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Improvement of Students' Critical Thinking Skills by Guided Inquiry with Augmented Reality-based Solar System Learning Media

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Abstract. Critical thinking is an important skill of the 21st century. An intensive observation during the learning process at State Junior High School (SMP Negeri) 8 Semarang found that students had low critical thinking abilities in solar system topics. Thus, a guided inquiry model assisted by augmented reality media on the solar system study material is expected to engage students by allowing them to participate actively in their learning process to improve their critical thinking skills. This research used a quasi-experimental method with a pretest-posttest control group design by applying the guided inquiry model assisted by augmented reality (AR) to improve students' critical thinking skills. The subjects of this research were students in VII F and VII G classes (Academic Year 2024). The research instruments included a multiple-choice test sheet with reasoning and a student response questionnaire. Data analysis employed the N-gain test and t-test. The results of the N-gain analysis showed an increase in students' critical thinking skills in the experimental class by 0.62 and in the control class by 0.27. The t-test results showed a significant difference between the critical thinking abilities of the experimental and control classes with Sig. (2-tailed) of 0.000 < 0.05. The guided inquiry model implementation with AR in improving the students' critical thinking skills is also supported by the results of the student response questionnaire, which showed a very good category (84.99%). This research concludes that learning using the guided inquiry model assisted by augmented reality could improve student's critical thinking skills.

Keywords: Guided inquiry model, augmented reality, critical thinking skill.

INTRODUCTION

The rapid technological development and changes in organizational behavior have impacted the characteristics of the current labor market, such as a rapidly changing work atmosphere. People, especially employees, must have 21st-century skills, including 4C (critical thinking, collaboration, communication, and creativity). Critical thinking is the most important among those four skills since it is the highest form of intelligence. The ability to think critically is the ability that a person hopes to face various conflicts in social and personal life. Critical thinking refers to the act or practice of thinking critically by applying reason, questioning assumptions, and evaluating information. It involves analyzing available facts, evidence, observations, and arguments to form rational, skeptical, and unbiased judgments. Critical thinking is essential for problem-solving, discerning biases, and making informed decisions (McGlynn, 2024). Critical thinking in science learning is a systematic process that involves mental activities such as analyzing assumptions and making decisions. Students with critical thinking skills can think when making decisions about certain statements, which is essential for developing students' potential. However, it cannot be mastered instantly within a short period. Therefore, family support, education schools, parents, and teachers are fundamental in infusing and preparing a supportive educational environment to stimulate critical thinking skills in students as early as possible (Thornhill-Miller et al., 2023).

In order to support the educational environment along with science and technology development, various learning media have emerged, especially those that utilize the latest technology, such as computers and mobiles (Punggeti et al., 2024). Teachers can use media to clarify their understanding of science concepts, including solar system study material. Solar system material is one of the materials that require suitable learning media to explain learning material concretely. Solar system study material is very theoretical. Students must be able to describe various celestial bodies found within the solar system. Therefore, special media is needed to help the learning process of the solar system concept and ensure student understanding and critical thinking skills (Rahmawati et al., 2019).

In Indonesia, solar systems are science learning materials studied in junior high school. This material is very close to everyday life, but the material on the process of Earth's rotation and revolution is challenging to understand and tends to be abstract. When students work on questions related to this material, they experience difficulties and have low analytical skills. Based on the preliminary study at State Junior High School (SMP Negeri) 8 Semarang, students still had relatively low critical thinking skills. Low critical thinking skills of students were observed when students were unable to work on questions that referred to higher-level thinking questions. When students are faced with high-level questions, there are still many students whose scores are below average. In addition, students with low critical thinking skills cannot reach arguments and conclude reasonably. According to an interview with the science teachers, it was obtained that students were less interested in participating in classroom learning activities due to the lack of learning innovation. Apart from that, students also quickly procrastinated in doing assignments, and students tended to get bored. They had little desire to look for information related to the material, and students' critical thinking abilities were also lacking, as seen from their low curiosity and lack of critical thinking in science learning. This results in students being less trained in developing analytical and argumentative skills as indicators of critical thinking abilities. Teachers also have not tried to provide questions that can train students' critical thinking skills. The lack of application of supportive learning models causes low critical thinking skills. This result aligns with research showing that students' low critical thinking abilities were caused by a monotonous teaching method and less innovative media (Surayya et al., 2014). Also, the questions given to students to evaluate only reach levels C1 (remember) and C2 (understand), so it is not enough to train students' critical thinking abilities (Baharuddin et al., 2017). Questions used to test thinking abilities critical

load level C4. (analysis), (analyzing), C5. (synthesis), and C6 (evaluate) with solar system material studied by students, which contain indicators of critical thinking skills.

One solution is to innovate using learning models and media to improve students' critical thinking skills in solar system material. Guided inquiry learning is a practical approach for enhancing critical thinking skills among students. Guided inquiry learning is a practical approach to improving critical thinking skills among students. The guided inquiry learning process becomes important to apply, especially in science learning, to make the learning process more meaningful. The steps taken direct students to think emancipatory when finding the concept. Indirectly, this will train them to think critically and creatively. In this model, learners actively explore topics, ask questions, and investigate problems, fostering more profound understanding and analytical abilities. A study conducted with 11th-grade students using guided inquiry models found a significant increase in critical thinking skills (29.9% improvement) and cognitive learning outcomes (22.9% improvement). The strong correlation ($r = 0.721$) between critical thinking skills and cognitive learning outcomes highlights the effectiveness of this approach (Rosania et al., 2023).

Apart from learning models, the role of learning media is also essential for the learning process. Learning media can train students' critical thinking skills by stimulating them to argue and answer questions. Media use appropriate learning as stated by Hasnunidah (2011) that a person's expertise teachers in choosing the proper learning media are one of the determining factors for the successful development of students' critical thinking skills. This follows the opinion of Mayer (2002) that students' critical thinking skills can be developed using appropriate learning media. Android-based media is learning media relevant to current conditions; one alternative learning media that can be applied to smartphones is augmented reality (Herlanti et al., 2019; Rahmawati et al., 2019). Augmented Reality (AR) learning media can significantly enhance students' critical thinking ability. By integrating AR technology into educational experiences, students engage with content more interactively and immersively, improving cognitive skills. AR learning media provides an innovative approach to enhancing critical thinking skills by promoting active engagement and more profound understanding (Bakri et al., 2021).

There are few research results on the guided inquiry model using AR media for solar system learning to improve students' critical thinking skills (Table 1). Therefore, based on theoretical and other study analysis, the guided inquiry learning model AR media in solar system study material is expected to enable learners to use authentic context by exploring the visualization using the AR, interact with virtual models, foster curiosity, and encourage critical thinking (Wen et al., 2023).

RESEARCH OBJECTIVES

Based on the background outlined, the research problem can be formulated as follows: 1) how does implementing the guided inquiry model assisted by augmented reality (AR) on the solar system study material enhance students' critical thinking skills? and 2) what are the students' responses to applying the guided inquiry model assisted by augmented reality in improving their critical thinking skills?

Table 1: Review of relevant research

Objectives and Results	Learning Model	Study Materials	Learning Media	References
To apply learning media based on a scientific approach using AR to improve critical thinking skills. It was found that students' critical thinking abilities increased after using learning media based on a scientific approach.	Scientific	Solar System	AR	(Gaol et al., 2022)
To improve students' critical thinking skills through the AR-assisted PBL model. The results of this research showed that the application of the AR-assisted PBL model enhanced critical thinking skills.	Project-based Learning	Solar System	AR	(Isatunada et al., 2023)
To determine the effect of AR-based learning media on students' critical thinking abilities. The research showed that the AR-assisted discovery learning model affected students' critical thinking abilities. The results of the essential thinking abilities in the experiment class were more significant than those in the control class by 11%.	Discovery Learning	Movement System	AR	(Ashari, 2019)
To produce an AR-integrated contextual learning module to improve students' critical thinking skills. This research showed that the integrated AR module improved students' critical thinking skills.	Contextual	Chemical Bond	AR	(Mashami et al., 2021)
To determine the validity, practicality, and effectiveness of STEM-based teaching materials using AR to improve students' critical thinking skills. This research showed that STEM-based teaching materials using AR effectively improved students' critical thinking skills.	STEM	Vibration, Wave, and Sound	AR	(Oktaviyanti et al., 2023)
To implement the guided inquiry model assisted by augmented reality (AR) on the solar system study material to enhance students' critical thinking skills.	Guided inquiry	Solar System	AR	This study

Research Tools

This research used an experimental method, a quasi-experimental design with a nonequivalent control group. The study consisted of a control class and an experimental class. The learning control class used conventional media (pictures and videos) with a discovery learning model, while the experiment class used digital media of augmented reality (AR) in the Assemblr EDU application (Figure 1) with a guided inquiry model. Figure 2 shows an example of a question that applies the guided inquiry model. The research design is presented in Table 2.

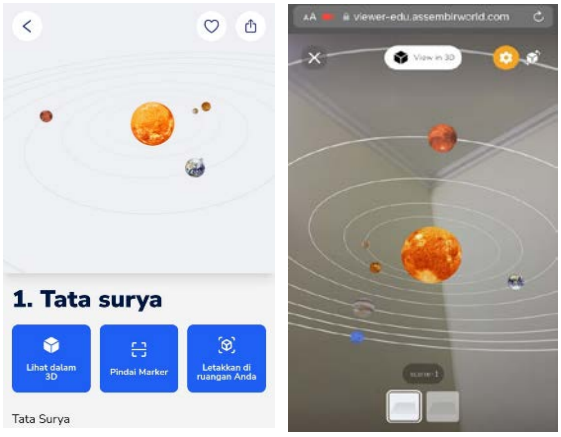

Figure 1: Assembler EDU application with AR-based learning media on solar system

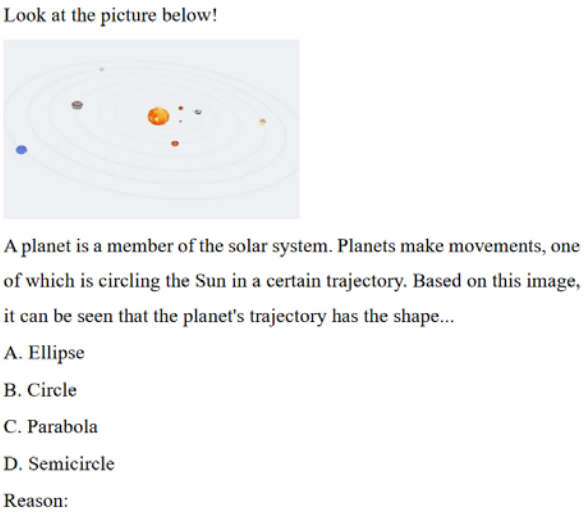

Figure 2: Example of a question applied to the Assemblr Edu application

Table 2: Research design

Group	Pretest	Treatment	Posttest
Experiment class	O_1	X	O_2
Control class	O_3	Y	O_4

Source: (Sugiyono, 2013)

Description:

X : experiment class (guided inquiry and AR media)

Y : control class (discovery learning and pictures-videos media)

O_1 : pretest of experiment class

O_2 : posttest of experiment class

O_3 : pretest of control class

O_4 : posttest of control class

Data Collection

The data collection technique was to determine students' critical thinking abilities before and after being given treatment. A reasoned multiple-choice test and a students' response questionnaire were employed. An example of a reasoned multiple-choice

question can be seen in Figure 2, which provides an indicator of thinking ability to focus on a question. The test measured the students' critical thinking abilities regarding solar system material. The test and questionnaire were prepared based on critical thinking indicators (Ennis, 2011) and were given to both samples before and after treatment.

Data Analysis

Parametric and non-parametric statistical techniques were used in this study. When the generated data follows a normal distribution and is in interval format, parametric statistics are used. Conversely, non-parametric statistics are employed if the data does not follow a normal distribution and is nominal. The analysis used to determine whether the guided inquiry model assisted by augmented reality could enhance students' critical thinking skills involved a t-test using SPSS Software.

RESULTS AND DISCUSSION

This quasi-experimental research involved control and experiment classes as research treatments. In both classes, learning was carried out in four meetings on solar system study material. The material taught at each meeting is the solar system, including understanding the Sun, planets, and their satellites, and getting to know the Sun more closely.

Based on the pretest and posttest data on students' critical thinking abilities in all classes, all data were distributed normally and homogeneously. Thus, parametric statistics were applied using a t-test. The results of the average pretest and posttest scores for the critical thinking abilities of experimental and control class students can be seen in Figure 3.

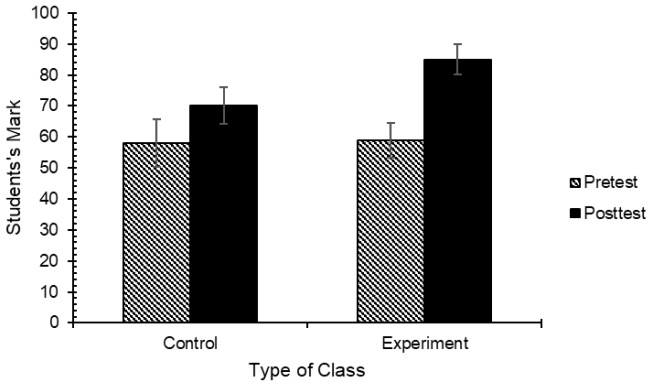

Figure 3: Pretest and posttest results of control and experiment classes

Based on Figure 3, the pretest scores for both classes are not significantly different. In contrast to the results of the posttest scores in the experimental class, the results are significantly higher than those in the control class. As for the results of the pretest value testing using the related t-test, the Sig. (2-tailed) value was 0.377 > 0.05, meaning there is no significant difference in the pretest results of the control and experiment classes because the significant value is > 005. Thus, no other factors could influence students' critical thinking abilities in both classes apart from the treatment given. Therefore, testing the presence of treatment given was done using student posttest data.

Based on the test results for the application due to posttest data treatment using the related t-test, a Sig. (2-tailed) value of 0.000 > 0.05 was obtained. Based on the t-test results, there was a significant difference in the posttest results for the experiment and control classes. Based on the t-test results of students' pretest and posttest data, it can be concluded that applying the guided inquiry model assisted by augmented reality can improve students' critical thinking skills regarding solar system material.

Furthermore, significant differences can be observed based on the analysis of pretest and posttest data using the N-gain test. This test was used to determine the effectiveness of the treatment given before and after learning. The N-gain test was carried out twice based on the average and each student's critical thinking ability indicator in the pretest and posttest questions. The N-gain test calculation based on the average in the control class increased by 0.27, while in the experiment class, it increased by 0.62. These results showed that the increase in the experiment class was higher than in the medium category of the control class ($0.3 \leq g \leq 0.7$). Next, the pretest and posttest data were carried out with an N-gain test on each indicator of critical thinking ability used. According to Ennis (2011), ten indicators of student's critical thinking abilities were used and distributed in 15 reasoned multiple-choice questions. The results of the N-gain test for critical thinking ability indicators in the control and experimental classes are presented in Figure 4.

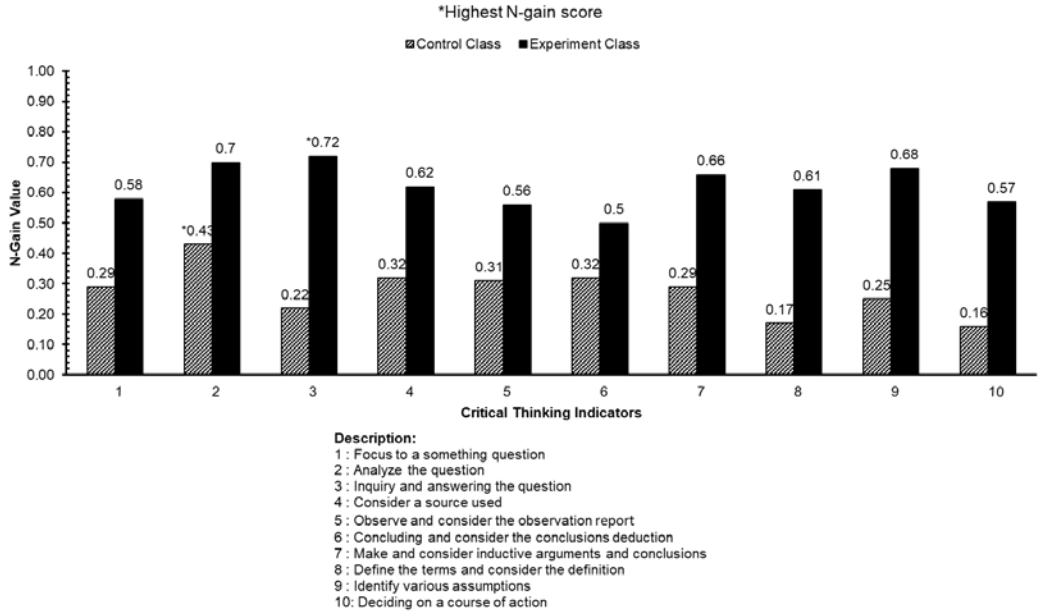

Figure 4: N-gain test for critical thinking ability indicators

Figure 4 shows increased students' critical thinking abilities as seen in N-gain. The image results show that the N-gain value obtained in the experimental class is higher than the control class. The highest score in the experimental class was 0.72 in the high category, while in the control class, the highest score was 0.43 in the medium category. The results of the N-gain analysis stated significant differences in each indicator of students' critical thinking abilities in the control and experiment classes. This analysis data shows a better improvement in the experimental class than in the control class.

A person is considered to have critical thinking abilities if they meet the indicators of critical thinking abilities (Ennis, 2011). The increase in students' critical thinking skills was measured using N-gain, which was analyzed for each indicator. The critical thinking ability indicators in this research adopt indicators from Ennis (2011), which have five aspects: providing simple explanations, building essential and basic skills, concluding, making further explanations, and organizing strategies and tactics. The first aspect, namely providing a simple explanation, was divided into three indicators: focusing on a question, analyzing the question, and asking and answering questions. Each indicator between the experimental and control classes had a significant difference, where the results of increasing N-gain in the experimental class were higher than in the control class.

The increase in results was influenced by, among other things, the use of the guided inquiry model with the help of AR, which occurred at the orientation or problem

formulation stage. During the learning process, the teacher motivated students to ask questions because they were facilitated by jointly observing narratives, learning videos, and AR media in the experimental class, which stimulated students to focus and think to ask questions. It is related to guided inquiry learning, which requires students to think actively, formulate problems, focus, and try to identify questions that arise from observed physical phenomena to develop their critical thinking abilities (Thornhill-Miller et al., 2023).

Furthermore, regarding the second aspect of building basic skills, the experiment class was better than the control class. There are two indicators, i.e., considering a source used and considering observation reports (Koksal & Berberoglu, 2014). The highest increase occurred in the indicator considering the source used because students were asked to reconsider answers in learning activities based on AR media information. It allows students to observe the questions given. A person will carefully consider or determine whether to reject, accept, or delay receiving information with critical thinking skills. Adapting to sources is a person's ability to use existing procedures from trusted sources, such as formulas, statements, and facts, to solve a problem.

The third aspect is concluding, where two indicators were used, i.e., concluding and considering deductive conclusions and making and considering inductive arguments and findings. Of the two indicators above, the indicator of creating and considering inductive arguments and conclusions had the highest N-gain value. Students were trained to answer questions related to AR media and asked to come up with several options by considering these decisions. The existence of interaction activities between students creates an exchange of ideas, where this activity influences the indicators for making an induction. When making an induction, students must actively participate in the discussion to draw careful conclusions from specific problems (Komala et al., 2017).

The fourth aspect is making further explanations. In this aspect, two indicators were used to measure critical thinking skills, i.e., defining terms/considering definitions, and identifying various assumptions. The highest increase occurred in the indicator identifying various assumptions, where there was an increase in this indicator due to implementation using AR media, which trained students in thinking and producing a conclusion based on their assumptions. Critical thinking requires rigorously examining every assumptive knowledge or belief based on supporting evidence and the subsequent conclusions that result from it (Rahmawati et al., 2019; Zuniari et al., 2022).

The fifth aspect is organizing strategy and tactics, where deciding on an action occurs in the guided inquiry model syntax. Designing an experiment requires students to act according to the work method in the student worksheet. The use of AR media during the experiment was not only to make the experiment easier but also to make students interested in learning and gain more in-depth knowledge regarding AR media in student worksheets. In contrast to the control class, which only uses the discovery learning model with the help of learning videos, students felt bored more quickly. They were less enthusiastic about learning activities in class. Apart from that, in this indicator, students were trained to determine the reasons for and actions for decisions through observations on AR media. At the end of each activity on the worksheet, students were required to answer questions. The activities in AR media attempted to guide students in answering problems and determining appropriate actions. Determining an action can be improved by solving questions correctly (Khamhaengpol et al., 2021).

Overall, this research showed that learning using the guided inquiry model assisted by AR media implemented in the experimental class could improve student's critical thinking abilities. The AR-assisted guided inquiry model could train students' critical thinking skills and be more student-centered. This model's stages invited students to think about formulating problems and drawing conclusions. Meanwhile, AR media was used to conduct investigations to gain knowledge independently. This activity made students more

active and meaningful. It made obtaining information from various sources easier with the help of the internet or student teaching materials, improving their critical thinking abilities. Meanwhile, it was not optimal in the control class since learning through videos still made them lack understanding of the information. It did not facilitate investigations that could enable students to gain new knowledge and draw conclusions from the investigation results.

The guided inquiry learning model assisted by augmented reality can improve students' critical thinking skills. It was supported by analyzing the results of a questionnaire given to students after the learning process. The questionnaire analysis consists of 10 statement items grouped into five aspects of the student response questionnaire. The results of the data analysis are presented in Table 3.

Table 3: Percentage of students' responses to the questionnaire

Aspects of questionnaire	Percentage (%)
Interest in learning models and media	84.19
Utilization of learning models and media	84.19
Understanding learning material	89.33
Developing students' information	83.82
Generating students' critical thinking attitudes	83.45

Based on Table 3, it can be concluded that the results of the students' response questionnaire in the experimental class in the guided inquiry learning model assisted by augmented reality in every aspect obtained very good responses from students with an average of 84.99%. It shows that the guided inquiry learning model assisted by augmented reality learning media suits solar system study material use.

CONCLUSION AND IMPLICATIONS

Guided inquiry learning using AR technology media in the context of solar system study material significantly enhanced students' critical thinking skills. Application of augmented reality It has also been proven to give students the courage to express real ideas; it is part of the concepts that exist within them and should be developed and adequately directed (Hermawan & Hadi, 2024). Furthermore, Nugroho (2023) also explained that implementing augmented reality in learning spaces can enhance the experience and bring significant changes in learning. The guided inquiry model assisted by augmented reality received a positive response from students in the very good category—AR-enabled inquiry activities immerse learners in an authentic context. Students can explore the solar system, visualize celestial bodies, and interact with virtual models. This engagement fosters curiosity and encourages critical thinking. AR allows students to collect data beyond the classroom, and their experience promotes analytical thinking and problem-solving. AR also facilitates collaboration among students working together on complex solar system concepts. Effective communication and teamwork are essential for critical thinking. In summary, integrating guided inquiry learning with AR technology in solar system education enhances critical thinking by offering immersive experiences, data-driven exploration, and collaborative problem-solving. To strengthen the findings in this research, the researcher provides suggestions for future researchers to carry out experiments related to using augmented reality learning media to improve other science skills.

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