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The Effect of The Implementation of A Project-Based Learning Model Assisted By Augmented Reality on Sixth Graders' Critical Thinking Skills on Solar System Materials

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Abstract

Background/purpose. This study aims to evaluate the effect of the application of the PjBL learning model assisted by AR on students' critical thinking skills. The focus of this study is on sixth-grade students with solar system material, designed to explore how the integration of AR technology in PjBL can improve student engagement, conceptual understanding, and critical thinking skills.

Materials/methods. This research is quantitative research with an experimental type. Research design using nonequivalent control group (pre-test and post-test). Critical thinking data collection focuses on the FRISCO indicators, namely Focus (F), Reason (R), Conclusion (I), Situation (S), Clarity (C), and Overview (O). The instruments used in this study were cognitive tests and observation sheets. The measurement scale for critical thinking skills observation used a Likert scale, 1 (strongly disagree) - 5 (strongly agree)

Results. Both the control and experimental groups' pre-and post-test scores increased significantly. The experimental class achieved a post-test average of 79.61, whose average pre-test score was 56.92, while a post-test average of 60.27 was achieved by the control class, whose average pre-test score was 50.31. The data were first examined for normality and homogeneity using the Kolmogorov-Smirnov and Levene tests, which confirmed that the samples were distributed normally and were similar to one another. Then, hypothesis testing was initiated. After the hypothesis testing using a paired sample t-test was conducted, the null hypothesis (H0) was rejected due to a significance value of 0.00, which is less than 0.05.

Conclusion. These findings demonstrate a notable difference between the two groups and demonstrate that students' critical thinking skills are improved with the use of AR-assisted PjBL. Consistent with other findings, this study confirms that PjBL and AR effectively boost students' motivation, engagement, and critical thinking skills.

1. Introduction

The development of the 21st century has brought many changes in Indonesia, especially in the field of education, including changes in the curriculum from the school-based Curriculum (KTSP) to the 2013 Curriculum and changed again after COVID-19 to the Merdeka Curriculum. The existence of these two curricula requires educators (teachers) to implement character-based learning, which aims to develop students' 4C competencies, namely communication, collaboration, creative thinking, and critical thinking (Kemendikbud, 2017). One of the important skills that students must have is critical thinking.

Based on the 2022 PISA results show that Indonesian students' scores in mathematics, reading, and science have decreased, with 77.13% of students deficient in mathematics and 73.61% in science (Bilad et al., 2024; Dayantri & Nasution, 2024). Comparatively, out of 57 countries, Indonesia ranked 50th in mathematics and science literacy (Dayantri & Nasution, 2024). Key factors identified include teacher competencies, resource shortages, and the impact of the COVID-19 pandemic (Hilmi & Kismiantini, 2024; Wijaya et al., 2024).

This condition can be overcome by a new approach to the learning process, especially in developing students' critical thinking skills. Changing the teaching model and materials used in the classroom is one of several possible approaches to improving students' critical thinking skills. One method that can be used is project-based learning (PjBL), focusing on student learning as they complete projects or assignments.

If the right learning materials that are used are in line with this paradigm, students' critical thinking skills will increase rapidly. Teachers rely on this learning model to disseminate learning materials and guide students when they learn. Students also benefit greatly from this medium in their own learning (Dewey, 1986). The implementation of PjBL assists students in using their knowledge from various subjects to solve real-world situations. Besides, it allows students to gain new insights by guiding them through an exploration process that is connected to real-life scenarios. In addition to helping students find ideas independently through the use of various sources of knowledge, this approach can motivate students to build analytical and critical thinking skills (Mulyasa et al., 2016).

The implementation of PjBL models can be supported by various types of learning media. Making smart media choices can significantly increase class efficiency and effectiveness. Students can better understand abstract ideas through the use of learning media that are in line with standards and available resources (Hamdalia Herzon et al., 2017). Among the many forms of digital media that have the potential to improve the PjBL model is augmented reality (AR). With the help of AR technology, the virtual and physical worlds can merge to create an immersive experience that seems almost real (Novitasari & Fauziddin, 2022).

The use of AR learning media in PjBL has been the subject of many previous studies, including a study conducted by Wati et al. (2023) aiming to provide research results on the effectiveness of using AR in PjBL for elementary school students in grade three. Of the total students in cycle I, 9 students (34.6%) had met the minimum completion requirements (KKM), while 17 students had not. As a benchmark, we determined that 85% of students had to be able to achieve the class average score, which was 65.4%. In the first cycle, the average score was 76.5. The percentage of students who completed their learning increased in cycle II, with 23 students (88.5%) achieving KKM and three students (65.4%) still did not. Another study conducted by Dita et al. (2021) investigated the use of AR media together with the Problem-Based Learning (PBL) paradigm with eighth-grade students, highlighting the impact of the methodology on student achievement.

The originality of this research is the development of previous work by using AR media to support the implementation of PjBL models on content related to the solar system. The sixth-grade students

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in the Sapuran subdistrict were tested on their critical thinking skills during the 2023–2024 school year.

This study aims to evaluate the effect of the application of the PjBL learning model assisted by AR on students' critical thinking skills. The focus of this study is on sixth-grade students with solar system material, designed to explore how the integration of AR technology in PjBL can improve student engagement, conceptual understanding, and critical thinking skills. This study was conducted at State Elementary School (SDN) 1 Sedayu as an effort to provide innovative alternatives in a more interactive and effective learning process.

2. Literature Review

2.1. Project-Based Learning Model

The project-based learning model or we usually call it the project-based learning model includes learning methods with practical projects in everyday life referring to high enthusiasm, things to ask, assignments, or stimulating problems in training scientific understanding and trained skills to work together when solving problems (Mustika et al., 2022). This model emphasizes direct experience that is relevant to students' real lives, making the learning process more meaningful and in line with their lives (Kemendikbud, 2017).

PjBL is an educational approach that actively engages students in meaningful projects, promoting cognitive, social-emotional, and practical skills. It emphasizes contextualization, collaboration, and autonomy, allowing students to apply knowledge in real-world situations, and enhancing motivation and engagement (Sousa, 2024; Pazildzhanova, 2024; Becerra-Posada et al., 2022). Project-based learning is an educational model that enhances student learning and academic achievement by promoting engagement, critical thinking, collaboration, and innovative thinking despite challenges like project design complexity and resource constraints. It differs significantly from traditional teaching methods (Kunfeng, 2024; Marcia & Nation, 2008). PjBL involves students engaging in hands-on projects to explore real-world challenges, fostering critical skills like reasoning, problem-solving, and communication essential for modern professional success (Abilova et al., 2024; Nayak et al., 2024).

The benefits of using the PjBL approach include: (1) cultivating student activeness in learning, (2) developing critical thinking skills, (3) strengthening teamwork skills, (4) providing learning that is relevant to real life, and (5) developing students' imaginative capacity. In addition to making learning fun, this approach provides students with practice in project management, which increases their activity level, encourages teamwork, and helps them become better problem solvers (Azuma, 1997).

2.2. Augmented Reality

AR integrates digital data into the real world, enhancing user perceptions. It is pivotal in mechanical system design and prototyping, offering creativity, effectiveness, and accuracy in the process (Jindal, 2024; Omkar, 2022; Sarkar et al., 2022). AR overlays digital information onto the real world, transforming education by enhancing student engagement, fostering interactive learning, and promoting a deeper understanding of complex concepts in immersive environments (Shonima & Sowmya, K, 2024). AR enables users to see the real world displayed through virtual objects (Barone et al., 2023; Chaudhari, 2024; Piekarski & Thomas, 2002; Ceolin et al., 2023).

In this study, the type of AR utilized is image recognition. Image recognition in AR involves the process of taking pictures, analyzing features, and processing data to match images from the real world with a digital database. This process plays an important role in ensuring the suitability and accuracy of the integration between virtual elements and the real environment (Sumarni, 2015) which usually uses AR in this type using the help of QR codes. The use of AR in this study was assisted

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by 4D books and flashcards that required assistance from applications in the form of Devar and Assembler Edu. The following is an example of the application of AR with the help of the Devar and Assembler Edu applications.

2.3. Critical Thinking Skills

Critical thinking is a thought involving several abilities, including the ability to analyze, evaluate, and interpret information obtained logically (Ennis, 1987; Itsnaini et al., 2024; Mızrak & Çaylan, 2024; Savchuk & Yehorova, 2024). Critical thinking is a focused and reflective thought that includes several other abilities, such as the ability to recognize, evaluate, assess arguments, collect, and analyze information obtained carefully (Bıldırcın, 2024; Ranbir, 2024; Spring, 2019). Another premise is that critical thinking is an active mental process that includes several steps, such as methods for assessing, evaluating, and drawing conclusions from data presented in various forms (eg, arguments, ideas, and circumstances) (Chukwuere, 2024; Paul & Elder, 2006; Vincent-Lancrin, 2024). This ability is key to understanding and solving problems, including in an academic context.

3. Methodology

3.1. Research Design

This research is quantitative research with an experimental type. The research design used is quasi-experimental because, in this study, the researcher cannot control the variables that influence the process of the research experiment (Sugiyono, 2021). The independent variables (exogenous) in this study are project-based learning models (X1) and Augmented Reality (X2). The dependent variable (endogenous) in this study is critical thinking skills (X3).

Research with experimental methods is considered research that can accurately test hypotheses regarding causal relationships (Gay et al., 1981). The following is a quasi-experimental plan conspires to employ a nonequivalent control group (pre-test and post-test):

Table 1. Nonequivalent control group scheme (pre-test post-test)

Group	Pre-test	Free variables	Post-test
Experimental class	O1	X	O2
Control class	O3	-	O4

3.2. Population and Sample

The populace in this ponder was understudies at SDN 1 Sedayu. The sample of this study involved sixth-grade students of SDN 1 Sedayu, located in the Sapuran subdistrict, Wonosobo Regency, in the 2024/2025 academic year as research subjects. As a control group, the research sample consisted of 6A grade students, and an experimental group consisted of 6B grade students, who were randomly selected using a probability sampling procedure with a random sampling technique. Random sampling is a random approach where all members have an equal opportunity to be selected as research samples (Wang, 2024).

3.3. Data collection techniques

The information collection method utilized was a test conducted by the analysts with a descriptive test type. The test was utilized to degree students' critical thinking skills based on critical thinking indicators. The critical thinking indicators used were based on Ennis' supposition, specifically FRISCO. The use of the multi-element FRISCO model was one of the indicators used to measure students' critical thinking skills such as Focus (F), Reason (R), Conclusion (I), Situation (S), Clarity (C), and Overview (O). This indicator helps assess various aspects of critical thinking skills, such as focusing

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on the main problem, reasoning based on facts, concluding, understanding the context, clarity of communication, and reviewing the entire information. Focus refers to identifying the main problem or students' understanding of the core of the problem.

The reason relates to students' ability to identify and evaluate relevant reasons and support decisions based on logical facts. Inference means assessing the quality of conclusions by ensuring that conclusions are based on acceptable reasons or that students can draw the right conclusions. Situation emphasizes understanding the context by considering all the information that is appropriate to solve the problem. Clarity ensures clarity in the language or terminology used, where students provide a more in-depth explanation. Finally, Overview is the ability of students to see the entire process from start to finish as a whole, ensuring that all aspects have been reviewed (Lidiawati & Aurelia, 2023).

In this study, the researchers applied the deep-thinking pattern parameters in the form of FRISCO proposed by Ennis. However, the researchers made modifications to the parameters that would be applied when measuring the deep-thinking skills of students at SD N 1 Sedayu, namely by using the FRISC indicator. The researcher used this indicator because O in FRISCO is used to recheck the FRISC indicator. So, in the FRISCO indicator proposed by Ennis is only used for FRISC.

The approval of the test instrument was carried out by master judgment from the viewpoint of the legitimacy of the grid, content, construct, and language. In expansion, testing the validity of the test was carried out by calculating the comes about of the experts' appraisal utilizing Aiken's v evaluation and calculating the level of trouble and segregating control of the questions. The results of the validity test were calculated utilizing Microsoft Excel and after that, the reliability test calculations were carried out utilizing the SPSS 25 program.

The instruments used in this study were cognitive tests and observation sheets. The measurement scale for critical thinking skills observations used the Likert scale, (1) = strongly disagree, (2) = disagree, (3) = neutral, (4) = agree, and (5) = strongly agree (Harpe, 2015). The comes about of the validation test for the science materials comprised of 10 questions. The comes about Aiken's v calculations with 5 validators produced 10 valid statements for science materials, 10 valid statements for chemistry materials, and 10 valid questions for physics materials with the comes about of each material $V \geq 0.8$. The analysts utilized 10 questions that had the most noteworthy level of validity, and the 15 questions were at that point tried. The comes about of trials were at that point analyzed for the level of trouble and the separating control of each item. The result of the calculation of the trouble level with a run of trouble file values was $0.30 \leq P \leq 0.70$. The level of trouble within the science materials that had been tried created 10 valid substantial explanations out of 10 statements. Moreover, based on the calculation of the separating control, the differential file which was break even with two or more noteworthy than 0.30 was considered to have a great differential index ($D \geq 0.30$). The separating control in science materials that had been tried created 10 substantial questions.

The comes about of the unwavering quality of the critical thinking skill test instrument were calculated utilizing the Alpha Cronbach equation utilizing the SPSS 25 program. The reliability test of 10 questions on the instrument for critical thinking skills in sciences was 0.875 and 0.691 accepting a adjusting of 0.70 and 0.825 so that based on the premise for the choice making, in case the reliability coefficient is 0.70 or $r11 \geq 0.70$, it can be said that the critical thinking skill instrument is reliable.

3.4. Data Analysis Techniques

The analysis prerequisite test is a statistical test used to test important assumptions before applying a particular analysis model so that the results are more accurate. The investigation prerequisite tests utilized in this think about included the normality test and the homogeneity test.

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The normality test is utilized by analysts to see that the test information utilized comes from a normal population. This homogeneity test can be carried out to decide whether the chosen test incorporates a homogeneous variation or not. The hypothesis test carried out by analysts was the t-test. Zhou et al. (2021) states that the t-test is one of the parametric testing models. The t-test was carried out by considering the centrality of 0.05.

Information investigation was conducted utilizing SmartPLS 4 program. A Partial Least Squares (PLS) investigation was utilized to decide the connections between the dependent and independent variables (Huang, 2021). The tests performed included approval with cross-loadings for discriminant validity, reliability testing with build reliability and validity, and hypothesis testing with the inner model. The study utilized PLS examination with the assistance of SmartPLS 4.0.

The design of the structural model (Inner model) determines the relationship between variables that are tested for validity and reliability, then creates a relationship between latent constructs and is evaluated based on the coefficient of determination (R2) and path. R2 measures the magnitude of the influence of independent variables on the relationship.

The R2 value criteria > 0.67 indicates that the model is in the good category, a value of 0.33 - 0.67 indicates a moderate category, while < 0.33 is in the weak category. While the Adjusted R Square is the average value of the model. The R Square value corrected with standard error shows a more substantial range in assessing an exogenous variable to explain the endogenous variable. Goodness of Fit (GoF) is applied to validate the performance of the structural measurement model. GoF is based on the Stone Geisser Q2 Value criteria which refers to the Q Square predictive relevance test which functions to validate the model.

The developed model has predictive relevance if the Q Square number > 0, so it can be concluded that the exogenous variable is right as a variable that can predict the endogenous variable. Meanwhile, it is said to have minimal predictive relevance if the Q Square number <0 to see the deviation of a model based on the population covariance matrix on the Root mean square error (RMSEA). The RMSEA value <0.05 indicates that the model is very suitable, and the value> 0.05 means that the model is very suitable (Ghozali, 2016).

Hypothesis testing based on Inner model testing includes path coefficient values and T-Statistics. To determine which hypothesis can be accepted or rejected based on the significance value between constructs, T-Statistics, and p-value. T-Statistics based on Rules of Thumb is > 1.96. The beta coefficient is positive and significant, and its significance is based on a p-value of 0.05 (5%) with a path coefficient ranging from +1 to -1. The magnitude of the path coefficient value is in the range of 1, indicating an increasingly good relationship and is proven based on a significance test (Ghozali, 2016).

4. Results

The results of descriptive tests of the experimental class (6B) and control class (6A) carried out in class VI of SD Negeri 1 Sedayu can be seen in Table 1 below.

Table 1. Results of the Descriptive Test Scores

Class	Descriptive Test Data	The highest score	The lowest score	Average score
Experiment	Pre-test	70	37.5	56.92
	Post-test	97.5	62.5	79.61
Control	Pre-test	60	40	50.31
	Post-test	70	50	60.27

Table 1 shows an increment in scores from the pre-test and post-test within the expressive test. Within the explanatory lesson, the most elevated score from the pre-test was 70, and the most

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reduced score was 37.5, with an average score of 56.92. Within the post-test, the most noteworthy score came to 97.5, the lowest score was 62.5, and the average score was 79.61. In the interim, within the control course, the pre-test recorded the most noteworthy score of 60, the most reduced score was 40, and the average score was 50.31. Within the post-test, the most elevated score came to 70, and the lowest score was 50, with an average score of 60.27.

Sometime recently, a prerequisite test was carried out to guarantee that the test information was from a normally distributed population, then a normality test was carried out. Information is considered normal if it has a noteworthiness esteem (Sig. 2-tailed) higher than 0.05. The significance level before and after testing in the control group was 0.200, but in the experimental group, it was 0.110 and 0.200, respectively. All data were considered normal because the significance value was more than 0.05.

Another test conducted was Levene's test utilized to decide whether the populace conveyance was homogeneous or not. On the chance that the homogeneity test comes about have a noteworthiness level more prominent than 0.05, at that point, the information is said to be homogeneous. Based on the comes about of the homogeneity test, the information was said to be homogeneous since it had an importance level of 0.069. After all the fundamental tests were carried out, the speculation test has proceeded employing a combined test t-test to compare the midpoints of the two bunches after the treatment. In this study, the post-test scores of the experimental and control bunches were compared. The null hypothesis (H0) was rejected because the test came about appeared a noteworthiness figure of 0.00 ≤ 0.05. The utilization of the PjBL approach with AR can make strides in the critical thinking skills of reviewing six understudies of SD Negeri 1 Sedayu within the 2024/2025 scholarly year and there is a factually noteworthy distinction between the two bunches.

The researchers conducted an internal consistency reliability test using SmartPLS 4.0. The results of the reliability test are as follows:

Table 2. Reliability Test

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Critical Thinking Skill	0.948	0.957	0.960	0.828
Experimental Class	0.916	0.935	0.935	0.705
Control Class	0.947	0.952	0.966	0.904

Table 2 shows that reliability testing utilized Cronbach's alpha (α), rho_A, and CR indicators, with values considered reliable if they surpass 0.70. The initial criteria evaluated within the estimation demonstrate inner consistency reliability. Reliability testing utilized Cronbach's alpha (α), rho_A, and Composite Reliability (CR) markers, with values considered reliable if they exceeded 0.70. Examination of Table 1 uncovered that all developments extended from 0.916 to 0.948 for (α), 0.935 to 0.957 for rho_A, and 0.935 to 0.966 for CR, showing that each development estimation surpassed the threshold of 0.7. This shows that the use of the show was reliable for improving critical thinking skills. Encourage assessment centered on convergent validity which aimed to determine the validity of the relationship between each marker and idle factors. This was done by utilizing Average Variance Extracted (AVE), with pointers that meet the convergent validity criteria in case AVE ≥ 0.50.

Table 3. Validity Test

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	Critical thinking skills	Experimental class	Control class
X1.1	-0.318	0.769	0.575
X1.2	-0.542	0.834	0.573
X1.3	-0.451	0.825	0.638
X1.4	-0.330	0.835	0.555
X1.5	-0.468	0.944	0.810
X1.6	-0.381	0.821	0.617
X2.1	-0.237	0.765	0.982
X2.2	-0.208	0.665	0.940
X2.3	-0.226	0.711	0.930
Y1	0.914	-0.399	-0.209
Y2	0.946	-0.479	-0.247
Y3	0.878	-0.405	-0.150
Y4	0.932	-0.441	-0.160
Y5	0.877	-0.562	-0.285

Table 3 shows that the measurement items on the critical thinking skill variable were higher than other variables, ranging from 0.877 to 0.946. In the AR-assisted project-based learning model variable used in the experimental class, the measurement item values were correlated higher than with other variables, ranging from 0.769 to 0.944. In the conventional learning model variable used in the control class, the correlation was higher than with other variables, namely 0.930 to 0.982. Based on these results, it can be seen that the measurement items correlated more strongly/higher with the measured variables and correlated less with other variables so that each variable can be said to be valid. The criteria are acknowledged on the chance that variables correlate less with other variables (Arshad et al., 2024).

Then, the results of the model fit test are presented. A test may be carried out to examine whether the demonstration and information are appropriate for testing the impact of factors (Cusipag et al., 2024). The necessity is that SRMR must be less than 0.10. The complete results are in Table 4.

Table 4. Model Fit Test

	Saturated model	Estimated model
SRMR	0.070	0.070
d_ULS	0.520	0.520
d_G	0.785	0.785
Chi-square	135.357	135.357
NFI	0.785	0.785

Table 4 shows the SRMR value of 0.070 < 0.10, so it can be seen that the model and data are suitable for testing the influence of the variables. The necessity is that SRMR must be less than 0.10. Then, in this study, hypothesis testing was carried out using intelligent PLS 4 software with the Inner

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Model Test. The inner model testing step was carried out to test the significance of the impact of exogenous variables on endogenous variables (Vanisri & Padhy, 2024). The criterion used to determine the impact of the model is if the p-value <0.05 or the T-value> 1.96. The complete results are in Table 5.

Table 5. Inner Model Test

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
AR-assisted PjBL Model -> Critical Thinking skill	-0.768	-0.802	0.155	4.960	0.000
Conventional Model -> Critical Thinking skill	0.342	0.353	0.217	1.573	0.116

Table 5 shows that the P-value and T-value in the AR-assisted PjBL model were 0.000 and 4.960. While the P-value and T-value in the model used by the control class were 0.116 and 1.573. Based on these results, you can see that the AR-assisted PjBL model has a greater effect on critical thinking skills than the conventional model. The test used to determine the effect of each syntax model of AR-assisted PjBL was carried out using smart PLS 4 software.

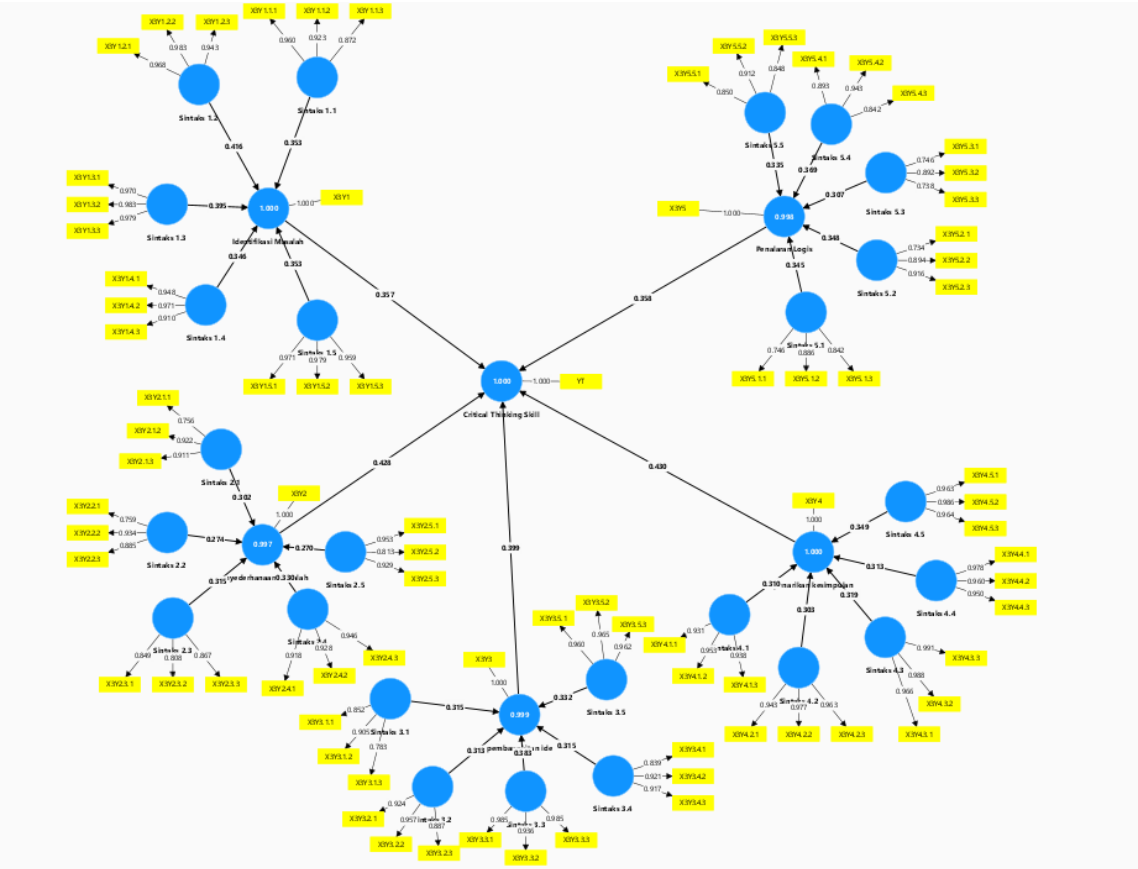

Figure 1. Syntax Validity Test Results

Figure 1 shows that the outer loading value of each syntax implementation observation item was greater than 0.07. The rule used to determine whether each syntax implementation observation item

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is valid or not was if the item value is > 0.07. Because the value of each syntax implementation observation item was > 0.07, it can be seen that each syntax implementation observation item was valid. Next, researchers conducted reliability tests. Cronbach's alpha (α), rho_A, and CR were used in the reliability test, and values above 0.70 were considered reliable. Table 5 shows the results of the reliability testing.

Table 6. Reliability Test

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
syntax 1.1	0.908	0.950	0.942	0.845
syntax 1.2	0.963	0.964	0.976	0.931
syntax 1.3	0.977	0.977	0.985	0.956
syntax 1.4	0.938	0.940	0.960	0.890
syntax 1.5	0.968	0.969	0.979	0.941
syntax 2.1	0.832	0.864	0.900	0.751
syntax 2.2	0.823	0.823	0.896	0.744
syntax 2.3	0.809	0.850	0.879	0.708
syntax 2.4	0.923	0.927	0.951	0.866
syntax 2.5	0.881	0.897	0.927	0.811
syntax 3.1	0.807	0.835	0.884	0.719
syntax 3.2	0.914	0.926	0.945	0.852
syntax 3.3	0.967	0.967	0.979	0.938
syntax 3.4	0.873	0.875	0.922	0.798
syntax 3.5	0.960	0.960	0.974	0.926
syntax 4.1	0.935	0.935	0.958	0.885
syntax 4.2	0.958	0.959	0.973	0.923
syntax 4.3	0.982	0.982	0.988	0.965
syntax 4.4	0.961	0.976	0.974	0.927
syntax 4.5	0.970	0.971	0.980	0.943
syntax 5.1	0.767	0.777	0.866	0.684
syntax 5.2	0.807	0.832	0.887	0.726
syntax 5.3	0.705	0.710	0.837	0.633
syntax 5.4	0.873	0.872	0.922	0.799
syntax 5.5	0.840	0.845	0.904	0.758

Table 6 shown that reliability test has used Cronbach's alpha (α), rho_A, and CR indicators, with values considered reliable if they exceed 0.70. Table analysis of the table revealed that all the constructions varied from 0.705 to 0.982 for (α), 0.710 to 0.977 for rho_A, and 0.837 to 0.985 for CR,

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indicating that each construction measure exceeded the of 0.7 threshold. This indicates that the use of the model was reliable for skills of critical thinking. Further evaluation focused on convergent validity which aimed to determine the validity of the relationship between each indicator and its latent variables. This was measured using AVE, with indicators that met the criteria for convergent validity if AVE ≥ 0.50.

In this study, the test of the influence of each syntax on the critical thinking skill indicators was carried out using smart PLS 4.0 software with the Inner Model Test. The internal model testing procedure was performed to test the significance of the impact of the exogenous variables on the endogenous variables. The criterion used to determine the impact of the model is if the P-value <0.05 or the T-value> 1.96. Complete results regarding the inner model test are presented in the table 7.

Table 7. Inner Model Test

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T-statistics (|O/STDEV|)	P-values
Problem Identification -> Critical Thinking Skill	0.357	0.359	0.029	12.172	0.000
Logical Reasoning -> Critical Thinking Skill	0.358	0.359	0.029	12.444	0.000
Syntax 1.1 -> Problem Identification	0.353	0.353	0.022	16.368	0.000
Syntax 1.2 -> Problem Identification	0.416	0.416	0.025	16.645	0.000
Syntax 1.3 -> Problem Identification	0.395	0.396	0.026	14.939	0.000
Syntax 1.4 -> Problem Identification	0.346	0.346	0.028	12.271	0.000
Syntax 1.5 -> Problem Identification	0.353	0.353	0.021	16.646	0.000
Syntax 2.1 -> problem simplification	0.302	0.304	0.019	15.505	0.000
Syntax 2.2 -> problem simplification	0.274	0.272	0.020	14.012	0.000
Syntax 2.3 -> problem simplification	0.315	0.315	0.018	17.768	0.000
Syntax 2.4 -> problem simplification	0.330	0.329	0.021	16.015	0.000
Syntax 2.5 -> problem simplification	0.270	0.269	0.022	12.531	0.000
Syntax 3.1 -> Idea generation	0.315	0.313	0.024	13.369	0.000
Syntax 3.2 -> Idea generation	0.313	0.312	0.020	15.402	0.000
Syntax 3.3 -> Idea generation	0.383	0.383	0.027	14.312	0.000
Syntax 3.4 -> Idea generation	0.315	0.315	0.022	14.063	0.000
Syntax 3.5 -> Idea generation	0.332	0.329	0.022	14.830	0.000
Syntax 4.1 -> Concluding	0.310	0.310	0.017	18.497	0.000
Syntax 4.2 -> Concluding	0.303	0.303	0.016	18.689	0.000
Syntax 4.3 -> Concluding	0.319	0.319	0.017	18.295	0.000
Syntax 4.4 -> Concluding	0.313	0.313	0.024	12.830	0.000
Syntax 4.5 -> Concluding	0.349	0.350	0.023	15.043	0.000
Syntax 5.1 -> Logical reasoning	0.345	0.344	0.022	15.590	0.000
Syntax 5.2 -> Logical reasoning	0.348	0.345	0.024	14.425	0.000
Syntax 5.3 -> Logical reasoning	0.307	0.306	0.018	16.783	0.000
Syntax 5.4 -> Logical reasoning	0.369	0.364	0.026	14.056	0.000
Syntax 5.5 -> Logical reasoning	0.335	0.334	0.026	13.059	0.000
Idea generation -> Critical Thinking Skill	0.399	0.401	0.040	9.901	0.000
Concluding -> Critical Thinking Skill	0.430	0.432	0.027	15.924	0.000
Problem simplification -> Critical Thinking Skill	0.428	0.429	0.028	15.014	0.000

Table 7 shows that each syntax of the AR-assisted PjBL model had a p-value <0.05 and a t-value> 1.96. These results show that each syntax of the AR-assisted PjBL model affected each critical thinking skill indicator. Then, the path coefficient value is used to see the magnitude of the contribution of each indicator. Complete results regarding the inner model test are presented in the table 8.

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Table 8. Inner Model Test

	Path coefficients
Problem Identification -> Critical Thinking Skill	0.359
Logical Reasoning -> Critical Thinking Skill	0.359
Idea generation -> Critical Thinking Skill	0.401
Concluding -> Critical Thinking Skill	0.432
problem simplification -> Critical Thinking Skill	0.429

Table 8 shows that the path coefficient value of each critical thinking skill indicator ranged from 0.359 to 0.432. These results indicate that the contribution between each critical thinking skill indicator was in a range of values that were almost the same as the conclusion-drawing indicator providing the largest contribution, namely 0.432 or 43%.

Next, the researcher conducted a path coefficient value test related to problem identification. The path coefficient value is used to determine the magnitude of each AR-assisted PjBL model syntax's contribution to the problem identification indicator. The complete results are presented in Table 9.

Table 9. Inner Model Test of Problem Identification Indicators

	Path coefficients
Syntax 1.1 -> Problem Identification	0.353
Syntax 1.2 -> Problem Identification	0.416
Syntax 1.3 -> Problem Identification	0.396
Syntax 1.4 -> Problem Identification	0.346
Syntax 1.5 -> Problem Identification	0.353

Table 9 shows that the path coefficient value of each AR-assisted PjBL model syntax to the problem identification indicator ranged from 0.346 to 0.416. These results indicate that syntax 2 or planning project activities provided the largest contribution, namely 0.416 or 42%. Next, a path coefficient test is conducted. The path coefficient value is used to see the magnitude of the contribution of each AR-assisted PjBL model syntax to the problem simplification indicator. The complete results are presented in Table 10.

Table 10. Inner Model Test of Problem Simplification Indicators

	Path coefficients
Syntax 2.1 -> problem simplification	0.304
Syntax 2.2 -> problem simplification	0.272
Syntax 2.3 -> problem simplification	0.315
Syntax 2.4 -> problem simplification	0.329
Syntax 2.5 -> problem simplification	0.269

Table 10 shows that the path coefficient value of each AR-assisted PjBL model syntax to the problem simplification indicator ranged from 0.269 to 0.329. These results indicate that syntax 4 or project result publication provided the largest contribution, namely 0.329 or 33%. Next, a path

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coefficient test is conducted. The path coefficient value is used to see the magnitude of the contribution of each AR-assisted PjBL model syntax to the idea generation indicator. The complete results are presented in the table 11.

Table 11. Inner Model Test of Idea Generation Indicators

	Path coefficients
Syntax 3.1 -> idea generation	0.313
Syntax 3.2 -> idea generation	0.312
Syntax 3.3 -> idea generation	0.383
Syntax 3.4 -> idea generation	0.315
Syntax 3.5 -> idea generation	0.329

Table 11 shows that the path coefficient value of each AR-assisted PjBL model syntax to the idea generation indicator ranged from 0.312 to 0.383. These results indicate that syntax three or monitoring provided the most significant contribution, namely 0.383 or 38%. Next, a path coefficient test is conducted. The path coefficient value is used to see the magnitude of the contribution of each AR-assisted PjBL model syntax to the conclusion-drawing indicator. The complete results are presented in the table 12.

Table 12. Inner Model Test Conclusion-Drawing Indicator

	Path coefficients
Syntax 4.1 -> concluding	0.310
Syntax 4.2 -> concluding	0.303
Syntax 4.3 -> concluding	0.319
Syntax 4.4 -> concluding	0.313
Syntax 4.5 -> concluding	0.350

Table 12 shows that the path coefficient value of each AR-assisted PjBL model syntax to the conclusion-drawing indicator ranged from 0.303 to 0.350. These results indicate that syntax 5 or evaluation provided the largest contribution, namely 0.350 or 35%. Next, a path coefficient test is conducted. The path coefficient value is used to see the magnitude of the contribution of each AR-assisted PjBL model syntax to the logical reasoning indicator. The complete results are presented in the table 13.

Table 13. Inner Model Test Logical Reasoning Indicator

	Path coefficients
Syntax 5.1 -> Logical Reasoning	0.344
Syntax 5.2 -> Logical Reasoning	0.345
Syntax 5.3 -> Logical Reasoning	0.306
Syntax 5.4 -> Logical Reasoning	0.364
Syntax 5.5 -> Logical Reasoning	0.334

Table 13 describes that the path coefficient value of each AR-assisted PjBL model syntax to the logical reasoning indicator ranged from 0.306 to 0.364. These results indicate that syntax 4 or publication of project results provided the largest contribution, namely 0.364 or 36%. Thus, it can be

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concluded that the AR-assisted PjBL model syntax makes a large contribution to the logical reasoning indicator.

5. Discussion

This study aims to specify the effect of using the PjBL model supported by AR on the critical thinking skills of grade six students at SDN 1 Sedayu. This study used 4 meetings in each class, both the control class and the experimental class. In the first meeting, the researcher conducted learning activities in each class. The first meeting in the control and experimental classes used a traditional learning model without the help of learning media. Then, a pre-test was administered in both classes. In the second and third meetings, the researchers focused on learning liveliness in the classroom. The control class used a traditional model with the help of PowerPoint while in the experimental class, the researchers used a learning model in the form of PjBL with the help of learning media in the form of AR. In the last meeting, the researchers focused on post-test activities that were completed directly by students.

The syntax for implementing PjBL with the help of AR media is carried out with the following steps: (1) Determining basic questions by asking students questions related to problems that encourage the emergence of new questions about the solar system; (2) Planning project activities by having students work in groups to design a project using AR media through the Assembler Edu application and preparing a schedule for implementing the project design; (3) Monitoring by having the teacher monitor the implementation of the project carried out by each group of students. At this stage, students can ask questions to the teacher if they face obstacles in the process of working on the project; (4) Publishing project results by having each formed group present the results of the project they have made through Assembler Edu. The teacher then provided an assessment and feedback on the results of each group's presented project; and (5) Evaluating by having teachers evaluate the project activities carried out by students and provide discretion for students to reveal their opinions regarding the project activities.

The research conducted in the control class and the experimental class was quite different. The difference was in the models and media used by the two classes. The delivery of learning materials was carried out through a conventional model in the control class, namely lectures with the help of software applications in the form of power points. PowerPoint is a practical and efficient media that elementary school teachers can use in teaching-learning materials, particularly in natural science subjects (Humairah, 2021). Learning materials are packaged through slides containing pictures and brief explanations which are then explained using a lecture model. PowerPoint is a practical and efficient media that elementary school teachers can use in teaching-learning materials, particularly in natural science subjects.

Meanwhile, the research in the experimental class used a PjBL model assisted by AR media. The implementation of the PjBL model assisted by AR media want to influence students' critical thinking skills, especially in the subject of science, solar system material delivered in grade six, with the help of 4D books and AR cards. These findings supported previous research conducted by Wahyu (2016) stating that the PjBL model was potent in influencing students' critical thinking skills. The study found that collaborative projects in the PjBL model encouraged students to be actively involved in the learning procedure, analyze problems, and develop critical thinking skills.

In addition, the use of AR in learning has also been proven to provide a positive endowment to improving students' critical thinking skills. As expressed by Mustaqim (2016) stating that interactive and interesting visualization through AR can increase students' concern and inner power to learn, and help students understand abstract concepts better. Thus, the combination of the PjBL model and the use of AR creates a conducive learning environment for the strengthening of students' critical thinking skills.

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Differences occurred in students' critical thinking skills in two different classes: the control class using a traditional learning model in the form of lectures assisted by PowerPoint media and the experimental class using a PjBL model assisted by AR. This study prioritized prerequisite tests before conducting hypothesis tests. The tests aimed to ensure that the proposed hypothesis testing can be in line with the inferential statistical model needed to analyze research data (Usmadi, 2020). The prerequisite analysis tests carried out in this study consist of normality testing, homogeneity testing, and hypothesis testing. In this study, the hypothesis test used SPSS software version 27 to assist in analyzing research data. To compare two different classes (control and experimental), the researcher chose the paired sample t-test (Sugiyono, 2021).

Students' critical thinking skills increased after participating in PjBL with the help of AR. This happened because students' learning motivation, especially their activity levels, could be increased through the implementation of the PjBL approach (Fathussyakir, 2018). In addition, PjBL using AR facilitated the achievement of learning objectives. These results were findings obtained by Wahyu (2016) revealing that the use of the PjBL paradigm moves significantly on students' critical thinking skills. According to another study, students can maximize their role in learning, think critically, and examine difficulties when they work on projects and experiment together (Anam et al., 2023). Furthermore, AR helped children develop better critical thinking skills. Mustaqim claims that students became more engaged and motivated when they used AR to see abstract ideas interestingly and dynamically (Mustaqim, 2016). Thus, a learning environment that encouraged the growth of students' critical thinking skills was created by combining PjBL with AR.

The increase in students' scores is in line with the change in students' attitudes. The change in attitudes is the character of students who were initially very passive in learning, only guided by books distributed by the teacher but became active because their curiosity increased. Students find it easy to interact with their classmates without distinguishing gender which was initially very disruptive during learning, especially during project activities involving group assessments. Students' critical thinking skills strengthened because they carried out project activities (Khasanah & Muthali'in, 2023).

The implementation of the PjBL model assisted by AR in measuring students' critical thinking skills could be measured through several indicators, including the first indicator of critical thinking skills, according to Ennis, is focus, reason, inference, situation, and clarity.

Table 14. Syntax of PJBL assisted by Augmented Reality on students' critical thinking skills

Critical Thinking

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No.	Stages	Activities	Indicators				
			F	R	I	S	C
1.	Defining Fundamental Questions	Asking students questions concerning problems that can stimulate the emergence of new questions about the solar system.	√				
2.	Planning Project Activities	Students work in groups to design a project using Augmented Reality media through the Assembler Edu application and create a schedule for implementing the project design.		√		√	
3.	Monitoring	Teachers monitor the implementation of the project worked on by each group. At this stage, students can ask questions to teachers if they experience obstacles in the process of working on the project.			√		
4.	Publishing Project Results	Every category provides the findings of the project they have made through Assemblr Edu. Then, teachers provide an assessment and feedback on the results of each group's project that has been presented by students.		√	√		
5.	Evaluating	Teachers evaluate the project activities and serve an occasion for students to express their opinions regarding the project activities that have been done.			√		√

Based on the table 14, the following is a description of the syntax of project-based learning for students' critical thinking indicators:

a) Determining Basic Questions

The first stage is to determine fundamental questions. Based on research conducted by Fadriati et al. (2023), questions are very important to stimulate students' ability to explain the knowledge they have. Explaining the knowledge they have is in line with critical thinking indicators (Kennedy et al., 1991). Fristadi & Bharata (2015) stated that being able to explain the knowledge possessed by students is one of the characteristics of students who have critical thinking skills and broad insights. Based on this study, questions were asked by the teacher to discover the extent of students' knowledge in understanding the solar system materials.

b) Planning project activities

The second stage is planning project activities. Facione (2019) stated that planning project activities involves students' ability to determine the steps and workflow in achieving project goals. Kennedy et al. (1991) agree with Facione, stating that determining project steps and workflow is the critical thinking ability of students to provide reasons because students have to provide reasons and situations for why they choose the project scheduling and reasons regarding the results of the project activities they have worked on. Based on this study, students who worked together in groups to design a project using AR media through the Assembler Edu application and prepared a schedule for implementing the project design were included in the critical thinking indicators of reason and situation.

c) Monitoring

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The third stage is monitoring ongoing project activities. Andini & Rusmini (2022) stated that monitoring is the stage of controlling the development of the project carried out by students. In completing the project. Student activities are monitored by teachers with full responsibility. Siswanto & Andriyani (2025) stated that monitoring student assignments is included in Ennis' inference critical thinking indicator. Based on the monitoring stages, teachers and students identified project progress, analyzed problems, and made decisions based on these observations. Students who faced obstacles during project work often asked questions to the teacher. This process requires inference skills to find appropriate solutions or alternatives based on the project situation.

d) Publishing Project Results

This stage is the fourth stage in the PjBL syntax. This stage contains an assessment of the work results carried out by students. This is done to help teachers measure the achievement of standards, evaluate student development, and prepare for the next steps. Every category provides the findings of the project they have made through Assemblr Edu. Teachers then provide an assessment and feedback on the results of each group's project that has been presented. This stage is included in the critical thinking indicators of reason and inference. The implementation of the publication of the results of this project requires students to provide appropriate reasons for their performance, besides that, they also need inferences that are in line with the project situation.

e) Evaluating

This is the last stage. The evaluation process is carried out related to things concerning group project completion and discovery (Fitriyani et al., 2018). This is in line with the opinion of Chusni et al. (2021) stating that evaluation is included in the clarity category in the critical thinking ability indicator. In the project evaluation stage, students or teachers need to convey the results clearly, either in a presentation or in a written assessment. This includes organizing information well so that understanding the project results is easy (Brookhart, 2017). The teacher provides clear feedback on what has been done well by students and what is necessary to be optimized (Anam et al., 2019).

In the condition of this study, students' ability to focus on questions, provide reasons, draw conclusions, express important factors that need to be considered in making conclusions, and compile explanations can be measured from their responses to descriptive questions in the pre-test and post-test. The pre-test data showed that the highest scores were in the intervals of 47-51 and 57-61 in the control class, which illustrates that the majority of students were still unable to focus on questions, provide reasons, draw conclusions, express important factors that need to be considered in making conclusions, and compile explanations in depth. In the experimental class, although there was variation in the pre-test value interval, the highest frequency distribution was also in the interval of 52-66, indicating that students were slightly better at focusing on questions than the control class. After the practice of the AR-assisted PJBL model, final test data in the experimental class showed a significant increase in students' ability to focus on questions, provide reasons, draw conclusions, express important factors that need to be considered in making conclusions, and compile explanations as evidenced by the dominance of the interval 79-86. This indicates that this model helped students to be more critical in identifying the core problems and relevant questions compared to the conventional model used in the control class.

The use of AR media that accompanies the PjBL model made the science learning process in grade six interesting and enjoyable. Students practiced using AR media that has been prepared through the 4D book and several AR flashcards formed from flashcards modified with the AR program from Assmblr Edu. One experimental class was divided into 4 groups, namely the Mercury, Venus, Mars, and Earth groups. The four groups were previously guided to download two applications on the Play store, namely Devar and Assembler Edu. After the two applications were installed, the four groups practiced scanning the barcodes in the book and cards and then providing each other with

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information obtained from several types of planets analyzed using the two applications. This helped students understand the material in depth, especially the solar system material that requires discussion between groups in the implementation of AR.

This is related to the cognitive theory proposed by Bruner (1966), which emphasizes that new knowledge is constructed by students independently through experience or information they already have. One of the core concepts of Bruner's cognitive theory is Discovery Learning. In this theory, he highlights the importance of providing opportunities for learners to discover key concepts and principles themselves through independent exploration and understanding, rather than simply receiving direct instruction. Another study reported that systematic learning designs, such as inquiry learning, encourage active learning, provide continuous feedback, and develop critical thinking skills in students' learning environments (Sapriati et al., 2024).

The results of this study indicate that the practice of the PjBL model assisted by AR has a significant positive impact on the critical thinking skills of grade six students in the solar system material. As explained by Santoso (2018), a positive sign on the t-value reveals an unidirectional influence between the independent and the dependent variable. This means that if the value of the independent variable is greater, then the value of the dependent variable is also greater.

This invention promotes another research conducted by Wahyu (2016) stating that students' critical thinking skills are the impact of implementing the PjBL model in the classroom. The study found that collaborative project work in the PjBL model encourages students to be roundly involved in learning activities, analyze problems, and develop critical thinking skills. In addition, the use of AR in learning has also been shown to provide a positive contribution to strengthening students' critical thinking skills. Mustaqim (2016) states that interactive and interesting visualization through AR can increase students' attention and participation to learn, and help students understand abstract concepts better. Thus, the combination of the PjBL model and the use of AR creates a conducive learning environment for students and strengthens students' critical thinking skills.

6. Conclusion

The use of the AR-based PjBL model has a positive impact on the progress of critical thinking skills of grade VI students, especially the solar system material. An innovative and interesting learning environment has been successfully created when PjBL is combined with AR to strengthen students' critical thinking skills. These findings contribute positively to the advancement of education. In this case, policy makers are advised to integrate this model into the education curriculum. This integration becomes practical information for teachers to adopt this type of model in classroom learning, both at elementary and secondary school levels. In addition, teachers can also make this topic a discussion topic in teacher group meetings. These findings also provide insights for curriculum developers and educators to optimize the implementation of Augmented Reality-based Project Based Learning to improve educational outcomes and encourage students' critical thinking skills.

7. Suggestion

This study has several limitations, such as the subjects only focused on sixth grade elementary school students. Thus, future research should expand the subject area. For example, aiming at all elementary school students from grades 1 to 6. The results are expected to be generalizable. Then, this study also has limitations in terms of only being tested with a quantitative approach. This only captures the condition of the data quantitatively. Further researchers are recommended to analyze the truth of the results of this statistical test qualitatively through in-depth interviews with full observations in the learning process. Further research is recommended to refine this approach through qualitative or other approaches to ensure students' understanding and deeper application of learning principles.

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Declarations

Author Contributions. I.R.W.A. and D.Y.S.: Literature review, conceptualization. I.R.W.A., R.K.D. and F.P.A.: methodology, data analysis. I.R.W.A. and M.S.: review-editing and writing, original manuscript preparation. R.M.R. and L.H.: supervision, validation.

Conflicts of Interest. The author declares that this research has obtained ethical permission from the informants (sixth grade elementary school students) and parents.

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