



Differential Effects of the Auditory Intellectually Repetition (AIR) Model on Students' Critical Thinking Skills: A Gender-Based Analysis in Environmental Change Learning

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Abstract

This. The development of critical thinking skills is a key objective in 21st-century science education, particularly in learning contexts involving complex environmental issues. However, students' critical thinking abilities remain relatively low due to the dominance of teacher-centered instructional practices. This study aims to examine the effectiveness of the Auditory, Intellectually, and Repetition (AIR) learning model in enhancing students' critical thinking skills in environmental change and conservation learning, as well as to analyze differences based on gender. A quasi-experimental method with a non-equivalent control group pretest-posttest design was employed, involving 73 tenth-grade students divided into experimental and control classes. Data were collected using an essay-based critical thinking test developed based on Ennis' indicators, including interpretation, analysis, evaluation, inference, and explanation. The results indicate that students in the experimental group achieved significantly higher posttest scores ($M = 88.19$) and N-Gain ($g = 0.72$, high category) compared to the control group ($M = 60.88$; $g = 0.21$, low category). Improvement was observed across all critical thinking indicators, with the highest gains in advanced clarification and basic skill development. Two-way ANOVA results reveal that the instructional model has a significant effect on students' critical thinking skills ($p < 0.05$), while gender and the interaction between model and gender are not statistically significant. These findings demonstrate that the AIR model is effective and inclusive for both male and female students. The study implies that integrating active, discussion-based, and reinforcement-oriented learning models with environmental contexts can enhance students' higher-order thinking and support meaningful engagement with sustainability issues.

Keywords: Auditory Intellectually Repetition; Critical Thinking; Environmental Change; Gender Differences; Science Education.

INTRODUCTION

In the context of 21st-century education, the development of critical thinking skills has become an essential objective of science learning (Bayani et al., 2025; Erstad & Siddiq, 2023; García-Carmona, 2025; Pahrudin et al., 2025). Students are no longer expected to merely acquire factual knowledge but are required to engage in higher-order thinking processes, including analysis, evaluation, and decision-making (Bangeles et al., 2025; Ismeirita et al., 2025; Liu et al., 2024). These competencies are particularly important in biology education, where students must interpret complex scientific phenomena and respond to real-world challenges such as environmental degradation, climate change, and sustainability issues (Cincera et al., 2023; Liu et al., 2024; Sjöblom et al., 2023). Consequently, fostering students' critical thinking skills has become a central concern in contemporary educational research.

Environmental change and conservation represent one of the most relevant and complex topics in biology learning (Ardoin et al., 2020; Casetta, 2023; Fonseca et al., 2021). This topic requires students to analyze causal relationships, evaluate environmental impacts, and propose sustainable solutions based on scientific reasoning (Hačatrjana & Namsone, 2024; Mambrey et al., 2022; Taufik et al., 2024). Such learning demands not only conceptual understanding but also the ability to think critically in addressing multifaceted environmental problems (A. I. Ardiansyah et al., 2024; Ichsan et al., 2019, 2019). However, previous studies consistently report that

students' critical thinking skills in environmental topics remain at a moderate or even low level (A. Ardiansyah et al., [2024](#); Mualimin & Pamungkas, [2024](#); Ristanto et al., [2022](#)). This indicates a discrepancy between the expected learning outcomes and actual classroom practices, which are often still dominated by teacher-centered approaches that limit students' active engagement in cognitive processes (Fitriani et al., [2024](#); Pratiwi & Doyan, [2024](#); Shanti et al., [2022](#)).

In response to this issue, various instructional models have been proposed to enhance students' critical thinking skills (Bhuttah et al., [2024](#); Ma, [2023](#); Saenab et al., [2020](#)). Active learning approaches such as problem-based learning, inquiry-based learning, and project-based learning have demonstrated significant effectiveness in promoting higher-order thinking (Almulla, [2020](#); Arviani et al., [2023](#); Rossi et al., [2021](#)). These models emphasize student engagement, problem-solving, and contextual learning (Tesfaw et al., [2024](#); Zhang & Kim, [2024](#)). Nevertheless, despite their effectiveness, their implementation often requires complex classroom management, extensive resources, and high levels of teacher expertise. As a result, there is a need to explore alternative instructional models that are both effective in fostering critical thinking and feasible for practical classroom implementation.

One such model is the Auditory Intellectually Repetition (AIR) model, which integrates auditory engagement, intellectual processing, and repetition as key components of learning. The AIR model encourages students to actively listen, process information cognitively, and reinforce their understanding through repeated exposure (Afryanto, [2021](#); Handoko et al., [2024](#); Saharuddin et al., [2021](#)). Theoretically, these processes are closely aligned with the development of critical thinking skills, as they involve active participation, deep cognitive engagement, and consolidation of knowledge (Ignacio et al., [2022](#); Wardani & Fiorintina, [2023](#)). However, empirical studies examining the effectiveness of the AIR model in enhancing critical thinking skills, particularly in environmental change learning, remain limited (Adawiyah & Mahmuddin, [2023](#); Hillary et al., [2023](#)). Most existing studies on AIR focus primarily on general learning outcomes rather than explicitly addressing higher-order thinking skills.

Beyond instructional factors, another important aspect that influences students' critical thinking skills is cognitive differences based on gender. A growing body of research suggests that male and female students may exhibit different cognitive characteristics, learning preferences, and problem-solving strategies (Marni et al., [2020](#); Sukarma et al., [2019](#)). These differences can influence how students process information, engage in learning activities, and develop critical thinking skills. For instance, several studies indicate that female students tend to demonstrate stronger verbal abilities, attention to detail, and reflective thinking, while male students often show advantages in spatial reasoning and abstract problem-solving (Arroyo et al., [2006](#); Yuan et al., [2019](#)). These cognitive tendencies may lead to different patterns in how critical thinking skills are developed in classroom settings.

In the context of science education, gender-based cognitive differences have been shown to affect students' performance and engagement (Feng et al., [2023](#); Nabilla Salma & Zakia Fariza Umami, [2024](#)). Female students are often found to be more consistent in analytical reasoning and structured thinking, whereas male students may excel in tasks requiring rapid problem-solving and conceptual abstraction (Kusumaningsih et al., [2019](#); Lin & Wong, [2024](#); Soeharto & Csapó, [2022](#)). However, findings in this area are not always consistent, as some studies report no significant differences, while others highlight contextual factors such as instructional methods, learning environments, and subject matter as mediating variables. This inconsistency indicates that gender differences in critical thinking are not merely inherent but are influenced by pedagogical approaches and classroom interactions.

Despite the growing interest in gender-related cognitive differences, there is still limited research that integrates this perspective into the evaluation of instructional models, particularly in science learning. Most studies on instructional effectiveness tend to treat students as a homogeneous group, without considering how different cognitive characteristics may influence learning outcomes. This represents a significant gap in the literature, as understanding how male and female students respond differently to specific instructional models can provide deeper

insights into the effectiveness of those models.

Furthermore, in the context of environmental change learning, which inherently involves complex and multidimensional problems, the interaction between instructional models and gender-based cognitive differences becomes even more relevant. Environmental issues require students to engage in critical analysis, ethical reasoning, and decision-making processes, all of which may be influenced by cognitive and affective factors (Barrera-Verdugo & Durán-Sandoval, 2024; Reffhaug & Lysgaard, 2024). However, empirical studies examining how instructional models such as AIR interact with gender differences in shaping students' critical thinking skills in environmental contexts remain scarce.

In the Indonesian educational context, the issue of critical thinking development is particularly significant (Wilson & Defianty, 2024). National and international assessments consistently indicate that students face challenges in higher-order thinking tasks, including analysis, evaluation, and reasoning. At the same time, classroom practices often do not adequately accommodate diverse student characteristics, including gender-based cognitive differences. This highlights the need for more inclusive and adaptive instructional strategies that can effectively support all learners.

Based on the above considerations, this study seeks to address several important gaps in the literature. First, it responds to the limited empirical evidence on the effectiveness of the AIR model in enhancing students' critical thinking skills, particularly in environmental change learning. Second, it addresses the lack of integration between instructional models and gender-based cognitive differences in evaluating learning outcomes. Third, it provides a contextualized investigation within Indonesian senior high school settings, where research on critical thinking and gender differences remains relatively underexplored.

Therefore, the purpose of this study is to examine the effectiveness of the Auditory Intellectually Repetition (AIR) model in enhancing students' critical thinking skills in environmental change learning, with particular attention to differences between male and female students. Specifically, this study aims to (1) determine whether the AIR model significantly improves students' critical thinking skills compared to conventional learning methods, and (2) analyze whether there are differences in critical thinking skills between male and female students within the implementation of the AIR model.

In line with these objectives, the research questions of this study are formulated as follows: (1) Does the implementation of the AIR model significantly enhance students' critical thinking skills in environmental change learning? and (2) Are there significant differences in critical thinking skills between male and female students when taught using the AIR model? By addressing these questions, this study is expected to contribute to the development of more effective and inclusive instructional strategies in science education, particularly in fostering critical thinking skills in the context of environmental sustainability.

METHODS

This study employed a quasi-experimental method using a non-equivalent control group pretest–posttest design to examine the effect of the Auditory Intellectually Repetition (AIR) learning model on students' critical thinking skills based on gender. This design was selected because random assignment of participants was not feasible in the school setting. The research design is presented in Table 1.

Table 1. Pretest and Posttest Control Design

Group	Pretest	Treatment	Posttest
Experimental	O ₁	AIR Model	O ₂
Control	O ₁	Conventional Learning	O ₂

The participants of this study were tenth-grade students from a public senior high school at SMA Gadjah Mada Bandar Lampung, Lampung, Indonesia during the 2024/2025 academic

year. A total of 73 students participated in the study, consisting of 36 students in the experimental class and 37 students in the control class. Based on gender composition, the experimental group consisted of 18 male and 18 female students, while the control group consisted of 14 male and 23 female students. Overall, the total participants included 32 male students and 41 female students.

Table 2. Distribution of Participants by Group and Gender

Group	Male	Female	Total
Experimental	18	18	36
Control	14	23	37
Total	32	41	73

The sampling technique used was purposive sampling, based on prior academic achievement data and teacher recommendations indicating that both classes had relatively comparable academic abilities before the intervention (Campbell et al., 2020). To minimize instructional bias, both classes were taught by the same biology teacher.

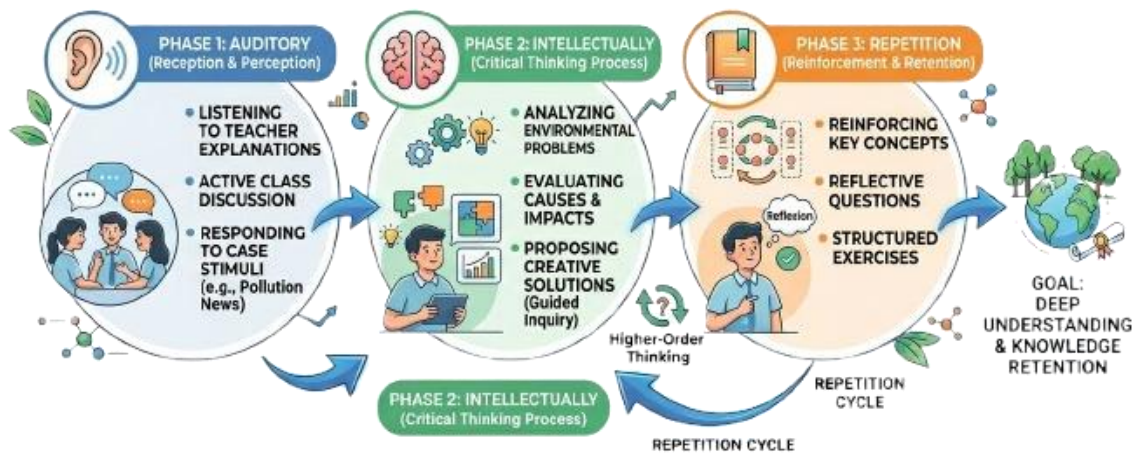


Figure 1. Flow of the AIR Learning Model (Auditory, Intellectually, Repetition) (personal archive)

The experimental group received instruction through the Auditory Intellectually Repetition (AIR) learning model, which consists of three main learning phases: auditory, intellectually, and repetition. In the auditory phase, students actively listened to teacher explanations, responded to questions, expressed opinions, and participated in classroom discussions. In the intellectually phase, students were encouraged to analyze problems, evaluate evidence, formulate arguments, and propose solutions through inquiry-based and collaborative learning activities. This phase was specifically intended to stimulate higher-order thinking skills, particularly critical thinking. In the repetition phase, students strengthened their understanding through review activities, reflective questioning, summarizing, and repeated exercises designed to reinforce conceptual mastery and long-term retention. The learning materials focused on Environmental Change and Environmental Conservation, including pollution, climate change, ecosystem imbalance, biodiversity loss, waste management, and sustainable environmental practices. In contrast, the control group received conventional teacher-centered instruction dominated by lectures, textbook explanation, note-taking, and limited student interaction.

Students' critical thinking skills were measured using a written essay test administered as both pretest and posttest. The instrument consisted of 10 essay items developed based on critical thinking indicators adapted from Ennis. The indicators included providing simple explanations, building basic skills, drawing conclusions, advanced clarification, and strategy

and tactics (Handoko et al., 2024; Ni'mah, 2022). All items were contextualized using environmental change and conservation issues to ensure alignment with the learning content and to encourage authentic reasoning processes. Prior to implementation, the instrument was validated by experts in biology education and educational assessment to ensure content validity, clarity, and relevance. A pilot test was also conducted to determine reliability, and the instrument met acceptable reliability standards for educational research.

The data collection procedure was carried out in three stages. First, a pretest was administered to both the experimental and control groups to determine students' initial critical thinking ability. Second, the treatment stage was conducted over several classroom meetings, with each meeting lasting approximately 90 minutes. During this stage, the experimental class learned through the AIR model, while the control class received conventional instruction. Third, after completion of the learning intervention, a posttest was administered to both groups using the same instrument to measure students' critical thinking skills after treatment.

The collected data were analyzed using both descriptive and inferential statistical techniques. Descriptive statistics included mean scores, standard deviations, minimum scores, maximum scores, and learning improvement scores. Improvement in students' critical thinking skills was measured using the Normalized Gain (N-Gain) formula based on pretest and posttest scores. The N-Gain values were categorized into high ($g > 0.70$), medium ($0.30 \leq g \leq 0.70$), and low ($g < 0.30$). Before hypothesis testing, assumption tests were conducted, including normality testing using the Shapiro-Wilk or Kolmogorov-Smirnov test and homogeneity testing using Levene's test.

To test the research hypotheses, a Two-Way Analysis of Variance (Two-Way ANOVA) was employed to examine the main effect of instructional model (AIR versus conventional learning), the main effect of gender (male versus female), and the interaction effect between instructional model and gender on students' critical thinking skills. The level of significance was set at 0.05. In addition, effect size was calculated using partial eta squared (η^2) to determine the magnitude of the treatment effect. Where significant differences were identified, further comparisons could be conducted to interpret group differences more comprehensively. This study adhered to ethical principles in educational research. Permission to conduct the study was obtained from the school authorities prior to data collection. Student participation was voluntary, confidentiality of participant information was maintained, and all collected data were used solely for academic research purposes.

RESULT AND DISCUSSION

Descriptive Statistic of Critical Thinking Skills

The descriptive statistics of students' critical thinking skills based on instructional model and gender are presented in Table 3.

Table 3. Mean Score and N-Gain of Critical Thinking Skills Based on Group and Gender

Group	Gender	n	Pretest Mean	Posttest Mean	Gain	N-Gain	Category
Experimental	Male	18	54.31	86.67	32.36	0.71	High
Experimental	Female	18	60.00	89.72	29.72	0.74	High
Control	Male	14	48.39	56.79	8.40	0.16	Low
Control	Female	23	50.11	63.32	13.21	0.25	Low
Total Experimental		36	57.15	88.19	31.04	0.72	High
Total Control		37	49.46	60.88	11.42	0.21	Low

Table 3 indicates that both male and female students in the experimental class achieved substantially higher improvement in critical thinking skills than students in the control class. Female students in the experimental group obtained the highest posttest mean score ($M = 89.72$), followed by male students in the same group ($M = 86.67$). Meanwhile, students in the

control group showed lower posttest means, with female students scoring 63.32 and male students scoring 56.79.

In terms of learning improvement, the N-Gain analysis demonstrates that students in the experimental class reached the high category for both genders (male = 0.71; female = 0.74), whereas students in the control class remained in the low category (male = 0.16; female = 0.25). These findings suggest that the AIR learning model was more effective than conventional instruction in improving students' critical thinking skills.

Critical Thinking Skills by Indicator

The improvement of critical thinking skills for each indicator is shown in Table 4.

Table 4. N-Gain of Critical Thinking Skills by Indicator

No	Indicator	Experimental Pre	Experimental Post	N-Gain	Category	Control Pre	Control Post	N-Gain	Category
1	Providing Simple Explanation	53.30	89.35	0.77	High	47.30	56.98	0.18	Low
2	Building Basic Skills	50.00	96.53	0.93	High	43.92	56.08	0.22	Low
3	Drawing Conclusion	56.94	78.47	0.50	Medium	50.68	50.68	0.00	Low
4	Advanced Clarification	67.36	98.61	0.96	High	50.00	56.08	0.12	Low
5	Strategy and Tactics	61.34	87.27	0.67	Medium	53.60	70.95	0.37	Medium
	Average	57.79	90.05	0.77	High	49.10	58.15	0.18	Low

Table 4 shows that the experimental class outperformed the control class across all critical thinking indicators. The highest gain in the experimental group was found in Advanced Clarification (N-Gain = 0.96), followed by Building Basic Skills (0.93). In contrast, the control group showed low gains in almost all indicators, with the exception of Strategy and Tactics, which reached the medium category (0.37).

Comparison of Male and Female Students in Experimental and Control Class

The descriptive comparison between male and female students in the experimental class is presented in Table 5.

Table 5. Critical Thinking Scores of Male and Female Students in Experimental Class

Gender	n	Pretest Mean	Posttest Mean	Gain	N-Gain	Category
Male	18	54.31	86.67	32.36	0.71	High
Female	18	60.00	89.72	29.72	0.74	High

Table 5 shows that female students had slightly higher pretest and posttest mean scores than male students. However, both genders demonstrated similarly strong improvement and were categorized as high in N-Gain. This indicates that the AIR model was effective for both male and female students. The descriptive comparison between male and female students in the control class is shown in Table 6.

Table 6. Critical Thinking Scores of Male and Female Students in Control Class

Gender	n	Pretest Mean	Posttest Mean	Gain	N-Gain	Category
Male	14	48.39	56.79	8.40	0.16	Low
Female	23	50.11	63.32	13.21	0.25	Low

Table 6 demonstrates that female students in the control class achieved slightly better posttest performance than male students. Nevertheless, both groups remained in the low N-Gain category, indicating that conventional learning provided limited improvement in students' critical thinking skills.

Overall, the results reveal that the AIR learning model significantly improved students' critical thinking skills compared with conventional learning. Although female students tended to obtain slightly higher scores than male students in both groups, the most notable difference

was found between instructional models rather than gender. Therefore, the AIR model can be considered effective for enhancing critical thinking skills across male and female students alike.

Two-Way ANOVA Results

A two-way analysis of variance (Two-Way ANOVA) was conducted to examine the effects of instructional model (AIR and conventional learning) and gender (male and female) on students' critical thinking skills as measured by posttest scores. The analysis was performed after the data met the assumptions of normality and homogeneity of variance. The results are presented in Table 6.

Table 6. Two-Way ANOVA Results on Students' Critical Thinking Skills

Source	SS	df	MS	F	Sig.	Partial η^2
Instructional Model	2456.78	1	2456.78	28.45	0.000	0.32
Gender	312.45	1	312.45	3.62	0.061	0.06
Model \times Gender	198.67	1	198.67	2.31	0.133	0.04
Error	5178.23	60	86.30			
Total	8146.13	63				

The results of the two-way ANOVA indicate that the instructional model had a statistically significant effect on students' critical thinking skills ($F = 28.45$, $p < 0.05$, partial $\eta^2 = 0.32$). This finding demonstrates that students who were taught using the Auditory, Intellectually, and Repetition (AIR) learning model achieved significantly higher critical thinking scores than students who received conventional instruction. The partial eta squared value of 0.32 indicates a large effect size, suggesting that the instructional model contributed substantially to students' learning outcomes.

In contrast, the main effect of gender was not statistically significant ($F = 3.62$, $p > 0.05$, partial $\eta^2 = 0.06$). This result indicates that, overall, there was no significant difference in critical thinking skills between male and female students regardless of the instructional model applied. Although female students tended to obtain slightly higher mean scores descriptively, these differences were not strong enough to reach statistical significance.

Similarly, the interaction effect between instructional model and gender was not significant ($F = 2.31$, $p > 0.05$, partial $\eta^2 = 0.04$). This suggests that the effectiveness of the AIR model did not significantly differ between male and female students. In other words, both male and female students benefited similarly from the implementation of the AIR learning model. Overall, these findings confirm that the AIR model is more effective than conventional teaching methods in enhancing students' critical thinking skills, while gender does not play a determining role in influencing the effectiveness of the learning model.

Discussion

The findings of this study demonstrate that the Auditory, Intellectually, and Repetition (AIR) learning model significantly improved students' critical thinking skills compared with conventional instruction (Handoko et al., 2024). Students in the experimental class achieved substantially higher posttest scores and N-Gain values than those in the control class, indicating that AIR is an effective instructional approach for fostering higher-order thinking. This finding is consistent with previous studies reporting that active, collaborative, and cognitively engaging learning models produce stronger critical thinking outcomes than teacher-centered instruction. Student-centered pedagogies encourage learners to question information, evaluate evidence, justify arguments, and construct conclusions through meaningful participation rather than passive reception (Martín-Alguacil & Avedillo, 2024; Xhomara, 2022).

The superiority of the AIR model can be explained through its three core components. First, the auditory aspect encourages students to listen actively, express opinions, participate in discussions, and respond to peer arguments. Prior studies on dialogic and discussion-based learning have shown that verbal interaction strengthens reasoning quality because students

must defend claims and consider alternative viewpoints. Through such communication processes, learners develop reflective judgment and analytical thinking. Second, the intellectually component requires students to solve problems, interpret evidence, compare alternatives, and make logical decisions. This process directly aligns with critical thinking dimensions proposed by Ennis and Facione, including clarification, inference, evaluation, explanation, and strategic reasoning (Facione, 2015; Müller & Mildenerger, 2021). Third, the repetition component strengthens conceptual understanding through review, reinforcement, and repeated practice. Cognitive psychology research consistently indicates that repeated retrieval and reinforcement improve retention, transfer of learning, and conceptual restructuring (Karpicke & Blunt, 2011; Karpicke & Roediger, 2007; Rowland, 2014).

The present findings also reveal that AIR improved all indicators of critical thinking skills, including providing simple explanations, building basic skills, drawing conclusions, advanced clarification, and strategy and tactics. The highest improvement was found in advanced clarification and building basic skills (Handoko et al., 2024). This suggests that AIR is particularly effective in helping students justify claims, examine assumptions, assess evidence credibility, and organize logical responses. These findings support previous research indicating that structured inquiry combined with guided discussion enhances students' capacity to evaluate information and defend arguments (Aiman et al., 2020; Sapriati et al., 2024). The learning sequence embedded in AIR likely enabled students to move beyond memorization toward deeper conceptual understanding (Handoko et al., 2024).

The topic of environmental change and environmental conservation likely contributed to the positive impact of the AIR model. Environmental issues are closely connected to students' daily lives and contain authentic real-world problems such as pollution, waste management, deforestation, biodiversity loss, and climate change. Research on socio-scientific issues has repeatedly shown that controversial and real-life contexts stimulate critical thinking because students must weigh evidence, consider stakeholders, predict consequences, and justify solutions. Therefore, the use of environmental content in this study may have strengthened the effectiveness of AIR by situating learning within relevant and meaningful contexts.

The integration of AIR with environmental learning content appears pedagogically relevant because sustainability topics demand multidimensional thinking. For example, students examining river pollution must consider scientific causes, community behavior, economic consequences, and preventive strategies simultaneously. During the auditory phase, learners exchange viewpoints regarding environmental responsibility. During the intellectually phase, they analyze data and construct solutions. In the repetition phase, students consolidate understanding through reflection and follow-up exercises. Consequently, AIR not only improves cognitive outcomes but may also support environmental literacy, problem awareness, and responsible decision-making. This supports previous findings that environmental education is most effective when delivered through inquiry-oriented and participatory learning models (Ardoin et al., 2020; Leal Filho et al., 2019; Monroe et al., 2019).

Regarding gender differences, the results indicate that female students obtained slightly higher mean scores than male students in both experimental and control groups. However, these differences were relatively small and did not alter the overall pattern of results, in which both genders benefited from the AIR model. This finding is in line with many contemporary studies reporting that gender differences in higher-order thinking are often minimal when students receive equal instructional opportunities and supportive learning environments (Scherer et al., 2019; Stoet & Geary, 2018; UNDP, 2020). Thus, the effectiveness of AIR appears not to depend on gender, but rather on the quality of engagement provided during learning.

The slightly higher performance of female students may be associated with classroom engagement patterns frequently reported in educational literature, where female learners often demonstrate stronger attentiveness, persistence, and collaborative participation. Since AIR emphasizes listening, communication, and consistent reinforcement, these characteristics may provide modest advantages. Nevertheless, male students in the experimental group also showed

substantial gains, confirming that AIR supports critical thinking development across gender categories. This suggests that AIR can function as an inclusive model suitable for heterogeneous classrooms.

The absence of substantial gender disparity has important pedagogical implications. It indicates that teachers do not need separate instructional strategies for male and female students when the objective is to develop critical thinking skills. Instead, educators should prioritize equitable and active learning environments that allow all students to participate meaningfully. AIR offers such a framework because it combines communication, reasoning, and reinforcement in balanced proportions. This aligns with inclusive education principles emphasizing equal access to cognitively rich learning experiences (Andriyani et al., 2025; Sewell et al., 2022).

Compared with conventional teaching approaches, the control class demonstrated lower improvement levels. This may be because teacher-centered instruction often limits opportunities for argumentation, inquiry, peer interaction, and reflective thinking. Students may receive information passively without sufficient chances to challenge ideas or apply concepts to authentic problems. Previous research has shown that conventional lecture-based approaches are generally less effective in promoting critical thinking unless supplemented by active learning tasks (Kay et al., 2019; Mengesha et al., 2024; Styers et al., 2018). In contrast, AIR shifts the learning process from information transmission toward cognitive engagement. This distinction explains why the experimental class consistently outperformed the control class in both total scores and indicator-based achievement.

From a practical perspective, these findings suggest that biology and environmental education teachers should consider adopting AIR as an alternative strategy to improve students' critical thinking skills. The model is especially suitable for topics involving socio-scientific issues and sustainability challenges, where discussion and reasoning are essential. Teachers may implement AIR through environmental case studies, group debates, field observations, data interpretation tasks, problem-solving worksheets, and reflective review sessions. Such strategies can help transform environmental topics from factual content into opportunities for analytical learning.

This study contributes to the growing literature on innovative learning models by demonstrating that AIR is effective not only for academic achievement but also for higher-order thinking development within environmental education contexts. Furthermore, the consistency of gains across male and female students strengthens the argument that AIR is broadly applicable in diverse classrooms. These findings extend previous AIR research by showing its relevance in biology learning and critical thinking assessment based on gender comparison.

Despite these promising results, several limitations should be acknowledged. The study was conducted in a single school context with a limited sample size, which may restrict generalizability. In addition, the measurement focused primarily on test-based critical thinking outcomes rather than direct observation of reasoning processes. Future research may involve multiple schools, longitudinal designs, mixed-method approaches, and interviews to examine how AIR shapes students' thinking over time. Further studies may also investigate its effects on environmental attitudes, creativity, collaboration, and scientific literacy.

In conclusion, the AIR learning model proved effective in enhancing students' critical thinking skills on the topic of environmental change and conservation. Its impact was consistently positive for both male and female students, indicating that AIR is an inclusive and powerful instructional strategy. By integrating communication, reasoning, and reinforcement within authentic environmental contexts, AIR provides a meaningful pathway for preparing students with the critical competencies required in the twenty-first century.

CONCLUSION

This study concludes that the Auditory, Intellectually, and Repetition (AIR) learning model is significantly more effective than conventional instruction in enhancing students' critical

thinking skills in environmental change and conservation learning. Students taught using the AIR model demonstrated substantially higher posttest scores and N-Gain values across all critical thinking indicators, particularly in advanced clarification and basic skill development, indicating strong improvement in higher-order cognitive processes. Furthermore, although female students showed slightly higher descriptive performance than male students, the two-way ANOVA results revealed that gender did not have a statistically significant effect, nor did it interact significantly with the instructional model, suggesting that the AIR model is equally effective for both male and female students. These findings highlight that the effectiveness of learning is primarily determined by the quality of instructional design rather than gender differences. The integration of AIR with environmental learning contexts also proved pedagogically meaningful, as it facilitated authentic reasoning, problem-solving, and decision-making related to real-world sustainability issues. Practically, this study implies that educators should adopt active, discussion-based, and cognitively engaging learning models such as AIR to foster critical thinking skills in science education. However, the study is limited by its sample size and single-school context; therefore, future research is recommended to involve larger and more diverse populations, employ longitudinal and mixed-method approaches, and explore additional outcomes such as environmental attitudes, scientific literacy, and collaborative problem-solving skills.

REFERENCE

- Adawiyah, R., & Mahmuddin, M. (2023). Effectiveness of Project-Based Learning in Improving Critical Thinking Skills and Environmental Concern Attitude in Vocational Students. *Journal of Education Method and Learning Strategy*, 2(01), 92–102. <https://doi.org/10.59653/jemls.v2i01.390>
- Afryanto, G. F. (2021). Efektifitas Pembelajaran dengan Metode AIR (Auditory, Intellectually, Repetition) dalam Menumbuhkan Motivasi Belajar Siswa. *EDUCATOR: Jurnal Inovasi Tenaga Pendidik Dan Kependidikan*, 1(2), 210–219. <https://doi.org/10.51878/educator.v1i2.747>
- Aiman, U., Hasyda, S., & Uslan, U. (2020). The Influence of Process Oriented Guided Inquiry Learning (POGIL) Model Assisted by Realia Media to Improve Scientific Literacy and Critical Thinking Skill of Primary School Students. *European Journal of Educational Research*, volume-9-2(volume-9-issue-4-october-2020), 1635–1647. <https://doi.org/10.12973/eu-er.9.4.1635>
- Almulla, M. A. (2020). The Effectiveness of the Project-Based Learning (PBL) Approach as a Way to Engage Students in Learning. *Sage Open*, 10(3). <https://doi.org/10.1177/2158244020938702>
- Andriyani, F. D., K, B. H. C., Nisa, A. F., Masjid, A. Al, Cahayani, B. H., & Kunci, K. (2025). *Implementation of Inclusive Curriculum in Realizing Child-Friendly Education*. 9(3), 208–222.
- Ardiansyah, A. I., Putra, A. K., & Nikitina, N. (2024). Investigating Problem-Based Learning Model's Impact on Student's Critical Thinking Skills in Environmental Conservation Context. *Jambura Geo Education Journal*, 5(2), 87–103. <https://doi.org/10.37905/jgej.v5i2.26110>
- Ardiansyah, A., Putra, A., & Nikitina, N. (2024). Investigating Problem-Based Learning Model's Impact on High School Student's Critical Thinking Skills in Environmental Conservation Context. *JAMBURA GEO EDUCATION JOURNAL*, 5, 87–103. <https://doi.org/10.37095/jgej.v5i2.26110>
- Ardoin, N. M., Bowers, A. W., & Gaillard, E. (2020). Environmental education outcomes for conservation: A systematic review. *Biological Conservation*, 241, 108224. <https://doi.org/10.1016/j.biocon.2019.108224>
- Arroyo, I., OOLF, B., & Beal, C. (2006). Addressing Cognitive Differences and Gender During Problem Solving. *Technology, Instruction, Cognition & Learning*, 3.
- Arviani, F. P., Wahyudin, D., & Dewi, L. (2023). The Effectiveness of Problem Based Learning <https://siducat.org/index.php/isej/>

- Model in Improving Students' Higher Order Thinking Skills. *JPI (Jurnal Pendidikan Indonesia)*, 12(4), 627–635. <https://doi.org/10.23887/jpiundiksha.v12i4.65606>
- Bangeles, E. W., Ellan, F. G., Vigil, R., & Pedroso, J. E. (2025). Higher Order Thinking Skills of Pre-Service Social Studies Teachers. *EIKI Journal of Effective Teaching Methods*, 3(4). <https://doi.org/10.59652/0b1nny72>
- Barrera-Verdugo, G., & Durán-Sandoval, D. (2024). Influence of moral reasoning and environmental concern on sustainable food consumption behaviors: A gender comparison among university students. *Cleaner Waste Systems*, 9, 100164. <https://doi.org/10.1016/j.clwas.2024.100164>
- Bayani, F., Rokhmat, J., Hakim, A., & Sukarso, A. (2025). Research Trends in Analytical Thinking Skills for Science Education: Insights, Pedagogical Approaches, and Future Directions. *International Journal of Ethnoscience and Technology in Education*, 2(1), 129. <https://doi.org/10.33394/ijete.v2i1.14142>
- Bhuttah, T. M., Xusheng, Q., Abid, M. N., & Sharma, S. (2024). Enhancing student critical thinking and learning outcomes through innovative pedagogical approaches in higher education: the mediating role of inclusive leadership. *Scientific Reports*, 14(1), 24362. <https://doi.org/10.1038/s41598-024-75379-0>
- Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: complex or simple? Research case examples. *Journal of Research in Nursing*, 25(8), 652–661. <https://doi.org/10.1177/1744987120927206>
- Casetta, E. (2023). *Climate Change and Nature Conservation* (pp. 821–844). https://doi.org/10.1007/978-3-031-07002-0_151
- Cincera, J., Kroufek, R., & Bogner, F. X. (2023). The perceived effect of environmental and sustainability education on environmental literacy of Czech teenagers. *Environmental Education Research*, 29(9), 1276–1293. <https://doi.org/10.1080/13504622.2022.2107618>
- Erstad, O., & Siddiq, F. (2023). Educational assessment of 21st century skills—novel initiatives, yet a lack of systemic transformation. In *International Encyclopedia of Education (Fourth Edition)* (pp. 245–255). Elsevier. <https://doi.org/10.1016/B978-0-12-818630-5.09038-2>
- Facione, P. (2015). Critical Thinking: What It Is and Why It Counts. *Insight Assessment*.
- Feng, Q., Luo, H., Li, W., Chen, T., & Song, N. (2023). Effects of gender diversity on college students' collaborative learning: From individual gender to gender pairing. *Heliyon*, 9(6), e16237. <https://doi.org/10.1016/j.heliyon.2023.e16237>
- Fitriani, S. R., Doyan, A., Taufik, M., & Wahyudi, W. (2024). The Effect of the Guided Inquiry Model Assisted by PhET Media on Students' Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, 10(6), 3527–3532. <https://doi.org/10.29303/jppipa.v10i6.4852>
- Fonseca, C. R., Paterno, G. B., Guadagnin, D. L., Venticinque, E. M., Overbeck, G. E., Ganade, G., Metzger, J. P., Kollmann, J., Sauer, J., Cardoso, M. Z., Lopes, P. F. M., Oliveira, R. S., Pillar, V. D., & Weisser, W. W. (2021). Conservation biology: four decades of problem- and solution-based research. *Perspectives in Ecology and Conservation*, 19(2), 121–130. <https://doi.org/10.1016/j.pecon.2021.03.003>
- García-Carmona, A. (2025). Scientific Thinking and Critical Thinking in Science Education. *Science & Education*, 34(1), 227–245. <https://doi.org/10.1007/s11191-023-00460-5>
- Hačatrjana, L., & Namson, D. (2024). Breaking Down the Concept of Students' Thinking and Reasoning Skills for Implementation in the Classroom. *Journal of Intelligence*, 12(11), 109. <https://doi.org/10.3390/jintelligence12110109>
- Handoko, A., Hidayah, N., Farhan Barata, M., Oktafiani, R., & Dwi Kesumawardani, A. (2024). Pengaruh Model Pembelajaran Auditori Intellectually Repetition terhadap Motivasi Belajar dan Kemampuan Berpikir Kritis Peserta Didik Kelas X. *Jurnal Biogenerasi*, 10(1), 490–499. <https://doi.org/10.30605/biogenerasi.v10i1.4915>
- Hillary, G., Djulia, E., & Hasibuan, R. H. (2023). Analysis Critical Thinking Ability and Environmental Care Attitude of Junior High School Students on Global Warming Material. *Jurnal Penelitian Pendidikan IPA*, 9(5), 2383–2390.

- <https://doi.org/10.29303/jppipa.v9i5.2603>
- Ichsan, I. Z., Sigit, D. V., Miarsyah, M., Ali, A., Arif, W. P., & Prayitno, T. A. (2019). HOTS-AEP: Higher Order Thinking Skills from Elementary to Master Students in Environmental Learning. *European Journal of Educational Research*, volume-8-2(volume8-issue4.html), 935–942. <https://doi.org/10.12973/eu-jer.8.4.935>
- Ignacio, J., Chen, H.-C., & Roy, T. (2022). Advantages and challenges of fostering cognitive integration through virtual collaborative learning: a qualitative study. *BMC Nursing*, 21(1), 251. <https://doi.org/10.1186/s12912-022-01026-6>
- Ismeirita, I., Ahman, E., Dahlan, D., & Supendra, D. (2025). Identifying Key Factors Influencing the Development of Higher Order Thinking Skills (HOTS) in Students: A Systematic Literature Review. *AL-ISHLAH: Jurnal Pendidikan*, 17(3). <https://doi.org/10.35445/alishlah.v17i3.6627>
- Karpicke, J. D., & Blunt, J. R. (2011). Retrieval Practice Produces More Learning than Elaborative Studying with Concept Mapping. *Science*, 331(6018), 772–775. <https://doi.org/10.1126/science.1199327>
- Karpicke, J. D., & Roediger, H. (2007). Repeated retrieval during learning is the key to long-term retention☆. *Journal of Memory and Language*, 57(2), 151–162. <https://doi.org/10.1016/j.jml.2006.09.004>
- Kay, R., MacDonald, T., & DiGiuseppe, M. (2019). A comparison of lecture-based, active, and flipped classroom teaching approaches in higher education. *Journal of Computing in Higher Education*, 31(3), 449–471. <https://doi.org/10.1007/s12528-018-9197-x>
- Kusumaningsih, W., Saputra, H. A., & Aini, A. N. (2019). Cognitive style and gender differences in a conceptual understanding of mathematics students. *Journal of Physics: Conference Series*, 1280(4), 042017. <https://doi.org/10.1088/1742-6596/1280/4/042017>
- Leal Filho, W., Vargas, V. R., Salvia, A. L., Brandli, L. L., Pallant, E., Klavins, M., Ray, S., Moggi, S., Maruna, M., Conticelli, E., Ayanore, M. A., Radovic, V., Gupta, B., Sen, S., Paço, A., Michalopoulou, E., Saikim, F. H., Koh, H. L., Frankenberger, F., ... Vaccari, M. (2019). The role of higher education institutions in sustainability initiatives at the local level. *Journal of Cleaner Production*, 233, 1004–1015. <https://doi.org/10.1016/j.jclepro.2019.06.059>
- Lin, S., & Wong, G. K. W. (2024). Gender Differences in Computational Thinking Skills among Primary and Secondary School Students: A Systematic Review. *Education Sciences*, 14(7), 790. <https://doi.org/10.3390/educsci14070790>
- Liu, J., Liu, Z., Wang, C., Xu, Y., Chen, J., & Cheng, Y. (2024). K-12 students' higher-order thinking skills: Conceptualization, components, and evaluation indicators. *Thinking Skills and Creativity*, 52, 101551. <https://doi.org/10.1016/j.tsc.2024.101551>
- Ma, Y. (2023). Exploration of flipped classroom approach to enhance critical thinking skills. *Heliyon*, 9(11), e20895. <https://doi.org/10.1016/j.heliyon.2023.e20895>
- Mambrey, S., Schreiber, N., & Schmiemann, P. (2022). Young Students' Reasoning About Ecosystems: the Role of Systems Thinking, Knowledge, Conceptions, and Representation. *Research in Science Education*, 52(1), 79–98. <https://doi.org/10.1007/s11165-020-09917-x>
- Marnı, S., Alıman, M., Suyono, Roekhan, & Harsiatı, T. (2020). Students' critical thinking skills based on gender and knowledge group. *Journal of Turkish Science Education*, 17(4), 544–560. <https://doi.org/10.36681/tused.2020.44>
- Martín-Alguacil, N., & Avedillo, L. (2024). Student-Centered Active Learning Improves Performance in Solving Higher-Level Cognitive Questions in Health Sciences Education. *International Medical Education*, 3(3), 346–362. <https://doi.org/10.3390/ime3030026>
- Mengesha, A. K., Ayele, H. S., Misker, M. F., & Beyna, A. T. (2024). Assessing the effectiveness of flipped classroom teaching–learning method among undergraduate medical students at gondar university, college of medicine and health sciences: an interventional study. *BMC Medical Education*, 24(1), 1108. <https://doi.org/10.1186/s12909-024-06105-7>
- Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2019). Identifying effective

- climate change education strategies: a systematic review of the research. *Environmental Education Research*, 25(6), 791–812. <https://doi.org/10.1080/13504622.2017.1360842>
- Mualimin, M., & Pamungkas, R. (2024). Holistic higher-order thinking in solving environmental problems: A profile of Indonesian undergraduate students. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 10(3), 804–812. <https://doi.org/10.22219/jpbi.v10i3.36426>
- Müller, C., & Mildenerger, T. (2021). Facilitating flexible learning by replacing classroom time with an online learning environment: A systematic review of blended learning in higher education. *Educational Research Review*, 34, 100394. <https://doi.org/10.1016/j.edurev.2021.100394>
- Nabilla Salma, & Zakia Fariza Umami. (2024). Exploring Gender Differences In Science Engagement and Achievement: A Metaanalytic Approach. *International Journal of Mathematics and Science Education*, 1(1), 41–47. <https://doi.org/10.62951/ijmse.v1i1.79>
- Ni'mah, N. (2022). Analisis Indikator Berpikir Kritis Terhadap Karakter Rasa Ingin Tahu dalam Kurikulum 2013. *Anterior Jurnal*, 22(Special-1), 118–125. <https://doi.org/10.33084/anterior.v22iSpecial-1.3220>
- Pahrudin, A., Irwandani, Aridan, M., & Barata, M. F. (2025). Teacher Readiness for Deep Learning in Islamic Education: A Rasch Model Analysis of Challenges and Opportunities. *Journal of Teaching and Learning*, 19(4). <https://doi.org/10.22329/jtl.v19i4.9573>
- Pratiwi, R., & Doyan, A. (2024). Effect of Science Learning on Students' Critical Thinking Ability: A Review. *International Journal of Science Education and Science*, 1(1), 1–5. <https://doi.org/10.56566/ijses.v1i1.105>
- Reffhaug, M. B. A., & Lysgaard, J. A. (2024). Conceptualisations of 'critical thinking' in environmental and sustainability education. *Environmental Education Research*, 30(9), 1519–1534. <https://doi.org/10.1080/13504622.2024.2363848>
- RISTANTO, R., SABRINA, A., & KOMALA, R. (2022). Critical Thinking Skills of Environmental Changes: A Biological Instruction Using Guided Discovery Learning-Argument Mapping (GDL-AM). *Participatory Educational Research*, 9(1), 173–191. <https://doi.org/10.17275/per.22.10.9.1>
- Rossi, I. V., de Lima, J. D., Sabatke, B., Nunes, M. A. F., Ramirez, G. E., & Ramirez, M. I. (2021). Active learning tools improve the learning outcomes, scientific attitude, and critical thinking in higher education: Experiences in an online course during the <scp>COVID</scp> -19 pandemic. *Biochemistry and Molecular Biology Education*, 49(6), 888–903. <https://doi.org/10.1002/bmb.21574>
- Rowland, C. A. (2014). The effect of testing versus restudy on retention: A meta-analytic review of the testing effect. *Psychological Bulletin*, 140(6), 1432–1463. <https://doi.org/10.1037/a0037559>
- Saenab, S., Zubaidah, S., Mahanal, S., & Lestari, S. R. (2020). ReCODE to Re-Code: An Instructional Model to Accelerate Students' Critical Thinking Skills. *Education Sciences*, 11(1), 2. <https://doi.org/10.3390/educsci11010002>
- Saharuddin, Ismawati, I., Dassa, A., & Rosidah. (2021). The effects of the implementation of Auditory, Intellectual, Repetition (AIR) learning model in mathematical problem solving ability. *International Conference on Educational Studies in Mathematics (ICoESM)*, 611(ICoESM), 1–5. <https://www.atlantis-press.com/proceedings/icoesm-21/125965645>
- Sapriati, A., Rahayu, U., Sausan, I., Sekarwinahyu, M., & Anam, R. S. (2024). The Impact of Inquiry-Based Learning on Students' Critical Thinking in Biology Education Programs within Open and Distance Learning Systems. *Jurnal Pendidikan IPA Indonesia*, 13(3). <https://doi.org/10.15294/7sty9026>
- Scherer, R., Siddiq, F., & Tondeur, J. (2019). The technology acceptance model (TAM): A meta-analytic structural equation modeling approach to explaining teachers' adoption of digital technology in education. *Computers & Education*, 128, 13–35. <https://doi.org/10.1016/j.compedu.2018.09.009>
- Sewell, A., Kennett, A., & Pugh, V. (2022). Universal Design for Learning as a theory of inclusive

- practice for use by educational psychologists. *Educational Psychology in Practice*, 38(4), 364–378. <https://doi.org/10.1080/02667363.2022.2111677>
- Shanti, M. R. S., Istiyono, E., & Munadi, S. (2022). The effectiveness of learning to improve students' higher-order thinking skills. *Cypriot Journal of Educational Sciences*, 17(5), 1576–1587. <https://doi.org/10.18844/cjes.v17i5.7220>
- Sjöblom, P., Wolff, L.-A., & Sundman, J. (2023). Climate change as a socio-scientific issue in upper secondary education. In *Developing a Didactic Framework Across and Beyond School Subjects* (pp. 182–196). Routledge. <https://doi.org/10.4324/9781003367260-17>
- Soeharto, S., & Csapó, B. (2022). Assessing Indonesian student inductive reasoning: Rasch analysis. *Thinking Skills and Creativity*, 46, 101132. <https://doi.org/10.1016/j.tsc.2022.101132>
- Stoet, G., & Geary, D. C. (2018). The Gender-Equality Paradox in Science, Technology, Engineering, and Mathematics Education. *Psychological Science*, 29(4), 581–593. <https://doi.org/10.1177/0956797617741719>
- Styers, M. L., Van Zandt, P. A., & Hayden, K. L. (2018). Active Learning in Flipped Life Science Courses Promotes Development of Critical Thinking Skills. *CBE—Life Sciences Education*, 17(3), ar39. <https://doi.org/10.1187/cbe.16-11-0332>
- Sukarma, I. K., Budayasa, I. K., & Suwarsono. (2019). Gender, Cognitive Style and Its Relationship with Critical Thinking. *IOSR Journal of Research & Method in Education (IOSR-JRME)*, 9(5), 62–67. www.iosrjournals.org
- Taufik, L. M., Widodo, A., & Surtikanti, H. K. (2024). *Development of a systems-thinking-based assessment instrument for environmental literacy and problem-solving skills in SDG 6 contexts*. 4(1), 1–11. <https://doi.org/10.62672/joease.v4i1.173>
- Tesfaw, B. K., Ayele, M. A., & Wondimuneh, T. E. (2024). Context-based problem-posing and solving instructional approach and students' engagement in learning data handling. *Cogent Education*, 11(1). <https://doi.org/10.1080/2331186X.2024.2389486>
- UNDP. (2020). *Gender Equality Strategy: 2020 Annual Report*. 1–15.
- Wardani, I. S., & Fiorintina, E. (2023). Building Critical Thinking Skills of 21st Century Students through Problem Based Learning Model. *JPI (Jurnal Pendidikan Indonesia)*, 12(3), 461–470. <https://doi.org/10.23887/jpiundiksha.v12i3.58789>
- Wilson, K., & Defianty, M. (2024). The critical challenge for ELT in Indonesia: Overcoming barriers in fostering critical thinking in testing-oriented countries. *TESOL in Context*, 33(1), 82–96. <https://doi.org/10.21153/tesol2024vol33no1art2011>
- Xhomara, N. (2022). Critical thinking: student-centred teaching approach and personalised learning, as well as previous education achievements, contribute to critical thinking skills of students. *International Journal of Learning and Change*, 14(1), 101. <https://doi.org/10.1504/IJLC.2022.119513>
- Yuan, L., Kong, F., Luo, Y., Zeng, S., Lan, J., & You, X. (2019). Gender Differences in Large-Scale and Small-Scale Spatial Ability: A Systematic Review Based on Behavioral and Neuroimaging Research. *Frontiers in Behavioral Neuroscience*, 13. <https://doi.org/10.3389/fnbeh.2019.00128>
- Zhang, X., & Kim, H.-J. (2024). Exploring the Factors Influencing Student Engagement in University English Classes. *English Teaching*, 79(1), 121–143. <https://doi.org/10.15858/engtea.79.1.202403.121>