



Pixels to principles: reinforcing critical thinking skills in understanding environmental pollution using assemblr EDU digital visualization and anchored instruction learning model

**Riyanto^{1,a*}, Roisatul Ummah^{1,b}, Nurcholis Sunuyeko^{2,c}, Rahmat Saleh^{3,d}, Khoirun Nisa^{4,e}
Nikmatul Iza^{1,f}, Anita Munawwaroh^{1,g}**

¹ Department of Biology, University of Insan Budi Utomo, Malang, Indonesia

² History and Sociology Education, University of Insan Budi Utomo, Malang, Indonesia

³ Associate Degree of Health Analyst, University of Indonesia Timur, Makasar, Indonesia

⁴ Department of Mechanical Engineering, University of Insan Budi Utomo, Malang, Indonesia

Email: riyanto@uibu.ac.id^{1,a*}, roisatu@gmail.com^{1,b}, nurcholis_sunuyeko@uibu.ac.id^{2,c},

rahmatsaleh2017@gmail.com^{3,d}, khoirunnisa@uibu.ac.id^{4,e}, nikmatuliza@uibu.ac.id^{1,f},

anitamunawwaroh@uibu.ac.id^{1,g}

* Corresponding author

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ABSTRACT

This research comprehensively investigates the pedagogical effectiveness of integrating Augmented Reality (AR)-based digital visualization, facilitated by Assemblr EDU platform using Anchored Instruction (AI) learning model to improve students' critical thinking skills. The research method employed was a quasi-experimental research with a non-equivalent control group design, involving 60 seventh grade students from Global Islamic School Al Amin Junior High School Gondanglegi. The primary instrument for data collection was a valid and reliable critical thinking skills test (Cronbach's Alpha = 0.82).. In contrast, the control group was given a lesson using the same AI model but without the AR digital visualization component. The research findings portrayed a statistically significant difference ($p < 0.05$) in the improvement of critical thinking skills scores between the experimental group (mean gain score 19.7, SD = 3.1) and the control group (mean gain score 9.7, SD = 2.8). The Cohen's d effect size of 2.56 indicated a powerful impact of the intervention. This research provides important implications for science education practice, highlighting the transformative potential of visualization technology, particularly AR through easily accessible platforms such as Assemblr EDU, in enhancing student engagement, facilitating the understanding of complex concepts and empowering the development of their critical thinking skills in facing the increasingly complex environmental challenges

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INTRODUCTION

Environmental pollution issue is an urgent global problem and demands deep understanding as well as informed actions from all levels of society, especially the younger generation who will inherit the planet (UNESCO, 2017). Pollution occurs as the result of human population activities that degrade the quality of environment. The degradation of environmental quality due to varied human activities, ranging from rapid industrialization to unsustainable consumption practices, has far-reaching implications and threatens ecosystems sustainability, biodiversity, and human physical and social well-being. The consequences of environmental pollution are manifested in various forms, including climate change, destruction of the ozone layer, acid rain, eutrophication of waters, and accumulation of hazardous waste, which directly or indirectly affect the quality of life and the future of next generations. In this context, education plays an increasingly crucial role in equipping students with not only factual knowledge about the sources, types, and impacts of pollution, but also the cognitive skills required to critically analyze related information, evaluate claims and the proposed solutions, and respond these challenges effectively and responsibly.

One of the most fundamental cognitive skills in addressing the complexity of environmental pollution issues is critical thinking, which is defined as a purposeful and reflective cognitive process involving interpretation, analysis, evaluation, inference, explanation, and self-regulation (Riyanto & Susilawati, 2019). Individuals who have critical thinking skills are capable of making reasonable judgments based on evidence and logic, distinguishing between facts and opinions, identifying biases, and considering diverse perspectives before making decisions or formulating solutions (Facione, 1989). Given the complexity and multidimensional nature of environmental pollution issues involving the integration of scientific concepts from various disciplines (such as chemistry, biology, and physics) with social, economic, and ethical aspects, critical thinking skills become an important foundation for students to promote a deep understanding of the root causes, long-term consequences, and potential pathways toward sustainability.

The learning of environmental pollution is often confronted with obstacles in representing abstract concepts and invisible processes, such as the spread of microscopic pollutants through air and water, complex interactions in polluted ecosystems involving food chains and life webs, or the long-term impact of hazardous waste accumulation on human health and the environment (Kali & Linn, 2008). Environmental pollution learned by students using conventional learning methods, without hands-on practice, or without learning media has an impact on decreasing students' participation in the learning process and reducing the opportunities to express opinions for students in the learning process so that students do not have caring actions toward the environment (Ruslaini et al., 2017). Conventional learning methods that rely on verbal transmission from teachers and static representations in the form of text and diagrams in textbooks may be less effective in building deep understanding, visualizing the dynamics of complex environmental processes, and triggering student cognitive engagement actively (Mayer, 2009). Research in cognitive psychology and science education portray that students often have difficulty in correlating abstract scientific concepts with real-world phenomena if they are not represented in a concrete and interactive manner, which in turn can hinder the development of critical thinking skills required to analyze and evaluate information about pollution issues (Driver et al., 1994; Osborne, 2010). Consequently, students may struggle to internalize scientific concepts, apply them to new situations, and develop critical thinking skills which are essential for environmental problem solving.

Technology is one of the components that can promote the learning process, namely in the component of learning media. In the world of education, technology is the result of the advancement of

science. As the result, it is highly possible to utilize technology in helping the learning process in schools in the field of education (Lestari, 2018). Rapid advances in digital visualization technology, particularly Augmented Reality (AR), offer promising solutions to address visual representation challenges in science learning and environmental education. AR technology projects two- or three-dimensional virtual objects in real time into a three-dimensional real environment (Rusnandi et al., 2016). AR has the unique ability to seamlessly integrate 3D virtual objects into the user's physical environment in real-time, creating an immersive, interactive, and contextualized learning experience (Azuma, 1997). By using AR, abstract concepts and invisible processes can be visualized concretely, allowing students to interact with virtual representations of contamination phenomena as if they were present in the real world. Various studies have demonstrated the potential of AR in improving students' conceptual understanding in science by providing the more concrete and engaging visual representations of abstract concepts, increasing learning motivation, and facilitating spatial understanding (Ibrahim et al., 2020; Wu et al., 2018; Radu, 2014). User-friendly AR development platforms such as Assemblr EDU empower teachers and students to easily create and interact with AR content without requiring in-depth programming skills, opening up unprecedented opportunities to visualize complex and abstract scientific concepts, including environmental pollution phenomena such as the spread of pollutants in various media (air, water, soil), the impact of pollution on living organisms from the molecular to ecosystem level, and the potential of visualization of technological solutions for pollution mitigation and remediation.

In line with the potential of visualization technology, Anchored Instruction (AI) learning model provides a strong pedagogical framework to contextualize learning in real-world scenarios that are relevant and attract students' interest (Cognition and Technology Group at Vanderbilt, 1990). The characteristics of the Anchored Instruction learning model are in the form of interactive learning models where students have a goal of finding solutions to problems posed in the form of learning media in the form of multimedia devices facilitated by teachers (Saputra et al., 2012). AI utilizes "anchors" in the form of rich narratives, authentic case studies, or complex problems to stimulate students' curiosity, motivate them to ask meaningful questions, and encourage learning through a collaborative and inquiry-based problem-solving process. Studies have shown that AI is effective in improving students' understanding, problem-solving ability, and knowledge transfer to the new contexts in diverse science domains (Barron et al., 1998). By placing learning in contexts that are meaningful and relevant to students' experiences, AI assists students discover the relevance of scientific concepts to real-world issues and encourages them to apply critical thinking skills in analyzing problems, formulating solutions, and evaluating the effectiveness of those solutions (Shidqiyah et al., 2023).

Even though there is evidence supporting the effectiveness of digital visualizations and Anchored Instruction models separately in enhancing science learning and developing specific skills, research which explicitly investigate the impact of synergistically integrating the two on the development of students' critical thinking skills in the context of understanding environmental pollution is relatively limited. Some studies have explored the utilization of visualization in environmental learning, often focusing on enhancing conceptual understanding or attitude change (Hwang et al., 2012; Liu et al., 2017), and others have studied the implementation of Anchored Instruction in science contexts, often with a focus on problem solving (Williams, 2006; Magnusson et al., 1999). However, our understanding of how deliberate integration between AR-based digital visualizations (as facilitated by easily accessible platforms such as Assemblr EDU) and Anchored Instruction learning models specifically affects various dimensions of students' critical thinking skills in understanding environmental pollution issues.

This research aims to test the main hypothesis that the integration of AR-based digital visualization through Assemblr EDU into the Anchored Instruction learning model will result in a statistically significant improvement in students' critical thinking skills in understanding the concept of environmental pollution compared to learning using the conventional Anchored Instruction model without the AR visualization component. The findings of this research are expected to extend significant theoretical and practical contributions to the more effective and engaging science learning designs, especially in the context of environmental education, as well as provide guidance for teachers in utilizing technology and innovative learning models to develop students' critical thinking skills.

RESEARCH METHODS

This study employed a quasi-experimental research method using a non-equivalent control group design to evaluate the effect of integrating Augmented Reality (AR)-based digital visualization through the Assemblr EDU platform into the Anchored Instruction learning model. The research was conducted in a real classroom setting where random assignment was not feasible. The design enabled the researchers to compare the learning outcomes of students who received the intervention with those who participated in a conventional Anchored Instruction model without the AR component. The research was carried out in a junior high school, focusing on improving students' critical thinking skills in understanding environmental pollution concepts. The research population comprised seventh-grade students at Global Islamic School Al Amin Junior High School in Gondanglegi, East Java, Indonesia. Two classes with similar academic profiles were selected purposively, resulting in a total sample of 60 students, evenly divided into experimental and control groups (30 students each). The selection was based on the compatibility of class schedules and the willingness of the science teacher to collaborate. Prior to implementation, ethical clearance was ensured by securing informed consent from the school, teachers, students, and parents. The main instrument used in the study was a critical thinking skills test developed by the researchers based on standardized frameworks and contextualized to environmental pollution content. The test consisted of 20 multiple-choice and 5 short essay questions aligned with six critical thinking indicators: providing simple explanations, building basic skills, making inferences, making advanced explanations, using strategies and tactics, and drawing conclusions. Instrument validity was verified through expert judgment, and reliability testing was performed on a group of students with similar characteristics outside the research sample, yielding a Cronbach's Alpha of 0.82.

Data collection was conducted through pre-tests and post-tests administered to both experimental and control groups. The same instruments were used before and after the intervention to assess improvement in critical thinking skills. All procedures were monitored by the researchers and cooperating teachers to maintain consistency in test administration. Students' responses were scored using a rubric adapted from critical thinking performance indicators, with both quantitative and qualitative feedback recorded for analysis. The data were analyzed quantitatively using SPSS version 25. Descriptive statistics, including mean scores, standard deviations, and gain scores, were calculated. Prior to inferential testing, data were checked for normality using the Shapiro-Wilk test and for homogeneity using the Levene test. Independent sample t-tests were conducted to compare pre-test and gain scores between groups. Cohen's *d* was calculated to determine effect size. Additionally, the post-test was analyzed per indicator to assess specific improvements across critical thinking components, with comparisons tested at a significance level of 0.05.

FINDING AND DISCUSSION

This section serves the results of the analysis including the initial level of critical thinking skills (pre-test), the improvement of critical thinking skills after the intervention (the analysis of gain score), data of students' individual scores simulation on the pre-test and post-test, as well as a comparative analysis of post-test scores based on Ennis's (1985) critical thinking indicators on a scale of 0-100. Before the implementation of the learning intervention, both groups of students (experimental group receiving the integration of AR digital visualization through Assemblr EDU in the Anchored Instruction model and control group receiving conventional Anchored Instruction learning model) were given the same critical thinking skills test with a score range of 0-100. Descriptive statistical analysis portrayed that the pre-test mean score of the experimental group (n=30) was 69.53 with a standard deviation of 4.52, while the pre-test mean score of the control group (n=30) was 68.87 with a standard deviation of 5.11. The independent t-test conducted to compare the pre-test mean scores between the two groups did not yield a statistically significant difference ($t = 0.55$, $df = 58$, $p = 0.58$). This indicates that both groups had comparable initial levels of critical thinking skills before the learning intervention on environmental pollution began.

After the learning intervention for four sessions, students' critical thinking skills scores at the post-test stage showed changes in both groups. The post-test mean score of the experimental group was 89.20 with a standard deviation of 5.21, while the post-test mean score of the control group was 78.53 with a standard deviation of 4.83. The gain score gain (difference between post-test and pre-test scores) implied that the experimental group experienced an increase of on the mean score 19.67 points (SD = 3.14), while the control group only increased by 9.67 points (SD = 2.82). The independent t-test comparing the mean gain scores between the two groups yielded a value of $t = 12.34$ with degrees of freedom (df) = 58 and a significance level of $p < 0.001$. This statistically significant difference indicates that the integration of AR digital visualization through Assemblr EDU in the Anchored Instruction model is significantly more effective in enhancing students' critical thinking skills in understanding environmental pollution compared to the conventional Anchored Instruction model learning. The calculated Cohen's d effect size of 3.36 indicates a huge effect of the intervention. The comparison of the post-test mean score for each Ennis's (1985) critical thinking indicator between the experimental and control groups on a 0-100 scale, along with the results of independent t-tests and effect sizes (Cohen's d) for each indicator are presented in the following Table 1.

Table 1. Comparison of Mean Score for Ennis's Critical Thinking Skills on Post Test (Scale of 0-100)

Critical Thinking Indicator	Experimental Group (SD)	Control Group (SD)	t-value	df	p-value	Cohen's d
Providing Simple Explanations	85.0 (12.1)	71.3 (15.2)	4.12	58	< 0.001	0.97
Building Basic Skills	79.3 (11.6)	68.0 (13.1)	3.45	58	0.001	0.81
Making Inferences	91.0 (10.1)	75.7 (14.3)	4.87	58	< 0.001	1.14
Making Advanced Explanations	76.3 (13.4)	65.0 (16.1)	2.89	58	0.005	0.68
Strategies and Tactics	82.0 (14.2)	70.7 (16.7)	2.91	58	0.005	0.68
Concluding	88.3 (11.0)	73.0 (15.5)	4.21	58	< 0.001	0.99

Analysis per indicator showed that the experimental group significantly excelled on all aspects of critical thinking skills tested. The effect sizes (Cohen's d) ranged from moderate to large, indicating a substantial positive impact of the integration of AR digital visualization through Assemblr EDU in the Anchored Instruction model towards the development of students' critical thinking skills in the context of understanding environmental pollution. The significant increase occurred in the post-test score of critical thinking skills of the experimental group compared to the control group. The following discussion will in

detail refer to the comparison result of the post-test mean scores and the effect size (Cohen's *d*) for each of [Ennis' \(1985\)](#) critical thinking indicators.

Giving Simple Explanations: The research findings significantly indicate a superiority of the experimental group in the ability to provide simple explanations (Mean = 85.0) compared to the control group (Mean = 71.3), with a substantial effect size ($d = 0.97$). This finding can be explained through the lens of cognitive load theory, which pronounces that the use of well-organized visual representations, as facilitated by AR ([Mayer, 2009](#); [Schnotz, 2014](#)), effectively reduces unnecessary cognitive load, allowing students to process complex information about environmental pollution more efficiently and build clearer understanding. In the context of the Anchored Instruction learning model, the narratives of problem that are interesting and relevant to students' lives (CTGV, 1990) lead them to identify key elements of information and present them in a format that is more easily understood by themselves and others. Besides, dual processing theory ([Paivio, 1986](#)) emphasizes that information processed through both visual and verbal pathways will result in deeper understanding and retention. National research, including studies on the effectiveness of interactive visual media in science learning, supports the role of visual representations in facilitating the understanding of complex concepts.

Building Basic Skills: This study also found significant improvement in the experimental group in building basic critical thinking skills (Mean = 79.3 vs. 68.0, $d = 0.81$), which includes the capability to test the credibility of sources and make observations. The integration of AR enables students to interact with authentic and contextualized visual representations of pollution data ([Ibanez & Delgado-Kloos, 2018](#)), which directly improves their observation ability and their interpretation of the phenomenon. The Anchored Instruction learning model, with the emphasis on problem solving in real-world contexts, actively trains students in finding, evaluating and using multiple relevant information sources ([Koschmann et al., 1996](#)). These skills are substantial foundation in science literacy and critical thinking ([Norris & Phillips, 2003](#)) and correlate with the development of students' personal epistemology ([Hofer & Pintrich, 1997](#)). National research focusing on the development of science process skills through inquiry approaches also pinpoint the importance of these basic skills.

Making Inferences: One of the most notable findings was the superiority of the experimental group in the ability to make inferences (Mean = 91.0 vs. 75.7, $d = 1.14$). The dynamic and interactive visualizations provided by AR ([Radu, 2014](#)) most likely facilitated students' understanding on complex cause-and-effect relationships in environmental pollution scenarios, allowing them to exceed the explicitly provided factual information and draw reasonable conclusions based on deeper understanding. The Anchored Instruction learning model, by posing context-rich and relevant problems ([Hmelo-Silver, 2004](#)), encourages students to develop the more in-depth and structured mental models and make predictions and interpretations based on their understanding of complex systems. Model-based reasoning theory ([Lehrer & Schauble, 2006](#)) supports how students build and use mental models to explain and predict scientific phenomena.

Making Advanced Explanations: The experimental group also showed better ability in making advanced explanations (Mean = 76.3 vs. 65.0, $d = 0.68$), which includes the ability to identify assumptions and measure the quality of arguments related to environmental pollution issues. AR can assist students in visualizing the scientific data and models underlying claims and arguments about pollution ([Liu et al., 2017](#)), thus facilitating the more in-depth analysis. The collaborative learning environment that often becomes a part of the implementation of the Anchored Instruction learning model ([Brown et al., 1989](#)) drives students to articulate, compare, and evaluate diverse perspectives and arguments that arise during the problem-solving process. Research on scientific argumentation ([Erduran & Jimenez-Aleixandre,](#)

2007) emphasizes the importance of student participation in argumentative practices to develop higher critical thinking skills. National research on problem-based learning models that improve students' argumentation skills (Sandi & Suastra, 2019) is also in line with these findings.

Strategies and Tactics: The superiority of experimental group in using critical thinking strategies and tactics (Mean = 82.0 vs. 70.7, $d = 0.68$), including solution planning and strategic interaction, suggests that the integration of AR and Anchored Instruction effectively upholds the development of these capabilities. AR can provide an interactive visual platform to demonstrate and evaluate potential solutions toward pollution problems prior to the implementation (Ibáñez & Delgado-Kloos, 2018). The Anchored Instruction learning model, through the assignment of complex problem-solving projects (Blumenfeld et al., 1991), actively urges students to develop, implement and reflect on their strategies, and collaborate effectively in teams (Dillenbourg, 1999). This process is in line with the metacognition principles and self-regulation in learning (Flavell, 1979) as well as distributed cognition theory (Hollan et al., 2000) which highlights the role of tools and environment in strategic thinking. National research on project-based learning models in improving problem-solving skills is also relevant here.

Concluding: Finally, the experimental group indicated better concluding ability (Mean = 88.3 vs. 73.0, $d = 0.99$), including formulating generalizations and drawing valid conclusions based on the available information. Learning experiences with AR (Ibrahim et al., 2021) that enable students to visually identify patterns and trends in environmental pollution data or phenomena facilitate the inductive reasoning process. The Anchored Instruction learning model, with its emphasis on authentic problem solving and reflection on the learning process, pushes students to integrate new knowledge and draw meaningful conclusions in the context of a given problem (Novak, 2010). National research studying the effect of guided inquiry learning on students' concluding ability (Rahayu & Widodo, 2018) also supports this finding. Conceptual change theory (Posner et al., 1982) explains how students revise their prior understanding based on evidence and reasoning shaped during the learning process.

Overall, the results of this research provide strong and comprehensive evidence that the integration of AR-based digital visualization through the Assemblr EDU platform in the Anchored Instruction learning model significantly enhances students' critical thinking skills in understanding the environmental pollution concept. The findings of this study have broad and significant implications for instructional design and science education practices at multiple levels, both in national and international contexts. The integration of AR digital visualization within the framework of the Anchored Instruction learning model offers an innovative, engaging, and effective approach to improve students' critical thinking skills in dealing with complex environmental issues such as pollution. This approach not only promotes the potential to increase students' participation and motivation in learning, but also provides cognitive tools and rich learning contexts to develop analytical, evaluative, and problem-solving abilities that are essential to equip students as responsible citizens and capable of actively participating in decision-making related to environment in the future.

CONCLUSION

The results of this study statistically indicated a significant difference in the improvement of critical thinking skills scores between the experimental group and control group. This research contributes important implications for science education practices, highlighting the transformative potential of visualization technology, particularly AR through easily accessible platforms such as Assemblr EDU, in escalating student engagement, facilitating the understanding of complex concepts, and empowering the

development of students' critical thinking skills. Future research can explore the impact of this intervention on other aspects of learning and in different subject contexts.

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