The Use of Assemblr edu as an Interactive Learning Medium to Improve Mathematical Critical Thinking Skills

Afifah Ainun Nadjla[1*, a)] and Deasy Wahyuni[2, a)]

Author Affiliations
[1,2] *Department of Mathematics Education, Yogyakarta State University, Yogyakarta, Indonesia*

Author Emails
a)mailto:afifahainun.2023@student.uny.ac.id

Abstract. Critical thinking skills are essential competencies in 21st-century mathematics education, requiring students to analyze, evaluate, and reflect on concepts deeply. However, the abstract and symbolic nature of mathematics often hinders students' conceptual understanding. Augmented Reality (AR) provides an innovative approach by integrating three-dimensional digital objects into real-world environments, allowing interactive exploration of mathematical ideas. This study examines the effectiveness of *Assemblr Edu*, an AR-based learning medium, in enhancing students' mathematical critical thinking skills. Employing a quasi-experimental pretest–posttest control group design, the study involved 60 secondary students divided into experimental and control groups. A validated mathematical critical thinking test was used, and data were analyzed through Analysis of Covariance (ANCOVA) with pretest scores as covariates. The findings revealed a significant difference between groups $F(1.57) = 37.93, p < 0.001, \eta^2 = 0.399$. The experimental group's mean improvement was $+23.74$ points $N - Gain = 0.59$, high category), while the control group's improvement was $+10.21$ points($N - Gain = 0.25$, medium category). The 3D interactivity of *Assemblr Edu* effectively fostered clarification, analysis, and logical reflection, confirming its role in promoting higher-order thinking skills aligned with the critical reasoning dimension of Indonesia's *Merdeka Curriculum*.

INTRODUCTION

In the digital era with the demands of 21st century competencies, education is no longer enough to present content transmissively but must facilitate students to develop high thinking competencies, one of which is mathematical critical thinking (Astalini et al., 2024). This ability involves processes such as problem clarification, information analysis, argument evaluation, logical inference, and reflection on conclusions. The Merdeka Curriculum emphasizes the importance of the critical reasoning dimension as one of the main profiles of Pancasila learners, which encourages teachers to explore innovative media and strategies so that students do not just calculate but really reason (Kemendikbudristek, 2022).

Mathematics learning often faces challenges of abstraction, visualization difficulties, and infrequent opportunities for interactive conceptual exploration (Hidajat, 2024). To overcome this, augmented reality (AR) technology emerges as a potential solution by incorporating digital objects (2D/3D) into real environments in real time, allowing students to manipulate mathematical objects directly in visual space (Koparan et al., 2023). Several systematic studies and meta-analyses mention that AR has a positive effect on learning outcomes, motivation, and higher-order thinking skills in various disciplines (Chang et al., 2022). For example, a meta-analysis of 134 studies from 2012 to 2021 found the effect of AR on learning achievement and student engagement.

Specifically in mathematics, a comprehensive literature review shows that AR applications are most often used on the topics of geometry, measurement, and spatial visualization, and show a positive impact on motivation, interest, spatial ability, and other cognitive aspects (İslim et al., 2024). In addition, Pahmi et al (2023) in the study Assessing the Influence of Augmented Reality in Mathematics Education concluded that AR is able to overcome barriers such

as mathematical anxiety and cognitive problems in students and expand students' understanding of difficult concepts of algebra and geometry at various levels of education.

While many AR studies in mathematics have shown positive results, there are some significant challenges that remain: (1) technical infrastructure, device compatibility, and network support; (2) teacher readiness and technological literacy; (3) suboptimal instructional design; and (4) lack of explicit integration between AR activities and systematically measured aspects of critical thinking (Voulgari et al., 2024).

Assemblr Edu as AR Learning Media

Among the various AR platforms, Assemblr Edu is one of the most attractive due to its ease of use, editable 3D content library, and support for integration into the learning process without high programming requirements (Mursyida et al., 2023). Fendi et al (2021) described that AR in their research used Assemblr Studio, producing interactive worksheets that can be scanned through the Assemblr application and show 3D objects and related multimedia. Media development research in Indonesia has also shown the success of Assemblr Edu in the context of flat geometry Fadilasari et al (2025) reported that AR media using Assemblr Edu had good validity and was able to improve students' math problem solving skills in R&D research in flat geometry. Quantitative research at SD N 3 Sekuro grade 5 showed that the application of Assemblr Edu-based AR media on 3D geometry material resulted in a significant increase in conceptual understanding ($N - Gain\ value = 0.88211; ES = 2.110$; high category) (Suaib & Sutriyani, 2024). This study strengthens the claim that Assemblr Edu can be an effective media in optimizing mathematics understanding, at least in the conceptual domain (3D geometry).

The mobile application of Assemblr Edu was also tested in mobile learning research conducted by Mahendra Halim et al (2024) showed that Assemblr Edu-based materials can be accessed anytime via mobile devices even though the results of improving students' problem solving skills were moderate ($N - Gain \sim 0.3$) this shows the potential of media in a flexible learning environment. Similar results were also reported by Kurnia et al (2025) that the integration of STEM PBL based Assemblr Edu in mathematics lectures was able to improve the critical thinking skills and creativity of prospective mathematics teacher students. The results of the topic network can be seen in Figure 1.

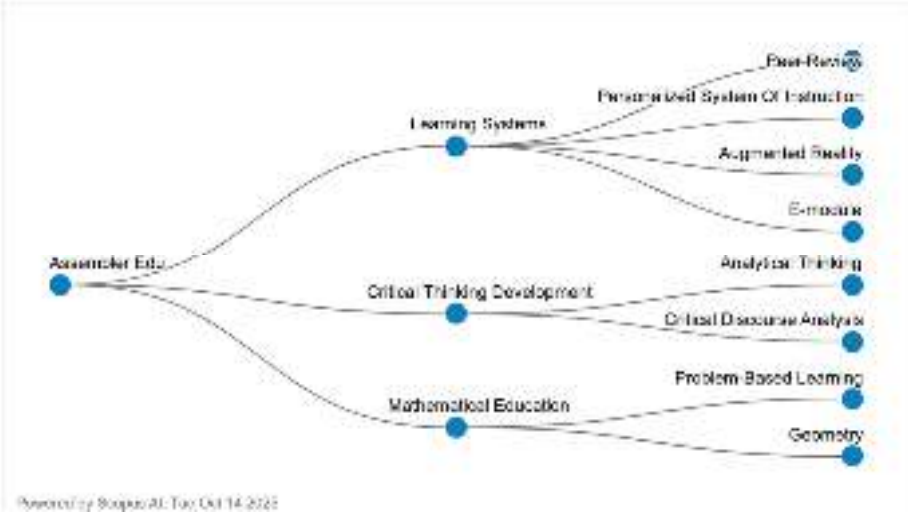

FIGURE 1. Results of the Assembler Edu Topic Network

Figure 1: Assemblr Edu's topic network that maps the interconnectedness of keywords that appear in recent publications. This figure shows that the concept of Assemblr Edu is often related to three major groups: a) Learning systems which includes personalized system of instruction, augmented reality, e-module, peer-review. this shows that

Assemblr Edu is often discussed in the context of structured learning systems and personalized learning media; b) Critical thinking development which includes analytical thinking, critical discourse analysis. This confirms that some literature explores the impact of AR (including Assemblr) on critical or analytical thinking aspects; c) Mathematical education which involves geometry, problem-based learning (PBL) as supporting themes that commonly appear in mathematical AR research. Thus it can be concluded that assemblr edu media has not been widely researched on interactive learning.

Based on the above description, it can be concluded that the use of Assemblr Edu as an augmented reality-based learning medium has strategic potential in supporting interactive, contextual mathematics learning that is oriented towards the development of critical thinking skills. However, the limited empirical studies that specifically examine the effectiveness of Assemblr Edu at the high school and higher education levels, particularly in the context of improving mathematical critical thinking, indicate a research gap that needs to be addressed. Therefore, this study aims to analyze the effect of using Assemblr Edu on improving students' mathematical critical thinking skills and to provide conceptual and practical contributions to the development of technology-based learning design in the era of 21st-century educational transformation.

METHOD

This study uses a quasi-experiment method with a pretest-posttest control group design, which aims to test the effectiveness of using Assemblr Edu as an Augmented Reality-based learning media in improving students' mathematical critical thinking skills. This design was chosen because it allows testing differences in learning outcomes between groups that receive treatment (experimental) and groups without treatment (control), while still considering the natural conditions of the class without full randomization (Creswell, 2023).

The research design structure is described as follows:

Group	Pretest	Treatment	Posttest
Experiment	O_1	X (Learning using Assemblr Edu)	O_2
Control	O_1	(Conventional learning)	O_2

Desciption :
O_1 = Mathematical critical thinking test before treatment (pretest)
O_2 = Post treatment mathematical critical thinking test
X = Treatment in the form of learning with Assemblr Edu media

The research subjects were high school students selected through purposive sampling technique based on equal academic characteristics and availability of learning technology facilities. Two parallel classes were used: one as an experimental class that learned using Assemblr Edu, and one as a control class that received conventional learning. The total number of participants was 60 students, each consisting of 30 students in the experimental group and 30 students in the control group. The research was conducted in the even semester of the 2024/2025 academic year in one of the public high schools in Yogyakarta, with the topic of learning spatial geometry and transformation.

The main instrument in this study was the Mathematical Critical Thinking Ability Test (TKBKM) developed based on Ennis (2011) indicators, including: (1) problem clarification, (2) argument analysis, (3) evidence evaluation, (4) logical inference, and (5) conclusion reflection.

Before use, the instruments were validated by three experts in mathematics education and digital learning media. Content validity was tested using Aiken's index (Aiken's V > 0.85), while reliability was calculated using Cronbach's Alpha with a result of 0.87 (high category). This instrument proved to be feasible to measure students' mathematical critical thinking skills in the context of AR-based learning. This research was conducted in four stages, namely: 1) preparation stage, 2) pretest implementation stage, 3) treatment stage, 4) posttest and analysis stage. Data were analyzed using Analysis of Covariance (ANCOVA) to test the difference in posttest scores between experimental and control groups with pretest as covariate. This technique is used to adjust for the effect of differences in students' initial abilities, so that the comparison results are more valid (Field, 2022).

The assumptions of the analysis included normality (Kolmogorov Smirnov), homogeneity (Levene's Test) and linearity of the relationship between the pretest and posttest. The results of the analysis showed a significant difference

between the two groups $p < 0.05$) indicating that the use of assemblr edu was effective in improving student's mathematical critical thinking skills. The results can be seen in Table 1.

TABLE 1. Pretest and posttest results of students' mathematical critical thinking skills

Group	N	Pretest Average	Sd Pretest	Posttest Average	Sd Posttest	N-Gain	Category
Experiment (Assemblr Edu)	30	59.73	6.21	83.47	5.89	0.59	High
Control (Convensional)	30	60.11	6.05	70.32	7.11	0.25	Currently

The effectiveness of the media is also reinforced by the $N - Gain$ score analysis. The formula for the N-Gain Score is as follows:

$$N - Gain = \frac{(Posttest - Pretest)}{(100 - Pretest)}$$

Then, the effectiveness of the media using N-Gain Score analysis showed an increase in the average score in the experimental group higher than the control group. This result is consistent with previous findings that AR-based learning can facilitate higher-order cognitive engagement (Chang et al., 2022; İslim et al., 2024).

RESULTS AND DISCUSSION

Results

Data analysis using Analysis of Covariance (ANCOVA) with pretest score as covariate showed significant differences in posttest scores of mathematical critical thinking skills between the experimental group (learning using Assemblr Edu) and the control group (conventional learning), with a value of $F(1.57) = 37.93, p < 0.001$, and partial $\eta^2 = 0.399$. These results show that after controlling for differences in initial ability, the use of interactive Augmented Reality (AR) media through Assemblr Edu gives a real advantage to improving students' mathematical critical thinking skills. The results can be seen in Table 2.

TABEL 2. Pretest and posttest results of students' mathematical critical thinking skills

Group	N	Pretest Average	Sd Pretest	Posttest Average	Sd Posttest	$N - Gain$	Category
Experiment (Assemblr Edu)	30	59.73	6.21	83.47	5.89	0.59	Tinggi
Control (Convensional)	30	60.11	6.05	70.32	7.11	0.25	Currently

The $N - Gain$ value in the experimental group reached 0.59 (high category) while in the control group it was only 0.25 (medium category). Thus the average increase (Δ) in critical thinking skills in the experimental group was $+23.74$ points much greater than the control group which was only $+10.21$ points. These results show that Assemblr Edu media is effective in facilitating higher-order thinking through students' direct interaction with three-dimensional (3D) mathematical objects. This finding is in line with the results of Bulut & Borromeo Ferri's research (2023) which showed that the use of AR improved middle school students' math learning outcomes and spatial understanding.

Discussion

Consistency of Findings with Current Research

The results of this study showed that the use of Assemblr Edu as an interactive AR media significantly improved mathematical critical thinking skills compared to conventional learning. This finding is consistent with the study of Hanggara et al (2024) who used AR game-based learning model on polyhedron material in junior high school, and reported that the group using AR obtained higher critical thinking scores than the control group ($p < 0.05$).

More broadly experimental research in higher education by Dutta et al (2023) found that the application of AR in a flipped classroom learning model improved not only motivation and knowledge, but also critical thinking skills of engineering students ($128, p < 0.05$). This reinforces the generalization that AR technology can be effective across educational levels.

Also relevant is the research of Koparan et al. (2023) "Integrating augmented reality into mathematics teaching" which reported that AR on geometry topics significantly improved the spatial abilities and mathematical reasoning skills of secondary school students. Your findings are in line with this evidence, especially corroborating that AR media not only helps visualization but also supports critical thinking processes in the context of geometry and transformation materials.

Mechanisms of AR Interactivity in Improving Critical Thinking

One of the main factors for the success of AR media is the active involvement of students in direct manipulation of 3D objects (rotating, zooming, breaking parts of objects). This activity allows students to clarify, analyze relationships, evaluate evidence, and inference with more concrete critical thinking processes that were previously difficult to do in a two dimensional space.

According to the literature, when students can compare their predictions with visual representations of AR objects, cognitive conflicts occur that trigger re-reflection and revision of thinking. This is consistent with the argument in AR-mathematics research that scaffolding and guidance questions during AR interaction reinforce the critical thinking effect (Koparan et al., 2023).

Furthermore, bibliometric research by Reina et al (2025) shows that the focus keywords "interactive", "conceptual understanding", and "critical thinking" have appeared more frequently in the AR-mathematics literature in the last decade, confirming that the research community is increasingly paying attention to the relationship between AR and higher order thinking processes, not just conceptual achievement.

Implications for Instructional Tasks and Learning Design

In order for AR to have a systematic effect on critical thinking, rather than merely a novelty effect, learning designers need to incorporate critical thinking questions (e.g., “Why does this shape change when rotated?”, “How are the sides related?”, “Is there any other evidence that can help you verify this?”). These guiding questions should be inserted at every phase of AR exploration.

Research by Rizki et al (2024) on the CAP (Cooperative, AR, Game) learning model found that the combination of AR and collaborative strategies resulted in an increase in critical thinking and motivation compared to single methods; this underscores that AR alone is not enough, but must be accompanied by supporting pedagogical strategies.

In addition, attention should be paid to transition scaffolding, which is moving students from manipulating AR objects to verbal or written reflection so that critical thinking does not stop at the visual aspect, but is also shifted to logical and evaluative arguments.

Thus, the application of Assemblr Edu in the context of mathematics learning not only serves as a means of visualizing concepts but also as a cognitive mediator that stimulates students to think reflectively, argumentatively, and analytically through multimodal exploration. In line with the findings of Rizki, Rahmawati, & Suryani (2024), which confirm that the combination of Augmented Reality and collaborative strategies in the CAP (Cooperative, AR, Game) model results in a significant increase in critical thinking and learning motivation, this study indicates that AR cannot stand alone without the support of explicit and cognitively oriented instructional design.

Furthermore, the effectiveness of AR in fostering critical thinking skills is highly dependent on the transition scaffolding process, which is a systematic transition from visual manipulative activities to verbal reflection and evidence-based argumentation. Teachers need to guide students to link the results of digital exploration with structured

mathematical explanations so that the interactive experience does not stop at mere visual impressions but transforms into the formation of conceptual knowledge structures and deep inferential logic. This approach is in line with the views of Koparan, Yildiz, & Seker (2023), who emphasize the importance of integrating reflective activities after AR interactions to strengthen students' reasoning and evaluative abilities.

Overall, the results of this study reinforce that the quality of learning design, including task design, exploration sequence, and conceptual scaffolding, are determining factors in the effectiveness of Assemblr Edu in improving mathematical critical thinking skills. AR offers tremendous potential as a medium for visualization and concept exploration, but its pedagogical value is only fully realized when synergized with teaching strategies that encourage dialogue, collaboration, and evidence-based reflection.

With these results, the study opens up space for the development of an AR-based mathematics learning design framework that explicitly integrates critical thinking indicators (clarification, analysis, evaluation, inference, and reflection), while emphasizing the importance of collaboration between technology and pedagogy to achieve learning transformation oriented towards 21st-century skills.

CONCLUSION

This study shows that Augmented Reality-based learning media through Assemblr Edu is effective in improving mathematical critical thinking skills of secondary school students compared to conventional learning. The ANCOVA test results show a significant difference ($p < 0.001$; $\eta^2 = 0.399$), which indicates that the use of AR contributes greatly to the development of higher order thinking skills (HOTS).

This improvement occurs due to the characteristics of Assemblr Edu that allow students to interact directly with 3D objects, conduct conceptual exploration, and test spatial relationships visually and logically. This interactivity encourages students to go through the critical thinking cycle-clarification, analysis, evaluation, and reflection-which is empirically proven to strengthen the understanding of mathematical concepts.

In addition to proving the effectiveness of AR, the results of this study emphasize the importance of systematic and cognitively oriented instructional design. The use of Assemblr Edu must be accompanied by conceptual scaffolding and critical thinking guiding questions so that the effect does not stop at the visual aspect, but rather leads to analytical and evaluative knowledge construction.

These findings have strategic implications for mathematics teachers and instructional designers:

1. AR integration should be placed in the context of inquiry-based or project-based learning that encourages collaborative reflection and discussion.
2. Mathematical critical thinking instruments need to be developed more explicitly so that learning outcomes can be measured in accordance with the desired cognitive indicators.
3. Further research is recommended to expand the context of cross-grade and cross-school trials, test moderators such as student digital literacy and teacher readiness, and report comparative effect sizes so that the results can be integrated into the international evidence base.

Overall, this study contributes to the global literature on immersive technology-based mathematics learning and provides an empirical basis for the development of an Augmented Reality learning model integrated with the Merdeka Curriculum and the Pancasila learner profile in the dimension of critical thinking. dan profil pelajar.

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