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Impact of the Auditory, Intellectually, and Repetition (AIR) Learning Model on Students' Mathematical Critical Thinking

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ABSTRACT

Critical thinking is an essential skill in 21st-century mathematics education; however, Indonesian students still demonstrate low achievement in this domain. Preliminary observations at SMP Negeri 8 Gunungsitoli revealed that students' mathematical critical thinking skills were not yet optimal, partly due to the predominance of conventional instructional approaches. This study examined the effect of the Auditory, Intellectually, and Repetition (AIR) learning model on students' mathematical critical thinking skills. A quasi-experimental method with a nonequivalent control group design was employed, involving 60 seventh-grade students divided into an experimental group (n = 30) and a control group (n = 30). The research instrument was an essay-based mathematical critical thinking test consisting of three items, which demonstrated logical and empirical validity and satisfactory reliability. The results indicated that both groups had relatively comparable low baseline performance. After the intervention, the experimental group achieved a mean score of 71.80 (high category), whereas the control group reached only 39.80 (low category). An independent-samples t-test showed that t = 10.683 exceeded t-table = 1.672 ($p < 0.05$), with a very large effect size (Cohen's d = 2.76). Simple linear regression analysis indicated that the AIR model accounted for 88.6% of the variance in students' mathematical critical thinking skills ($R^2 = 0.886$). These findings confirm that the AIR learning model effectively enhances mathematical critical thinking by engaging students in listening activities, reflective intellectual processing, and repeated practice. This study contributes theoretically to the development of higher-order thinking-oriented mathematics instruction and offers practical implications for teachers and policymakers in promoting interactive, student-centered learning models..

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Introduction

Mathematics education in the 21st century requires students to develop higher-order thinking skills, particularly critical thinking (Lehmann, 2023; Lestari et al., 2021; Zanden et al., 2020). Critical thinking helps students understand mathematical concepts and tackle complex real-world problems. It enables them to analyze information, evaluate arguments, and justify solutions (Lehmann, 2023). Without it, mathematics learning often narrows to procedural recall. International organizations therefore position critical thinking as a core competency in mathematics education (OECD, 2018). Despite its importance, Indonesian students' mathematical critical-thinking skills remain low. The Programme for International Student Assessment (PISA) 2022 reported that Indonesia ranked 68th with a mathematics score of 379, which is below the OECD average (OECD, 2018). This result suggests weaknesses in mathematical literacy, including the ability to formulate, interpret, and solve problems that require critical reasoning. It also indicates a substantial gap between global expectations and national learning outcomes (Habibi & Suparman, 2020; Safrudiannur & Rott, 2019; Zulkardi et al., 2020). For this reason, strengthening critical thinking in mathematics learning has become a key agenda for improving the competitiveness of Indonesian education.

This gap also emerged in a preliminary study at UPTD SMP Negeri 8 Gunungsitoli. Classroom observations and interviews indicated that many students struggled with mathematics problems that require reflective reasoning. Common errors included difficulties in formulating the problem, selecting an appropriate strategy, and drawing valid conclusions. Similarly, Lestari et al. (2021) reported that Indonesian junior high school students showed weaknesses in the analysis and evaluation components of critical thinking. These findings support the view that limited mathematical critical-thinking skills remain a persistent challenge in school mathematics.

One factor contributing to this condition is the continued reliance on conventional instruction. Teachers often dominate classroom activities through lecturing and routine exercises that emphasize procedural mastery. As a result, students have limited opportunities to explore, justify, and refine critical-thinking strategies (Kuntze et al., 2017; Yasin et al., 2019). Teacher-centered learning can reduce students' participation, reflection, and engagement in deeper mathematical discussions (Salay, 2019; Sormunen et al., 2020). This situation highlights the need for instructional innovation that promotes interaction, reflection, and active student involvement.

One potential approach is the Auditory Intellectually Repetition (AIR) model. AIR integrates three components: auditory activities that involve listening, speaking, and discussion; intellectual activities that promote reasoning, idea generation, and problem solving; and repetition that consolidates learning through structured practice (Farida et al., 2019; Huda et al., 2020; Rambe & Aisyah, 2023). By combining these elements, AIR can support more interactive and student-centered learning (Hobri et al., 2021; Kartika et al., 2023; Riyayani, 2021). Badawi et al. (2022) and Gultom & Zuardi (2025) also reported that AIR can improve students' social skills and conceptual understanding.

Previous studies have shown that AIR can enhance mathematics learning outcomes. For example, Huda et al. (2020) found that AIR encourages active student engagement, and Rambe & Aisyah (2023) reported that the repetition component can strengthen reasoning. However, much of this research emphasizes general achievement or motivation. Studies that specifically examine the effect of AIR on mathematical critical-thinking skills remain limited. This gap motivates the present study. This study also has practical value. Teachers need strategies that do more than deliver content. They must also promote discussion, reflection, and problem

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solving. AIR may offer a structured option to strengthen student-centered learning and support higher-order thinking (Kartika et al., 2023). This direction aligns with the Merdeka Curriculum policy, which emphasizes student agency, creativity, and critical thinking.

In summary, students' low mathematical critical-thinking skills require immediate attention through instructional innovation. The AIR model offers a promising approach through its complementary components. Accordingly, this study aims to examine the effect of the AIR model on junior high school students' mathematical critical-thinking skills. The study is expected to contribute to mathematics education research and offer practical recommendations for teachers to design more effective learning that responds to 21st-century demands.

Method

Types of Research

This study uses a quantitative approach with a type of experimental research that aims to test the effect of certain treatments on bound variables. In particular, the method used is a quasi-experiment with a Nonequivalent Control Group Design. This design was chosen because it is in accordance with the research context in schools, where the grouping of students into experimental and control classes is not carried out randomly, but still allows for valid comparisons between groups. In this design, both groups were given a pre-test to measure the initial condition, then the experimental class received treatment using the Auditory Intellectually Repetition (AIR) learning model, while the control class was taught using conventional learning, and then the two groups were given a post-test. Thus, the design of this study can show empirically the extent to which the application of the AIR model affects students' mathematical critical thinking skills.

Population and Sample

The research population is all grade VII students of SMP Negeri 8 Gunungsitoli for the 2024/2025 academic year with a total of 60 students divided into two classes. Demographically, class VII-A consists of 30 students with 17 males and 13 females, while class VII-B consists of 30 students with 16 males and 14 females. The sampling technique uses total sampling, which involves the entire population as a research sample. Thus, class VII-A was designated as the experimental class (n = 30) and class VII-B as the control class (n = 30). The use of total sampling aims to make the research results more representative of the population studied.

Instruments

The research instrument is in the form of a mathematical critical thinking ability test in the form of a description consisting of three questions, which are developed based on critical thinking indicators according to Facione (2015), including clarification, inference, and evaluation. The instrument was given twice, namely as a pre-test to determine the student's initial ability and as a post-test to measure improvement after treatment. Logical validation was carried out by three validators consisting of math subject matter experts, learning experts, and educational evaluation experts using an assessment scale. The validation results showed that the instrument was in the "very valid" category with an average score above 80%. Furthermore, the instrument was tested on 25 students outside the research sample to ensure empirical feasibility. The validity analysis of the question items was carried out with Pearson's Product Moment correlation, reliability was calculated with the Alpha Cronbach coefficient, and a test of difficulty and differentiating power was carried out. The results of the trial showed that all questions were valid, reliable (α = 0.82, high category), with a moderate level of difficulty and good discriminating power. Thus, research instruments are declared feasible to be used to measure students' mathematical critical thinking skills.

Procedure

The research procedure is carried out through several stages. First, both classes (experiment and control) were given a pre-test to determine the initial ability to think critically mathematically and ensure the homogeneity of the data. Second, the experimental class was treated using the AIR learning model, while the control class was taught using the conventional learning model. Learning takes place for several meetings according to the curriculum time allocation. Third, after the treatment was completed, both classes were given *a post-test* with the same instrument to determine the achievement of mathematical critical thinking skills after the treatment.

Data Analysis

The test result data is analyzed through several stages. First, scoring is carried out on students' answers using the assessment rubric that has been prepared, then the final score of each student is calculated. Second, the data was analyzed descriptively using mean values, variances, and standard deviations to provide an overview of students' mathematical critical thinking skills (Soesana et al., 2023). Third, the analysis prerequisite test was carried out with the normality test (using the Liliefors test) and the homogeneity test (using the Fisher test) to ensure that the data met the parametric statistical assumptions (Ananda & Fadhli, 2018). If the data is normally distributed and homogeneous, inferential analysis is performed using *an independent sample t-test*. This test was used to determine whether there was a significant difference between the experimental and control groups, with a significance level of 5%. The hypothesis decision is determined by the criterion: minus H0 if the calculation is > table, which means that there is a significant influence of the AIR model on students' mathematical critical thinking skills.

Research Findings

The results of the descriptive analysis showed that in the initial test (*pre-test*), the mathematical critical thinking ability of the experimental class students had an average of 33.06 (SD = 9.082), while the control class had an average of 30.10 (SD = 8.450). Both average scores are in the low category. This suggests that the initial abilities of the two groups were relatively comparable before being given treatment. In the final test (post-test), the average critical thinking ability of the experimental class increased to 71.80 (SD = 10.380), while the control class only reached 39.80 (SD = 12.705). A significant improvement in the experimental class showed a clear difference after the application of the Auditory Intellectually Repetition (AIR) learning model.

Table 1. Descriptive Statistics of Pre-Test and Post Test

Classes	N	Pre-test Mean (SD)	Post-test Mean (SD)
Experiments	30	33,06 (9,082)	71,80 (10,380)
Controls	30	30,10 (8,450)	39,80 (12,705)

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The results of the descriptive analysis showed that the initial (*pre-test*) ability of students in both groups was in relatively equal conditions. The average score of the experimental class was 33.06 and the control class was 30.10, both in the low category. This indicates that before the treatment, both the experimental and control groups had mathematical critical thinking skills that were both not optimally developed. This equivalence of the initial conditions is important, as it shows that the difference in outcomes in the final stage really comes from the treatment given, not from the difference in the student's initial ability. After treatment, there was a significant improvement in the experimental class. The average final test score (post-test) of students in the experimental class reached 71.80 in the high category, while the control class only reached 39.80 in the low category. The difference of 32 points between the two groups provides an early indication that the application of the Auditory Intellectually Repetition (AIR) learning model makes a real contribution to improving students' mathematical critical thinking skills. In other words, although both groups had relatively homogeneous initial conditions, the end result showed a very clear gap after the intervention was performed.

The normality test with Shapiro-Wilk showed that the pre-test and post-test data of both groups were normally distributed ($p > 0.05$). Furthermore, the homogeneity test with Levene's Test produced a significance value of > 0.05 for both the pre-test ($p = 0.649$) and post-test ($p = 0.310$). Thus, the data is eligible for parametric testing (independent samples t-test). The results of the normality test with Shapiro-Wilk showed that the pre-test and post-test data in both groups were normally distributed ($p > 0.05$). Similarly, the homogeneity test with Levene's Test showed that the variance of both groups was homogeneous, both before and after treatment ($p > 0.05$). With the fulfillment of these two assumptions, parametric statistical tests such as independent samples t-tests can be used appropriately. This condition adds to the belief that the differences in results obtained are methodologically valid and are not influenced by distorted data distribution. Hypothesis testing was carried out using independent samples t-test on post-test data.

Table 2. Independent Samples Test Results

Variable	t	df	Sig. (2-tailed)	Mean Difference	Remarks
Final Test	10,683	58	0,000	32,00	Significant

The results of *the independent samples t-test* showed a tcount value of 10.683 greater than the ttable of 1.672 at a significance level of 5%. Thus, H0 is rejected and Ha is accepted, which means that there is a significant influence of the use of the AIR model on students' mathematical critical thinking skills. Substantively, this means that students who learn with the AIR model gain greater learning advantages than students who only learn with the conventional model. In addition to the statistical significance, it is also important to see the magnitude of the effect of treatment. The result of the calculation of the effect size with Cohen's d shows a value of 2.76. According to Cohen's (1988) criteria, this value is included in the category of very large effect. This indicates that the AIR model not only has a significant impact, but is also strong and substantial on students' mathematical critical thinking skills. In other words, these learning interventions have real potential to improve the quality of learning outcomes in the classroom, not just small differences that are not practically relevant.

To determine the magnitude of the contribution of the AIR model to mathematical critical thinking skills, a simple regression analysis was performed.

Table 3. Simple Linear Regression Test Results

Models	R	R Square	Adjusted R Square	Std. Error
1	0,942	0,886	0,882	3,560

Simple linear regression analysis also reinforces these findings. A determination coefficient (R^2) of 0.886 indicates that 88.6% of the variation in students' mathematical critical thinking ability can be explained by the application of the AIR model. The remaining 11.4% were influenced by other factors outside of the study, such as learning motivation, student background, or environmental factors. The correlation value (R = 0.942) also showed a very strong relationship between the application of the AIR model and the improvement of mathematical critical thinking skills.

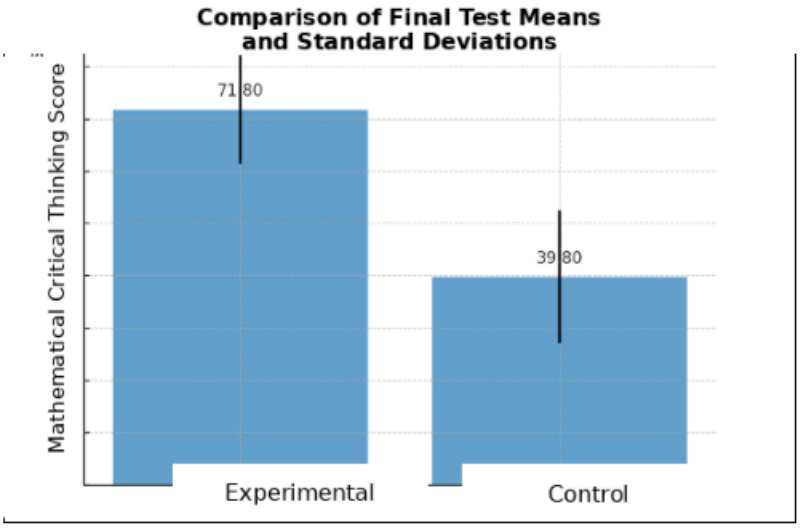

Figure 1. Comparison of Final Test Average with Standard Deviation

Figure 1 presents a comparison of the average score of the final test of mathematical critical thinking ability between the experimental class and the control class. The graph bar shows that the experimental class obtained an average score of 71.80, while the control class only reached 39.80. This difference becomes even more apparent when you consider the standard error bar indicated by the standard deviation of each group. This image provides a strong visual representation that the application of the Auditory Intellectually Repetition (AIR) learning model results in a significant improvement in students' mathematical critical thinking skills compared to conventional learning.

The average final test score in the experimental class of 71.80 was in the high category. This shows that students in this group have successfully internalized critical thinking skills after receiving treatment with the Auditory Intellectually Repetition (AIR) model. The standard deviation of 10.380 illustrates a relatively consistent variation in scores between students, so that the improvement in ability is not only experienced by a small number of students, but is equally pronounced in most class members. Thus, it can be affirmed that the AIR model is able to create an inclusive and effective learning experience for different levels of students' abilities.

In contrast, the control class only achieved an average score of 39.80 which was still in the low category. This condition reflects that conventional learning is not effective enough in developing mathematical critical thinking skills. In addition, the standard deviation in the control class was higher at 12.705, which indicated a wider variation in achievement between students. In other words, in addition to failing to improve average achievement, conventional learning also tends to increase the gap in student achievement in the class.

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The average difference of 32 points between the experimental class and the control class was not a small difference, but a very substantial leap. The results of the calculation of Cohen's effect size d = 2.76 further strengthen the conclusion that the influence of the AIR model is in the very large effect category. This means that interventions with the AIR model are not only statistically significant, but also practically meaningful in the context of education. With such a high measure of effect, the AIR model can be seen as a transformative pedagogical strategy in improving students' mathematical critical thinking skills.

These findings also have important implications for educational practice. Learning strategies that emphasize auditory activities, reflective thinking, and repetition have been proven to be able to create a learning environment conducive to the development of high-level thinking skills. Teachers who apply the AIR model not only help students understand mathematical concepts, but also train them to analyze, evaluate, and draw logical conclusions independently. Thus, the application of the AIR model not only improves students' test scores, but also equips them with essential skills that are relevant to face academic and real-life challenges.

Discussion

The results of this study show that the application of the Auditory Intellectually Repetition (AIR) learning model has a significant influence on improving students' mathematical critical thinking skills. The experimental class taught with the AIR model showed a much higher average final-test score than the conventionally taught control class (71.80 vs. 39.80). This 32-point difference indicates a substantial practical gap between the two groups on the study's scoring scale. The effect size (Cohen's d = 2.76) also indicates a very strong impact of AIR in supporting the development of critical thinking skills. The inferential test reported in the Results section confirms that this difference is statistically meaningful. These findings are consistent with the view that active learning and structured repetition can strengthen students' cognitive structures and facilitate higher-level thinking processes (Farida et al., 2019; Jami Ahmad Badawi et al., 2022; Kartika et al., 2023). At the same time, because the effect size is extremely large, the interpretation should consider group equivalence and score variability, which are reported in the Results section.

The success of the AIR model in improving critical thinking skills can be explained through its three components, namely auditory, intellectually, and repetition. First, the auditory component that involves listening, speaking, and discussing activities allows students to engage in constructive verbal interactions (Badawi et al., 2022; Jami Ahmad Badawi et al., 2022). These interactions not only enrich conceptual understanding, but also require students to organize arguments, provide logical reasons, and respond to peer opinions. This type of activity is in line with Kartika et al. (2023) emphasis on the role of social interaction in cognitive development, and it is also consistent with Ødegaard et al., (2024), Sormunen et al. (2020), and Stockero et al. (2020) findings that mathematical discussions can foster reflective and critical thinking. In this study, the discussion routine helped shift students from giving short answers to giving reasons, checking peers' ideas, and revising claims when counterarguments emerged.

Second, the intellectually component emphasizes deep thinking activities through analysis, problem solving, and concept construction. At this stage, students are challenged to relate the knowledge they have to new situations, conduct reasoning, and evaluate solutions (Badawi et al., 2022; Gultom & Zuardi, 2025; Hobri et al., 2021). This activity is closely related to critical thinking indicators described by Lehmann (2023), such as interpretation, inference, and evaluation. Thus, the AIR model provides space for students to practice metacognitive skills, namely monitoring, regulating, and reflecting on their own thought processes (Hartmann et al., 2024). This link also matches how critical thinking was assessed in this study, because the test required students to interpret information, infer relationships, and evaluate the validity of strategies and conclusions rather than only apply routine procedures.

Third, the repetition component provides an opportunity for students to repeat the learning process through practice questions, quizzes, and reflection. This repetition is not only mechanical activity, but serves as reinforcement of previously constructed critical thinking concepts and strategies. According to retrieval practice theory, active repetition strengthens long-term memory and improves transfer to new situations (Badawi et al., 2022; Gultom & Zuardi, 2025; Rambe & Aisyah, 2023). Thus, repetition in the AIR model not only strengthens understanding, but also increases students' flexibility of thinking when facing complex mathematical problems. In this study, repetition supported students in recalling justification patterns and evaluation steps across tasks, so they could apply them more consistently in the final test.

The findings of this study are also in line with the results of the study Lestari et al. (2021), which show that junior high school students in Indonesia are still weak in the aspects of critical thinking analysis and evaluation, so they need a more interactive and reflective learning model. Similarly, research by Gultom & Zuardi, (2025) and Riyayani (2021) found that the application of the AIR model can increase student engagement and deepen conceptual understanding. However, this study expands its contribution by showing that the impact of the AIR model is not only on general learning outcomes, but also specifically on mathematical critical thinking skills as measured through tasks that demanded interpretation, inference, evaluation, and justification. This point strengthens the novelty of the study because prior AIR studies more often emphasized achievement or motivation without focusing on critical thinking as a targeted outcome.

In terms of implications, these results confirm the importance of mathematics teachers moving from conventional learning to a more participatory model. The AIR model has been shown to be effective in creating a learning environment that emphasizes active engagement, intellectual reflection, and reinforcement of concepts through repetition. Teachers can translate this into concrete classroom actions. First, they can structure the auditory phase with short discussion protocols that require students to state claims and provide reasons. Second, they can select tasks that force students to compare strategies and evaluate conclusions, not only compute answers. Third, they can design repetition as retrieval-based practice with short quizzes and reflection prompts that revisit the same reasoning skills across sessions. As such, this model is not only relevant for improving students' academic achievement, but also for equipping them with essential skills needed to face global challenges, such as critical thinking, problem solving, and logical argumentation.

Conclusion

This study concludes that the application of the Auditory Intellectually Repetition (AIR) learning model has a significant effect on students' mathematical critical thinking skills. This is shown by the average final test score of the experimental class of 71.80 (high category), which is much better compared to the control class of 39.80 (low category). The results of the independent samples t-test produced tcount = 10.683 greater than t-table = 1.672 at a significance level of 5%, which confirms the existence of a significant influence. In addition, the effect size calculated with Cohen's d of 2.76 showed a very large influence, while a simple linear regression analysis showed that 88.6% of the variation in students' mathematical critical

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thinking ability could be explained by the application of the AIR model. Thus, the AIR model has proven to be effective in developing critical thinking skills which are one of the key competencies of the 21st century, so that it can be used as a relevant pedagogical strategy to improve the quality of mathematics learning.

However, this study has some limitations. First, the study was only conducted in one school with a limited number of samples, so the results could not be generalized widely. Second, the instrument used in the form of three description questions, although valid and reliable, is still limited in representing the diversity of critical thinking indicators. Third, this study only assesses short-term impacts, so it has not described the extent of sustainability and the transfer of critical thinking skills to other contexts.

Based on these limitations, further research is recommended to involve a broader sample of different school backgrounds, develop more comprehensive instruments with a combination of tests and non-tests, and examine the long-term impact of the application of the AIR model on the retention and transfer of critical thinking skills. In addition, advanced research can also examine the combination of AIR models with other innovative learning approaches, such as problem-based learning or digital technology integration, to see possible synergistic effects in improving 21st century skills.

Practically, the results of this study provide important implications for teachers and education policymakers. Mathematics teachers can use the AIR model to create a more active, reflective, and in-depth learning process, where students not only receive information, but are also invited to listen, discuss, think critically, and repeat concepts to be more internalized. This is in line with the spirit of the Independent Curriculum which emphasizes student-centered learning and strengthening high-level thinking skills. Meanwhile, for policymakers such as the Ministry of Education, Culture, Research, and Technology, the results of this research can be the basis for encouraging teacher training and policy development that emphasizes the importance of implementing innovative learning models that have been proven to be effective in improving critical thinking competencies. Thus, the AIR model is not only beneficial for improving academic achievement, but also contributes to preparing a generation capable of facing global challenges with strong critical thinking skills.

Conflict of Interest

The author declares no conflict of interest.

Authors' Contributions

The main author, I.N.H., understood the concept of the research presented and was responsible for data collection, theory development, and actively participated in theory development, methodology, organization, and data analysis. The second author, Y.N.T., actively participated in theory development, discussion of research results, approval of the final version of the work, data collection and data analysis. The third and fourth author, R.N.M., and N.K.M. actively participated in theory development, discussion of research results, approval of the final version of the paper, data collection, and data analysis. All authors declare that the final version of this paper has been read and approved. The total percentage of contributions to the conceptualization, preparation, and correction of this paper is as follows: I.N.H.: 70%, Y.N.T.: 10%, R.N.M: 10%., and N.K.M.: 10%.

Data Availability Statement

The authors declare that data sharing is not possible, as no new data was created or analyzed in this study.

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