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Development of Assemblr-Integrated Augmented Reality Science Media for Enhancing Elementary Students' Critical Thinking Skills

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Abstract

The limited use of interactive learning media and the low level of elementary students' critical thinking skills have become major challenges in science learning. This study aimed to develop Assemblr-integrated Augmented Reality (AR) science learning media and evaluate its feasibility and effectiveness in improving the critical thinking skills of fourth-grade elementary school students. This research employed the Research and Development (R&D) method using the ADDIE model. The participants were 60 fourth-grade students divided into an experimental class and a control class. Data were collected through expert validation questionnaires, pretests, posttests, and documentation. The data were analyzed using descriptive statistics, N-Gain analysis, the Wilcoxon Signed Rank Test, and the Mann–Whitney U Test. The developed media obtained validation scores of 91.9% from material experts, 91.6% from language experts, and 87.0% from design experts, with an overall average of 90.2%, indicating that the media was highly feasible. The experimental class achieved an N-Gain score of 0.71 (high category), while the Wilcoxon Signed Rank Test and Mann–Whitney U Test revealed statistically significant differences ($p < 0.05$). These findings indicate that Assemblr-integrated AR learning media is feasible and effective in improving the critical thinking skills of fourth-grade elementary school students.

Keywords: Augmented Reality; Assemblr; Science Learning Media; Critical Thinking Skills.

Abstrak

Rendahnya kemampuan berpikir kritis siswa serta masih terbatasnya penggunaan media pembelajaran interaktif menjadi salah satu permasalahan dalam pembelajaran IPA di sekolah dasar. Penelitian ini bertujuan mengembangkan media pembelajaran IPA berbasis Augmented Reality *(AR) terintegrasi Assemblr serta menguji kelayakan dan efektivitasnya dalam meningkatkan kemampuan berpikir kritis siswa kelas 4 sekolah dasar. Penelitian ini menggunakan metode* Research and Development *(R&D) dengan model ADDIE. Subjek penelitian berjumlah 60 siswa kelas 4 yang dibagi ke dalam kelas eksperimen dan kelas kontrol. Data dikumpulkan melalui angket validasi ahli, pretest, posttest, dan dokumentasi. Analisis data dilakukan menggunakan statistik deskriptif, uji N-Gain,* Wilcoxon Signed Rank

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Test, *dan* Mann–Whitney U Test. *Hasil penelitian menunjukkan bahwa media yang dikembangkan memperoleh skor validasi sebesar 91,9% dari ahli materi, 91,6% dari ahli bahasa, dan 87,0% dari ahli desain dengan rata-rata keseluruhan sebesar 90,2% sehingga termasuk kategori sangat layak. Kelas eksperimen memperoleh nilai N-Gain sebesar 0,71 (kategori tinggi), sedangkan hasil* Wilcoxon Signed Rank Test *dan* Mann–Whitney U Test *menunjukkan adanya perbedaan yang signifikan (**p**< 0,05). Temuan tersebut menunjukkan bahwa media pembelajaran IPA berbasis AR terintegrasi Assemblr layak dan efektif dalam meningkatkan kemampuan berpikir kritis siswa kelas 4 sekolah dasar.*
Kata kunci: Augmented Reality*; Assemblr; Media Pembelajaran IPA; Kemampuan Berpikir Kritis.*

INTRODUCTION

The development of technology in the 21st century has brought significant changes to the field of education, particularly in the learning process at the elementary school level (Triwoelandari, Rahmawati, and Gustiawati, 2023:2). Education is no longer focused solely on delivering learning materials, but also requires students to possess 21st-century skills such as critical thinking, creativity, collaboration, and communication (Rahmanda, 2025:73). Among these skills, critical thinking is considered one of the essential abilities that must be developed from an early age because it helps students understand information, analyze problems, evaluate evidence, and make logical decisions based on strong evidence. Through critical thinking skills, students are expected to solve both simple and complex problems (Putri et al., 2023:24254). Ennis, as cited in Hasanah et al. (2023:16), defines critical thinking as reflective and rational thinking used to determine what should be believed or done based on available evidence. In elementary science learning, this skill is particularly important because students are expected to investigate natural phenomena through scientific inquiry and logical reasoning.

According to Ritonga, Halimah Sakdiah Boru Gultom, and Nazliah (2020:42), science learning provides opportunities for students to develop scientific attitudes and critical thinking skills through direct experience and scientific inquiry. These skills should be fostered from the elementary school level because they play an important role in helping students solve problems encountered in their daily lives. However, Ramadani and Syafira (2026:101), reported that science learning in elementary schools remains predominantly teacher-centered, and the learning process tends to be one-way, limiting students' opportunities to develop higher-order thinking skills. In addition, the learning media commonly used in elementary schools remain limited to textbooks, static images, and simple

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presentations, providing limited opportunities to foster students' critical thinking skills (Halizah. A et al., 2025:3). Consistent with these findings, a preliminary observation conducted at SDIT Arrohmaniyah Bogor revealed that science learning primarily relied on textbooks, while the use of interactive learning media remained limited. Consequently, students had limited opportunities to engage in learning activities that encouraged them to analyze scientific phenomena, evaluate information, and draw conclusions based on evidence. These findings indicate the need for innovative learning media to support the development of students' critical thinking skills in science learning.

Since elementary school students are in Piaget's concrete operational stage, they require learning media capable of presenting abstract concepts in concrete and meaningful ways. Therefore, technology-based learning media have become a relevant alternative for supporting effective and interactive science learning(Tanod et al., 2025:560).

One of the emerging technologies in education is Augmented Reality (AR), which integrates virtual objects into real-world environments in real time, enabling students to interact with two-dimensional and three-dimensional objects (Rahmawati and Salimah, 2024:624). AR is characterized by the integration of real and virtual environments, real-time interaction, and the visualization of three-dimensional objects within real settings, making abstract science concepts more concrete and easier for students to understand (Angraini, 2023:36). In addition, Augmented Reality has been increasingly adopted in various fields, including education, due to its ability to provide interactive and immersive experiences (Saputro and Saputra, 2025:154). Therefore, AR has considerable potential in science learning because it encourages students to observe, analyze, evaluate, and draw conclusions systematically, thereby supporting the development of critical thinking skills.

Assemblr is an AR-based platform that enables teachers to create interactive learning media without requiring programming skills (Ramli, 2022:700). The platform provides a variety of two-dimensional and three-dimensional objects, as well as multimedia features such as animations, videos, and text that can be adapted to science learning needs (Monica, 2025:579). These features enable teachers to design more engaging learning experiences, encourage students' active participation, and facilitate student-centered learning. Consequently, Assemblr serves as a suitable platform for integrating Augmented Reality into science learning to support the development of students' critical thinking skills.

Previous studies have consistently reported the positive impact of Augmented Reality on students' critical thinking skills. Ghifari, Rienovita, and Amelia, (2025:31) found that AR-

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based learning media effectively improved students' critical thinking skills in science learning. Similarly, Saki, Usodo, and Santosa, (2025:40), reported that AR enhanced both elementary school students' critical thinking skills and learning interest. In addition, Handayani, (2025:450), demonstrated that Assemblr Edu-based learning media positively contributed to the development of students' critical thinking skills. These findings indicate the potential of AR to enhance science learning and provide a strong foundation for further research.

Nevertheless, several gaps remain in previous studies. Most previous research focused more on learning outcomes, motivation, or creative thinking skills rather than critical thinking skills in elementary science learning (Defita et al., 2025:1462). In addition, studies regarding the development of Augmented Reality-based science learning media integrated with Assemblr for fourth-grade elementary school students are still limited. Previous studies also predominantly used experimental methods rather than development research employing the ADDIE model.

To address these research gaps, this study develops an Assemblr-integrated Augmented Reality science learning media using the ADDIE model. The novelty of this study lies in the development of an Assemblr-integrated Augmented Reality learning media for fourth-grade elementary science learning while evaluating both its feasibility and effectiveness in improving students' critical thinking skills. Therefore, this study aims to develop the proposed learning media, evaluate its feasibility, and examine its effectiveness in enhancing fourth-grade students' critical thinking skills.

RESEARCH METHODS

This study used the Research and Development (R&D) method with the ADDIE model consisting of five stages, namely Analysis, Design, Development, Implementation, and Evaluation (Slamet, 2022:25). At the analysis stage, a learning needs analysis was conducted through interviews with fourth-grade teachers to identify the conditions of science learning, the use of learning media, and students' critical thinking skills. The design stage involved designing the Augmented Reality-based learning media, preparing learning materials, and developing the research instruments. The development stage involved creating the media using the Assemblr platform and validating the product through material, language, and design experts. The implementation stage involved classroom trials using a quasi-experimental pretest–posttest control group design, in which the developed media was

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implemented in the experimental class, while the control class received conventional instruction. Both groups completed pretests and posttests to measure the improvement of students' critical thinking skills. Finally, the evaluation stage was conducted to evaluate the effectiveness of the developed media based on the improvement in students' critical thinking skills as measured through the pretest and posttest results. The research was conducted at SDIT Arrohmaniyah located at Jl. K.H. Ahmad Sya'yani No.03, RT.05/RW.11, Mekarwangi Village, Tanah Sereal District, Bogor City, West Java 16168, with fourth-grade students as the research subjects. The research subjects consisted of 60 students from classes 4A and 4B who were involved in the implementation stage of the learning media. In addition, 8 students from class 4C were involved in the product trial stage, consisting of 3 students in the individual trial and 5 students in the small-group trial. Meanwhile, class 4D was used for the validity testing of the test instrument. This study also involved expert validators consisting of material experts, language experts, and design experts.

Data collection techniques were carried out through interviews, questionnaires, tests, and documentation (Sugiyono, 2023:194). Interviews were conducted with fourth-grade teachers to obtain information regarding science learning at school. Questionnaires were used to obtain media validation data from material experts, language experts, and design experts. Tests were administered to the experimental and control classes through pretests and posttests to measure the improvement of students' critical thinking skills after learning using AR media in the experimental class and without AR media in the control class. Documentation was used to support the research data in the form of photographs of activities during the research process. The validation sheets were prepared using a Likert scale (Sugiyono, 2023:145). The research instruments included interview sheets, expert validation sheets, and students' critical thinking skill test questions. The essay test was developed based on Ennis' critical thinking indicators, namely elementary clarification, basic support, inference, advanced clarification, and strategies and tactics. The test instruments had undergone validity and reliability testing to ensure the validity and consistency of the test items before being implemented in the study. Data analysis techniques were conducted using descriptive quantitative and inferential analysis (Sugiyono, 2023:206). Descriptive analysis was used to describe the pretest, posttest, and N-Gain scores in each class. N-Gain analysis was used to determine the improvement of students' critical thinking skills in the experimental and control classes. Inferential analysis was conducted using two techniques, namely the Wilcoxon Signed Rank Test to determine differences in critical thinking skills before and

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after treatment in each class, and the Mann–Whitney Test to determine differences in the improvement of critical thinking skills between the experimental class (4A) and the control class (4B). The use of these nonparametric tests was due to the data not being normally distributed.

RESULT AND DISCUSSION

Results

1. **Results of ADDIE-Based Media Development**

   The development of Augmented Reality (AR)-based science learning media integrated with Assemblr was carried out using the ADDIE model. At the analysis stage, it was found that fourth-grade students still experienced difficulties in developing critical thinking skills in abstract science learning, and the learning process was still dominated by conventional methods. At the design stage, the media design was developed in the form of storyboards, interaction flows, and material mapping into interactive 3D objects. The development stage produced an AR learning media product that could be used through digital devices with visualization and learning object interaction features. Furthermore, at the development stage, the AR learning media was produced and then validated by material experts, language experts, and design experts to determine the feasibility level of the media before being implemented in learning activities.

   The developed media integrates Augmented Reality technology with the Assemblr platform to create a more interactive and engaging science learning experience for elementary school students. The media was designed to help students visualize abstract science concepts through three-dimensional objects that can be directly observed and explored using digital devices. Through this learning media, students are expected to become more active during the learning process and better understand science concepts through direct interaction with the displayed AR objects.

2. **Expert Validation Results**

   The developed product was then tested for feasibility by material experts, language experts, and design experts.

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Calculation of Material Expert Validation Percentage

Table 1. Material Expert Validation Results

No	Assessment Aspect	Maximum Score	Obtained Score
1	Content Feasibility	72	66
2	Presentation Feasibility	36	33
3	Contextual Aspect	28	26
	Total	**136**	**125**

The feasibility percentage was calculated using the following formula adapted from Sugiyono, (2023:412):

$$P=\frac{\Sigma X}{\Sigma Xi} \text{ x } 100\%$$

Notes:
P : Feasibility percentage
ΣX : Total obtained score
ΣXi : Maximum score

Based on the material expert validation results, a total score of 125 out of the maximum score of 136 was obtained, resulting in the following calculation:

$$P=\frac{125}{136}\times 100\% = 91{,}9\%$$

Notes:

- The maximum score was obtained from the number of items × the highest score.
- Content feasibility: 18 × 4 = 72
- Presentation feasibility: 9 × 4 = 36
- Contextual aspect: 7 × 4 = 28

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Table 2. Feasibility Interpretation Criteria

Percentage	Category
81%–100%	Very Feasible
61%–80%	Feasible
41%–60%	Fairly Feasible
21%–40%	Less Feasible
0%–20%	Not Feasible

Source:(Sugiyono 2023:415)

Based on the calculation results, the developed learning media obtained a percentage of 91.9% and was categorized as "Very Feasible"

Table 3. Language Expert Validation Results

No	Assessment Aspect	Maximum Score	Obtained Score
1	Language Aspect	72	66

The feasibility percentage was calculated using the following formula:

$$P=\frac{\Sigma X}{\Sigma Xi} \times 100\%$$

Notes:

P : Feasibility percentage
ΣX : Total obtained score
ΣXi : Maximum score

Based on the calculation results, it was obtained that:

$$P = \frac{66}{72} \times 100\% = 91{,}6\%$$

The percentage of 91.6% indicates that the developed AR-based learning media was categorized as "Very Feasible".

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Table 4. Design Expert Validation Results

No	Assessment Aspect	Maximum Score	Obtained Score
1	Design	124	108

The feasibility percentage was calculated using the following formula:

$$P = \frac{\Sigma X}{\Sigma Xi} \times 100\%$$

Notes:

P : Feasibility percentage
ΣX : Total obtained score
ΣXi : Maximum score

Based on the calculation results, it was obtained that:

$$P = \frac{108}{124} \times 100\% = 87\%$$

The percentage of 87% indicates that the developed AR-based learning media was categorized as "Very Feasible."

After the AR learning media was declared feasible by the experts, the next stage was a limited trial conducted with students. The trial was carried out through individual testing and small-group testing to determine the usability of the media and to observe students' initial responses to the developed media. The individual test was conducted with 3 fourth-grade students from class 4C with different academic abilities. At this stage, students used the media independently with guidance from the researcher. The observation results showed that the students were able to use the media properly, were interested in the AR visual display, and became more active in understanding the science material presented. Furthermore, the small-group test was conducted with 5 fourth-grade students from class 4C. The results showed that the learning media could be used effectively in the learning process. Students appeared more enthusiastic, actively engaged in discussions, and found it easier to understand the material due to the three-dimensional visualization provided by AR technology. Based on the results

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of the limited trial, the media was considered suitable for broader implementation without major revisions.

3. Description of Students' Learning Outcome Statistics

Descriptive analysis was conducted to obtain a general overview of students' learning outcomes before and after the use of AR media.

Table 5. Descriptive Statistics of Pretest and Posttest Results

Class	Stage	N	Minimum Score	Maximum Score	Mean	Standard Deviation
Experimental	Pretest	30	55	95	77.3	11.29
Experimental	Posttest	30	83	100	93.97	4.72
Control	Pretest	30	57	94	79.3	9.74
Control	Posttest	30	60	95	84.07	9.47

Based on Table 5, the results of the descriptive statistical analysis show that there was an improvement in students' critical thinking skills in both classes after the learning process. In the experimental class, the mean score increased from 77.30 to 93.97, with an improvement of 16.67 points, while in the control class it increased from 79.30 to 84.07, or 4.77 points. Although the pretest mean scores in both classes were relatively high, the greater improvement in the experimental class indicates that appropriate learning interventions were still needed to further develop students' critical thinking skills. The improvement in the experimental class was also indicated by the increase in the minimum score from 55 to 83 and the maximum score from 95 to 100. In addition, the standard deviation decreased from 11.29 to 4.72, indicating that students' abilities became more homogeneous after the use of Augmented Reality-based learning media. Meanwhile, in the control class, the increase in minimum and maximum scores was relatively small, from 57 to 60 and from 94 to 95, with a standard deviation that remained relatively high, from 9.74 to 9.47. Overall, these results show that the improvement in students' critical thinking skills in the experimental class was higher than in the control class. Therefore, Augmented Reality-based learning media is considered more effective in improving students' critical thinking skills.

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4. N-Gain Results

To determine the level of effectiveness in improving critical thinking skills, an N-Gain analysis was conducted.

Table 6. N-Gain Score Results

Class	N	Average N-Gain	Category	Minimum	Maximum	Standard Deviation
Experimental	30	0.7113	High	0.08	1.00	0.22964
Control	30	0.2376	Low	0.04	0.72	0.19940

Based on Table 6, the N-Gain analysis showed that the experimental class obtained an average N-Gain score of 0.7113 (high category), whereas the control class obtained an average score of 0.2376 (low category). These findings indicate that students who learned using the Assemblr-integrated Augmented Reality media experienced substantially greater improvement in critical thinking skills than those who received conventional instruction. The descriptive statistics further show that the experimental class demonstrated more consistent improvement than the control class, as reflected in the distribution of N-Gain scores. Overall, these results indicate that the developed learning media was effective in enhancing fourth-grade students' critical thinking skills.

5. Wilcoxon Signed Rank Test Results

The Wilcoxon test was used to determine whether there was a significant difference between the pretest and posttest results because the data were not normally distributed (Putri dan Putri, 2024:160).

Table 7. Wilcoxon Test Results

Class	Negative Ranks	Positive Ranks	Z	p-value	Decision
Experimental	0	30	-4.787	< 0.001	Significant
Control	0	30	-4.798	< 0.001	Significant

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. The Wilcoxon Signed-Rank Test results indicated a statistically significant difference between the pretest and posttest scores in both the experimental and control classes ($p < 0.001$). These findings demonstrate that students' critical thinking skills improved significantly after the learning process in both groups. In the experimental class, all 30 students showed higher posttest scores than pretest scores, as indicated by 30 positive ranks with no negative ranks or ties. Similarly, the control class also demonstrated significant improvement based on the Wilcoxon Signed-Rank Test results. However, the magnitude of improvement was greater in the experimental class than in the control class, as evidenced by the descriptive statistics and N-Gain analysis.

6. Mann–Whitney Test Results

The Mann–Whitney test was conducted to determine the difference in the improvement of students' critical thinking skills between the experimental class and the control class because the data were not normally distributed (Selpia et al., 2024:21).

Table 8. Mann–Whitney Test Results

Mann–Whitney U	Z	Sig. (2-tailed)	Decision
138.5	-4.621	0.000	Significant

The results of the Mann–Whitney U test indicated a significance value of 0.000 ($p < 0.001$), which demonstrates a statistically significant difference in the improvement of students' critical thinking skills between the experimental and control classes. Furthermore, the mean scores and N-Gain analysis revealed that students in the experimental class achieved greater improvement than those in the control class. These findings suggest that the Augmented Reality-based learning media was more effective in enhancing students' critical thinking skills than conventional learning methods.

7. AR Learning Media Display

The media displays science objects in interactive 3D form that can be observed, rotated, and explored by students through digital devices. This visualization helps transform abstract concepts into more concrete and easily understandable forms.

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Figure 1. Augmented Reality-Based Science Learning

Discussion

The effectiveness of the Augmented Reality (AR)-based science learning media can be attributed to its ability to transform abstract science concepts into interactive three-dimensional visualizations. Unlike conventional learning media, AR enables students to observe scientific objects from different perspectives, making learning more concrete and engaging. This interactive learning experience encourages students to actively explore scientific concepts, analyze relationships between phenomena, evaluate information obtained through observation, and draw logical conclusions. These activities support the development of critical thinking skills, as students are actively involved in constructing knowledge rather than passively receiving information.

These findings are consistent with Ennis' theory, which states that critical thinking involves clarification, analysis, evaluation, and inference. The developed AR media facilitated these cognitive processes by providing meaningful learning experiences that encouraged students to observe, question, analyze, and conclude based on evidence. Furthermore, the systematic implementation of the ADDIE model ensured that the media was designed according to students' learning needs, validated by experts, and refined before classroom implementation. This systematic development process contributed to the effectiveness of the media in improving students' critical thinking skills.

These findings are consistent with previous studies reporting the positive impact of Augmented Reality on students' critical thinking skills. Ghifari, Rienovita, and Amelia, (2025:31), found that AR-based learning media significantly improved students' critical thinking skills in science learning by providing interactive learning experiences.

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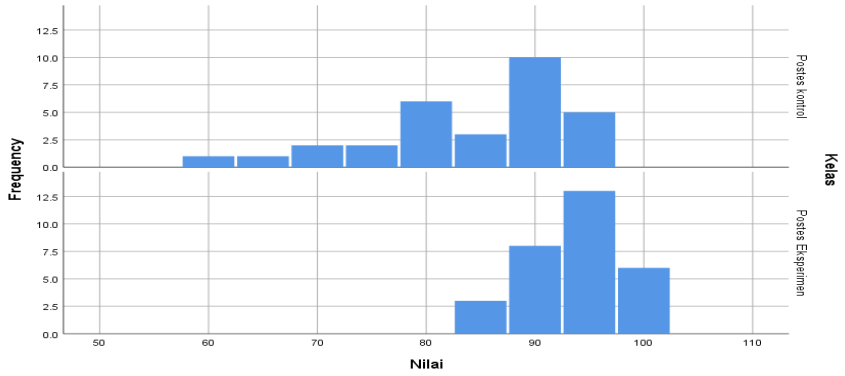
Similarly, Saki, Usodo, and Santosa, (2025:40), reported that the use of Augmented Reality enhanced elementary school students' critical thinking skills and learning interest. In addition, Handayani, (2025:450), demonstrated that Assemblr-based learning media effectively supported the development of students' critical thinking skills. The consistency between the present findings and previous studies indicates that integrating interactive visualization with student-centered learning activities enables students to actively construct knowledge and develop higher-order thinking skills.



Graph 1. Indicators of Improvement in Critical Thinking Skills

Based on the histogram, it can be observed that there is an improvement in students' critical thinking skills after the implementation of learning in the experimental class compared to the control class. In the control class, students' scores are still widely distributed, ranging from approximately 58 to 98. Most students obtained scores in the range of 80–92; however, there are still some students with low scores below 70. This indicates that students' critical thinking skills in the control class are not yet evenly distributed, and some students still experience difficulties. Meanwhile, in the experimental class, the score distribution tends to be higher and more concentrated in the range of 88–100. There are no students with very low scores, and the majority of students achieved scores above 90. The narrower distribution and dominance of high scores indicate that the learning applied in the experimental class was more effective in improving students' critical thinking skills. Thus, it can be concluded that the treatment or learning method in the experimental class had a positive effect on improving students' critical thinking skills compared to the control class.

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Figure 2. Research Activities Using AR Media at SDIT Arrohmaniyah Bogor

CONCLUSION

This study shows that the Augmented Reality (AR)-based science learning media integrated with Web Assemblr developed for fourth-grade elementary school students is considered feasible and effective for use in the learning process. The feasibility of the media is proven through validation results from material, design, and language experts, which fall into the "very feasible" category. In addition, the results of individual and small-group trials indicate that the media can be used effectively and helps students become more active and interested in science learning. The implementation results of the media in science learning also show an improvement in students' critical thinking skills after using the AR-based Web Assemblr media. This improvement is reflected in posttest scores that are higher than pretest scores and is further supported by N-Gain results in the high category. Although the data were not normally distributed, the results of nonparametric tests show a significant difference between the experimental and control classes. Therefore, AR-based learning media integrated with Web Assemblr has a positive impact on both the learning process and learning outcomes, particularly in improving the critical thinking skills of fourth-grade elementary school students. This study was limited to fourth-grade students at a single elementary school and focused only on science learning. Therefore, the findings may not be generalized to different educational settings or subject areas. Future research is recommended to involve larger and more diverse samples, apply the developed media to other science topics or different subjects, and examine the long-term impact of Augmented Reality-based learning media on students' critical thinking skills.

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