valid, but also practical for teachers and students and effective in improving the learning outcomes of Phase F students.

2.5. Multiple Representations in Chemistry

Multiple representation refers to using several forms of representation to describe a concept or phenomenon, including verbal, graphic, tabular, mathematical, figurative, visual, and operational representations (Waldrip et al., 2006). In the context of chemistry learning, this approach is known as the Chemistry Triplet, which consists of three levels of representation: macroscopic, sub-microscopic, and symbolic (Talanquer, 2011).

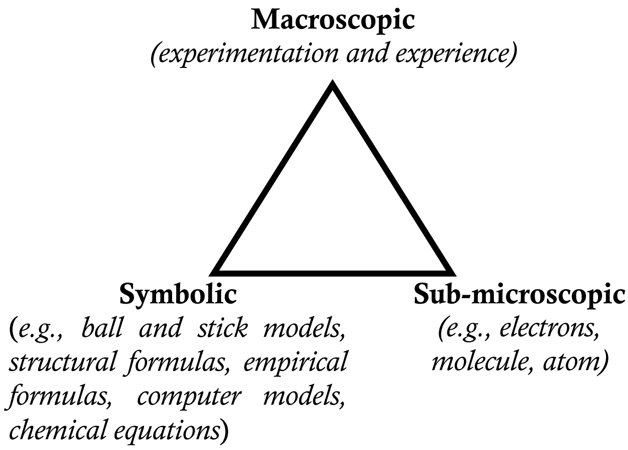

Figure.1. Three Levels of Representation in Chemistry (Treagust et al., 2003)

The macroscopic level reflects real observed phenomena; the sub-microscopic level explains processes at the particle level, such as atoms and molecules. In contrast, the symbolic level presents information through symbols, formulas, and equations (Treagust et al., 2003). These three levels are interconnected and need to be integrated in learning chemistry so that students can build a deep and comprehensive conceptual understanding (Kirna, 2012). Integration of multiple representations is proven to improve students' cognitive understanding and get positive responses in the learning process (Habibah et al., 2023).

2.6. Learning Outcomes

Learning outcomes become a benchmark in assessing the extent of student understanding after going through the learning process, which can be observed through evaluation through exams or assignments (Artama et al., 2023). Bloom in Ulfah & Arifudin (2023) categorizes learning outcomes into 3 domains, namely cognitive (knowledge and intellectual skills), affective (attitudes and emotions), and psychomotor (physical skills and real actions). In subsequent developments, Anderson et al. revised Bloom's Taxonomy by distinguishing between cognitive dimensions and cognitive process dimensions (Munzenmaier & Rubin, 2013). These dimensions are used to design learning objectives and question difficulty levels. In the context of this research, the measurement of learning outcomes is focused on the cognitive domain through pretests and posttests, because the buffer solution material emphasizes concept understanding as an important foundation, so that increasing students' knowledge and understanding becomes the leading indicator of the effectiveness of markerless augmented reality-based learning media.

Cognitive learning outcomes are related to the ability of students to understand, remember, and apply the knowledge that has been learned. Augmented reality technology contributes significantly to supporting the achievement of cognitive learning outcomes because it can present information visually and interactively, following dual-channel-processing theory, where the brain processes information simultaneously through visual and verbal channels, as well as cognitive-load theory, which emphasizes the importance of reducing cognitive load in learning. Several studies support this, such as those conducted by Hoai et al. (2024) and Damayanti & Guspatni (2024), which showed a significant increase in students' cognitive learning outcomes after using augmented reality-based media. Visualization of abstract concepts, such as buffer solution, becomes more concrete through interactive simulations, thus helping understand and retain information more effectively. Thus, using augmented reality in chemistry learning can improve students' cognitive learning outcomes.

2.7. Material Characteristics of Buffer Solutions

Buffer solution material has complex characteristics because it contains abstract concepts, such as equilibrium reactions and pH, which must be explained through a multiple representation approach (macroscopic, sub-microscopic, and symbolic) to form a comprehensive understanding. Macroscopic aspects include real phenomena such as indicator color changes; sub-microscopic features visualization of the particles that make up the solution; and symbolic representation by chemical reaction equations. These three levels require a strong delivery strategy to visualize abstract concepts well. In addition, this material includes factual (such as the components of buffer solutions), conceptual (such as the principle of equilibrium), and procedural (such as how to calculate pH using the Henderson-Hasselbalch formula) knowledge (Bhagavan, 2002). This material is also closely related to real-life contexts, such as its role in maintaining the pH stability of human blood, the fermentation industry, waste treatment, and drug production, so it is important to be delivered contextually so that students can relate learning to practical applications in everyday life.

Based on previous studies, the most significant misconceptions in buffer solution material were found in the mechanism of action of buffer solutions with a percentage reaching 51% (Nurhujaimah et al., 2016), which is in line with the results of other diagnostic assessments that show difficulties in understanding the mechanism of action, calculation of pH, and interpretation of equilibrium principles (Mapada et al., 2022; Pramesti, 2023). As a result, Students experience barriers in explaining how adding an acid or base does not directly change the pH of the solution drastically. Therefore, the multiple representation approach is crucial to reduce misconceptions and build conceptual understanding on buffer solution material.

3. Research Methods

This research continues the previous development with the *Educational Design Research* (EDR) approach using the Plomp development model (Plomp & Nieveen, 2013). This research tests the practicality and effectiveness of the markerless augmented reality integrated learning media validated for the buffer solution class XI SMA/MA. The type of research applied is pre-experimental design with a one-group pretest-posttest design, where one sample group is given treatment without a control group (Sugiyono, 2019). This type is taken because this research aims to test the effectiveness of learning media and allows researchers to compare learning outcomes before and after the application of the media, so that changes that occur can be assumed as a result of the treatment given. This design involves three stages, namely 1) pretest,

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2) treatment by providing markerless augmented reality integrated learning media, and 3) posttest to assess the effect of the media on learning outcomes. The research was conducted in the 2024/2025 academic year.

The population for this study was students in class XI IPA 2 at MAN 3 Padang City Plus Skills, with a total sample of 31 people taken through a purposive sampling technique based on the suitability/compatibility of the devices used by students as selection criteria. This study has an independent variable in the form of utilization of markerless augmented reality-based teaching media, while the dependent variable is students' cognitive achievement. The data collected consisted of quantitative and qualitative data, which were obtained through the distribution of practicality questionnaires and pretest-posttest tests. The questionnaire instrument assessed the practicality aspects of teachers and students. At the same time, the pretest and posttest questions consisted of eight essay questions that had gone through a validation process and had high reliability (0.88), with the quality of the questions based on Rasch analysis showing a good index of difficulty and differentiation, which had been developed by Hutagalung and Aini (2023).

The research procedure includes two main stages, namely the practicality test and the effectiveness test. The practicality test involved three teachers and ten students to assess the media's ease of use, efficiency, and benefits. The effectiveness test was carried out through giving a pretest, learning using the media, and giving a posttest to the experimental class. Data analysis techniques were carried out in stages, namely questionnaire analysis with a percentage formula to measure the level of media practicality, N-Gain test to see the improvement of learning outcomes, Kolmogorov-Smirnov normality test to determine data distribution, and paired sample t-test to test significant differences between pretest and posttest scores.

4. Results and Discussion

This study tests the practicality and effectiveness of learning media integrated with markerless augmented reality on buffer solution material. The results were obtained by filling out a practicality questionnaire by teachers and students and cognitive domain learning outcomes tests (pretest and posttest) from 31 students of class XI IPA 2. The data was collected during May-June 2025.

4.1. Research Results

4.1.1. Practicality Test Results

The results of the practicality test showed that the learning media that had been developed were in the "practical" category according to students, with an average percentage of 83.13% and "very practical" according to teachers, with an average of 89.55%. The assessed aspects include ease of use, time efficiency, and the benefits of media in learning. All indicators generally scored above 75%, indicating positive user acceptance

Table.1. Practicality Test Results on Teachers and Students

No.	Assessment Indicator	Students	Teacher
1.	Ease of Media Use	84.28%	90.47%
2.	Efficiency of Learning Time	83.33%	88.88%
3.	Benefits of Learning Media	81.78%	89.28%
	Average	83.13%	89.55%
	Decision Criteria	**Practical**	**Very Practical**

Several visual interfaces of the markerless augmented reality-integrated instructional media for the buffer solution topic are presented below.

Figure.2. Main Interface of the Learning Application

Figure.3. Display of Prerequisite Learning Materials

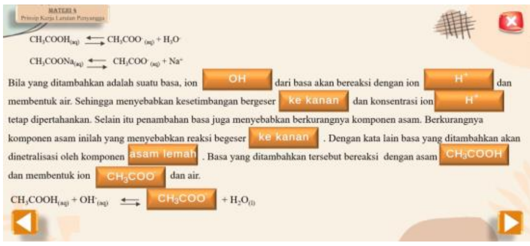

Figure.4. Display of Subtopic-Based Learning Content

Figure.5. Display of Preliminary Questions

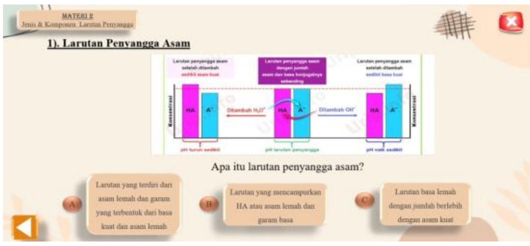

Figure.6. Display of Preliminary Questions

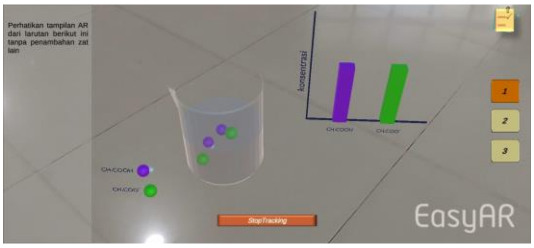

Figure.7. Display of Markerless Augmented Reality Feature

4.1.2. Effectiveness Test Results

The effectiveness of learning media is assessed based on students' pretest and posttest scores in the cognitive domain. The average pretest score before learning is 10.03, while the posttest score after learning increases to 63.60. The following table shows the percentage of students answering correctly per Learning Objective.

Table.2. The Percentage of Students' Answers by Learning Objective

Learning Objective	Question Number	Percentage of Correct Answers	
		Pretest Score	Posttest Score
Explain the components of buffer solution	1 and 2	27%	80.65%
Explaining the working principle of buffer solution	3 and 4	2.62%	54.03%
Calculating the pH of buffer solution	5 and 6	20.4%	79.72%
Explaining the function of buffer solution in daily life	7 and 8	2.15%	51.88%

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Table 2 shows the difference between the average pretest and posttest scores on the buffer solution sub-matter based on the Learning Objectives to be achieved. Then the N-Gain test was carried out on students' learning outcomes, which are presented in Table 3.

Table.3. N-Gain Test Results

Data	N	Pretest Average	Posttest Average	Average N-Gain	Category
Pretest and Posttest	31	10.03	63.60	0.61	Medium

Referring to the N-Gain value in Table 3, the N-Gain test results resulted in an average value of 0.61. This value is in the medium/medium category (Hake, 1998). The increase in the average value analyzed indicates increased learning outcomes and understanding of the material among students. Furthermore, the Kolmogorov-Smirnov normality test was carried out with a significance level (α) 0.05. This test produces a D_{max} value, where if the D_{max} value is lower than D_{table}, it indicates that the researcher rejects the null hypothesis, stating that the sample is usually distributed. The results of the normality test on the sample class can be seen in Table 4.

Table.4. Normality Test Results Using Excel

Test	N	D_{max}	D_{table}	Distribution
Pretest	31	0.217	0.238	Normally Distributed
Posttest	31	0.113	0.238	Normally Distributed

Table 4 shows D_{max} for pretest data is D_{max} (0.217) < D_{table} (0.238), and for posttest data D_{max} (0.113) < D_{table} (0.238). Because both datasets have D_{max} < D_{table}, the data obtained are normally distributed; therefore, the hypothesis test is continued. The normality test for the pretest and posttest data was conducted using two analytical tools, namely Microsoft Excel and SPSS. The Kolmogorov-Smirnov test in Excel indicated that the data were normally distributed; however, the results obtained through SPSS showed that the data were not normally distributed.

Tabel.5. Normality Test Result Using SPSS

	Statistic	df	Sig.
Pretest	0.218	31	0.001
Posttest	0.171	31	0.021

According to the guidelines provided by Field (2013), conducting normality testing using SPSS is more appropriate, as this software offers more accurate and objective inferential statistical tests compared to the exploratory descriptive analysis available in Excel. Therefore, the normality test results from SPSS were adopted as the primary reference. Consequently, since the data did not meet the assumption of normality, the analysis was continued using the Wilcoxon Signed-Rank Test as a non-parametric alternative to the parametric test.

Table.6. Wilcoxon Signed Ranks Test Result

Sum of Ranks	Mean Rank	Z	Asymp. Sig. (one-tailed)	W_{table}	W_{stat}	Signifikansi (α)	Description
496	16.00	-4.861	0.000	163	0.00	0.05	H_0 rejected, H_1 accepted

The one-tailed Wilcoxon Signed-Rank Test results showed W_{stat} = 0.00 < W_{table} = 163, Z = -4.861, Positive Ranks = 31 (Mean Rank = 16.00), Negative Ranks = 0 (Mean Rank = 0.00), and Asymp. Sig. (2-tailed) = 0.000001.

4.2. Discussion

Based on the results of the practicality test in Table 1, the markerless augmented reality integrated learning media is declared practical in three aspects: ease of use, time efficiency, and media benefits. The ease of use aspect is shown by the high score on the application interface indicator, clarity of material, and 3D visualization that is easily accessible without technical training. This practicality is supported by intuitive interface design and markerless technology that does not require physical markers so that users can use the cellphone camera (Aditia, 2024). Firmansyah's (2025) research confirms that good interface and navigation greatly affect the perception of practicality.

Regarding time efficiency, this media helps deliver abstract material such as buffer solutions more systematically and concisely and can be used offline, supporting learning flexibility (Handayani & Asih, 2024). 3D visualization makes learning chemistry easier to understand, following the results of research by Sahidi et al. (2025) and Tasya'ah et al. (2025), which states that augmented reality effectively represents chemical concepts. In terms of benefits, this media increases motivation and understanding of concepts. Interactive simulations make abstract concepts more real (Dendodi et al., 2024), and follow the digital-native generation's learning style (Ningrum et al., 2025). Overall, this media is feasible to use as a learning tool that is adaptive to the needs of the times.

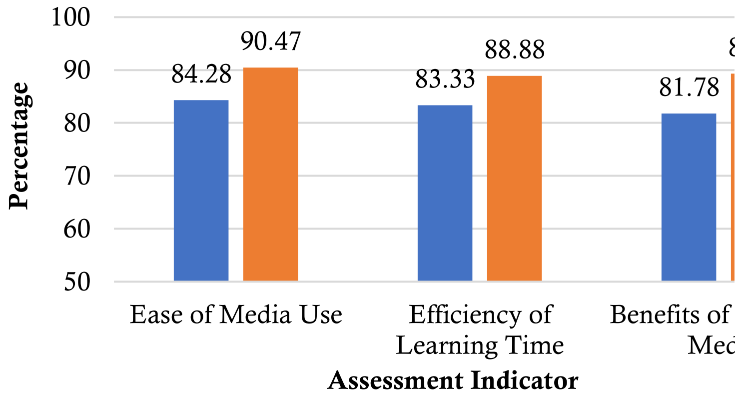

Figure.8. Percentage of Practical Test Results

The effectiveness test results showed that the media significantly improved cognitive learning outcomes, in line with the findings of Amirbekova et al. (2024), Santika & Guspatni (2024), and Damayanti & Guspatni (2024). The increase in scores indicates an improvement in mastery of the concept of buffer solution, both macroscopic, sub-microscopic, and symbolic. Gopalan et al. (2023) also stated that augmented reality increases understanding, motivation, and learning concentration.

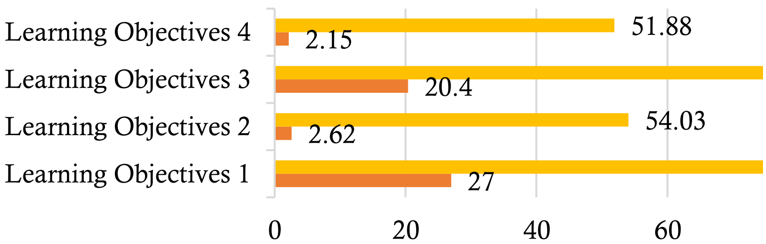

Figure.9. Improvement in Student Learning Outcomes

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In more detail, increased understanding occurs in all indicators of learning objectives. At level 1 chemical representation (submicroscopic), the ability to explain the components of buffer solution increased from 27% to 80.65%. This shows that after using the media, students are better able to identify and name the types and components of buffer solutions, such as weak acid mixtures and their conjugate bases. The 3D visualization in the application allows students to see the actual form of buffer solutions in real-life contexts, which previously could only be obtained through text or flat illustrations in books (Aini, 2022; Salsabila, 2022). At level 3 chemical representation (macroscopic, submicroscopic, and symbolic), the understanding of the working principle of the solution increased from 2.62% to 54.03%. This indicates that students are beginning to understand the mechanism of buffer solutions at the particle level. This is an aspect that is traditionally difficult to understand because it is invisible to the naked eye. However, with the help of markerless augmented reality, students can directly observe simulations of ion particle interactions in solutions, such as the addition of H^+ ions from the addition of a small amount of strong acid, and how they eventually bind with their conjugate bases, thereby building a stronger mental representation. The ability to construct microscopic knowledge is crucial in chemistry education as it serves as a bridge to understanding reaction dynamics (Suparwati, 2022). At level 1 chemical representation (symbolic), the increase from 20.4% to 79.72% reflects the Students' ability to calculate the pH of the solution. This increase is very significant because it shows that students not only understand the concepts theoretically but are also able to operate formulas for calculating the pH of buffer solutions. This indicates that learning media can support symbolic processing and improve conceptual mastery of the material (Syahri, 2023). In the last indicator, which explains the function of buffer solutions, in chemical representation level 1 (symbolic), the increase from 2.15% to 51.88% reflects the students' ability to relate the chemical concepts they have learned to their application in real-life contexts. This increase not only shows an improvement in factual and conceptual knowledge. Students are now better able to explain how buffer solutions work in the human body and in the agricultural industry. The increase observed in all four indicators demonstrates that this medium can support students' understanding of both factual and conceptual knowledge. This is in line with the multiple representations approach proposed by Johnstone, which states that a complete understanding of chemical concepts is built through three levels of representation: macroscopic (what can be seen directly), microscopic (what happens to particles), and symbolic (what can be formulated or calculated)(Salsabila, 2022; Treagust et al., 2003).

The effectiveness of the markerless augmented reality–integrated learning media in improving students' learning outcomes on buffer solution material is supported by the results of the N-Gain analysis and the paired sample t-test. Based on the N-Gain test results (Table 3), the average pretest score of 10.03 increased to 63.60 in the posttest, with an average N-Gain of 0.61, which falls into the moderate category according to Hake's (1998) classification. This category indicates that the learning media positively impacted improving students' learning outcomes.

Furthermore, the results of the Wilcoxon Signed Ranks Test provide strong statistical support for the effectiveness of the learning media. As presented in Table 6, the one-tailed Asymp. Sig. value was 10^{-6} (0.000001), which is far below the significance level of $\alpha = 0.05$. In addition, the calculated W_{value} (W_{stat}) of 0.00 was lower than the W critical value (W_{table}) of 163, leading to the acceptance of H_1 and the rejection of H_0. This indicates a statistically significant difference between the pretest and posttest scores, thereby confirming that there was a substantial improvement in students' cognitive learning outcomes after the implementation of the markerless augmented reality–integrated learning media.

These findings are consistent with previous studies showing that augmented reality–based media can enhance students' understanding in symbolic and conceptual processing, which are commonly challenging areas in chemistry learning. The media's ability to integrate macroscopic, microscopic, and symbolic representations enables students to develop a more comprehensive and meaningful understanding of buffer solution concepts.

All of these improvements indicate the effectiveness of the media in building a comprehensive chemical representation, as confirmed by the theory of multiple representations (Treagust et al., 2003). In addition to improving learning outcomes in the cognitive domain, students also respond positively to this media (Habibah et al., 2023). Thus, markerless augmented reality is important in presenting contextual and engaging chemistry learning (Rachim et al., 2024).

In its implementation, media distribution is done through Google Drive, but limited device compatibility requires an alternative transfer via Bluetooth. However, the relatively small file size (102 MB) facilitates distribution. This media can be a solution to previous limitations in similar research, with its advantages, namely, the media produced in the form of applications that can be accessed without using the internet. Second, this media is markerless, so there is no need to print or bring markers to bring up the augmented reality display. Third, it is easy to carry everywhere because it is available on students' cell phones. Based on the results and implementation, this media is practical and feasible to support chemistry learning, especially buffer solution material.

5. Conclusion

Markerless augmented reality integrated learning media is proven practical and effective in improving students' cognitive learning outcomes on buffer solution material. The practicality of the media is reflected in the ease of use, time efficiency, and benefits of helping to understand abstract concepts through interactive 3D visualization. The effectiveness of the media is indicated by a significant increase in posttest scores and N-Gain test results, which are in the moderate category. These findings contribute to the scientific development in educational technology, especially in applying markerless augmented reality as a means of experiential learning that supports digital scientific transformation. Therefore, this media is recommended as an innovative alternative in learning chemistry, especially in complex materials that require a multiple representations approach. Further research is recommended to evaluate the use of this media on a broader scale and aspects of learning motivation, chemical literacy, learning achievement, and others.

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