JPPIPA 12(1) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Peer Tutoring for Sustainable Biology Education: Enhancing Student Activity, Motivation, and Learning Outcomes in the Respiratory System Unit

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Received: November 26, 2025
Revised: December 27, 2025
Accepted: January 25, 2026
Published: January 31, 2026

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DOI: 10.29303/jppipa.v12i1.14096

Abstract: This study aims to analyze the effect of the peer tutoring method on learning activity, learning motivation, and biology learning outcomes of grade XI students at SMAN 15 Gowa. This quasi-experimental research employed a pretest-posttest control group design involving 54 students divided into experimental (n = 27) and control groups (n = 27). Learning activity was measured using observation sheets based on Paul B. Diedrich indicators, motivation was assessed through questionnaires using Keller's ARCS model, and learning outcomes were evaluated using cognitive tests consisting of 25 multiple-choice and 5 essay questions based on revised Bloom's taxonomy. Data were analyzed using Independent Samples t-test to compare groups and Paired Samples t-test to analyze improvements within groups, with a significance level of α = 0.05. The results showed significant effects of peer tutoring on learning activity (p = 0.015), motivation (p = 0.000), and learning outcomes (p = 0.000). The experimental group demonstrated higher mean scores in activity (25.93 vs 24.44) and substantial improvements in motivation (N-Gain 0.61, medium category vs 0.12, low category) and learning outcomes (N-Gain 0.57, medium category vs 0.29, low category). The mastery level achievement in the experimental group (92.60%) was substantially higher compared to the control group (66.70%). Superior performance can be attributed to enhanced peer interaction facilitating deeper conceptual understanding through social constructivism and the Zone of Proximal Development. These findings indicate that the peer tutoring method effectively enhances students' learning activity, motivation, and outcomes in complex biology topics, with practical implications for improving biology education quality at the secondary school level.

Keywords: Biology education; Learning activity; Learning motivation; Learning outcomes; Peer tutoring

Introduction

The quality of education in Indonesia continues to face serious challenges as reflected in the Programme for International Student Assessment (PISA) 2022 results. Although Indonesia experienced a rank increase of 5-6 positions compared to 2018, Indonesia's absolute position remains at rank 69 for literacy and rank 67 for mathematics out of 81 participating countries with still low scores: mathematics (379), science (398), and reading (371) (OECD, 2022). These PISA results indicate that the quality of learning in Indonesia, particularly in the science fields including biology, still requires fundamental improvement (Samala et al., 2024). This low achievement at the international level is also reflected in learning outcomes at Indonesian secondary schools, where students continue to struggle with science subjects, particularly in understanding complex biological concepts that require higher-order thinking skills.

How to Cite:
Arini, N., Hala, Y., Rachmawaty, Daud, F., & Ismail. (2026). Peer Tutoring for Sustainable Biology Education: Enhancing Student Activity, Motivation, and Learning Outcomes in the Respiratory System Unit. *Jurnal Penelitian Pendidikan IPA*, *12*(1), 633-641. https://doi.org/10.29303/jppipa.v12i1.14096

Twenty-first century education faces global challenges demanding a paradigm transformation from conventional teacher-centered approaches toward student-centered learning. This change aligns with recommendations from various international education organizations emphasizing the importance of collaborative learning in developing students' communication, collaboration, and critical thinking skills (Faridi & Lutfi, 2023). Recent educational innovations emphasize collaborative learning in digital contexts (Hakim & Suyatna, 2024) and virtual laboratory integration (Ilyas et al., 2022), demonstrating the evolving landscape of science education. Biology, as a branch of natural science, has complex and abstract characteristics that often create difficulties for students in understanding the taught concepts. The complexity of biology material covering various levels of life organization from molecular to ecosystem requires learning approaches that can facilitate students in building integrated and meaningful understanding (Adinugraha et al., 2021).

Recent research in science education has increasingly emphasized the effectiveness of collaborative learning effectiveness. Studies by Rahayu (2016) demonstrated that problem-based learning significantly enhances science process skills in elementary students. Andima et al. (2021) found strong correlations between multiple intelligences and biology learning outcomes. Pakaya et al. (2023) highlighted the importance of science process skills assessment in biology lesson planning. Additionally, research on collaborative learning contexts shows positive effects across various settings, from cooperative learning in secondary schools (Aryana et al., 2016) to peer tutoring in language learning (Anam & Nurman, 2020). These findings provide additional support for peer-based collaborative methods in biology education.

The respiratory system topic, specifically, is considered particularly challenging for students due to several factors: first, abstract physiological processes that cannot be directly observed, such as gas exchange at the alveolar-capillary level and cellular respiration mechanisms; second, the requirement to integrate anatomical structures with their complex functions; third, the involvement of multiple interconnected systems, including the respiratory, circulatory, and nervous systems in respiratory regulation; and fourth, the necessity to understand concepts simultaneously at molecular, cellular, tissue, and organ system levels. These complexities necessitate collaborative learning approaches like peer tutoring that facilitate deeper understanding through peer interaction and explanation in more accessible language.

Conventional learning problems not only lie in methodological aspects but also significantly impact student activity and involvement in the learning process. Traditional learning, where teachers deliver information and students receive it passively, contradicts constructive learning principles requiring active student participation to build their own knowledge. The lack of peer interaction in conventional learning results in lost valuable opportunities for students to share understanding, clarify misconceptions, and build knowledge collaboratively (Yusup & Mastoah, 2025).

Based on observations and interviews with grade XI biology teachers at SMAN 15 Gowa, information was obtained that grade XI students' learning outcomes are still relatively low with a Minimum Mastery Criteria (KKM) of only 75. The data show that most students experience difficulties reaching the established mastery standards, with low student activity levels during the learning process. Students tend to be passive, lack initiative to ask questions or express opinions, and show unenthusiastic learning motivation toward biology learning.

One alternative solution to overcome these problems is the peer tutoring method. This method is a collaborative learning approach where more competent students act as tutors to help their peers who are experiencing difficulties in understanding learning material. Peer tutoring has advantages because it uses language and thinking methods more aligned with other students, making communication and knowledge transfer more effective compared to conventional one-way learning (Khoiriyah, 2021). The effectiveness of peer tutoring has been demonstrated across various educational contexts and subjects, showing improvements in both academic achievement and social skills development (Bowman-Perrott et al., 2013).

The research gap that still needs further investigation relates to the limited peer tutoring research in biology subjects at the senior high school level, particularly those comprehensively analyzing three variables simultaneously: student activity, student motivation, and learning outcomes. Additionally, no specific research has been conducted at SMAN 15 Gowa, which requires empirical evidence about the effectiveness of the peer tutoring method in this school's specific context (Dewi & Priansa, 2024).

While previous studies have explored peer teaching in various contexts such as English education (Handayani, 2022) and art education (Yulianto, 2019), and examined collaborative learning outcomes in mathematics (Nuriyani & Winarso, 2021), the specific application of peer tutoring for complex biological topics such as the respiratory system remains understudied.

Recent developments in biology education have shown promising results with digital literacy integration (Hafiza et al., 2022) and collaborative skills development (Marita et al., 2023; Suhendra et al., 2023), yet comprehensive peer tutoring research addressing multiple learning dimensions simultaneously is still limited.

The novelty of this research lies in several key aspects: first, the comprehensive simultaneous analysis of three interconnected variables (activity, motivation, and learning outcomes) in the biology education context, which previous studies rarely examined together; second, the specific application of peer tutoring for the respiratory system topic, which involves highly complex and abstract concepts requiring deep conceptual understanding; third, the integration of multiple theoretical frameworks, including Vygotsky's Zone of Proximal Development, Keller's ARCS motivation model, and revised Bloom's taxonomy in analyzing peer tutoring effects; and fourth, the provision of empirical evidence from the Indonesian secondary school context where peer tutoring research in biology education remains limited, particularly for complex topics like the respiratory system.

This research is important because it addresses the urgent need for effective alternative teaching methods in biology education. The findings can contribute to: first, solving persistent problems of low student engagement and achievement in complex biology topics; second, providing evidence-based strategies for teachers to implement collaborative learning effectively; third, demonstrating how peer resources can be optimized to improve learning quality without requiring substantial technological or infrastructure investment, aligning with Sustainable Development Goal 4 (Quality Education); and fourth, contributing to Indonesia's efforts to improve the quality of science education as reflected in international assessments like PISA.

This study aims to analyze the effect of the peer tutoring method implementation on student activity in biology learning, evaluate students' learning motivation toward the peer tutoring method implementation, and measure the effectiveness of the peer tutoring method on biology learning outcomes of grade XI students at SMAN 15 Gowa.

Method

This research employed a quasi-experimental design with a pretest-posttest control group design. The study was conducted at SMAN 15 Gowa, Bontolempangan District, Gowa Regency, South Sulawesi Province, during the odd semester of the 2025–2026 academic year. The population consisted of all grade XI classes at SMAN 15 Gowa. Samples were selected using a cluster random sampling technique, resulting in 54 students being divided into an experimental class (n = 27) and a control class (n = 27).

The experimental group received learning using the peer tutoring method, while the control group received conventional learning. The peer tutoring implementation procedure included: pretest administration; tutor selection based on pretest scores ≥75 and communication ability; tutor briefing about roles and responsibilities; heterogeneous group formation (4-5 students per group); peer tutoring implementation for five meetings; and posttest and final motivation questionnaire administration. The complete research procedure is illustrated in Figure 1.

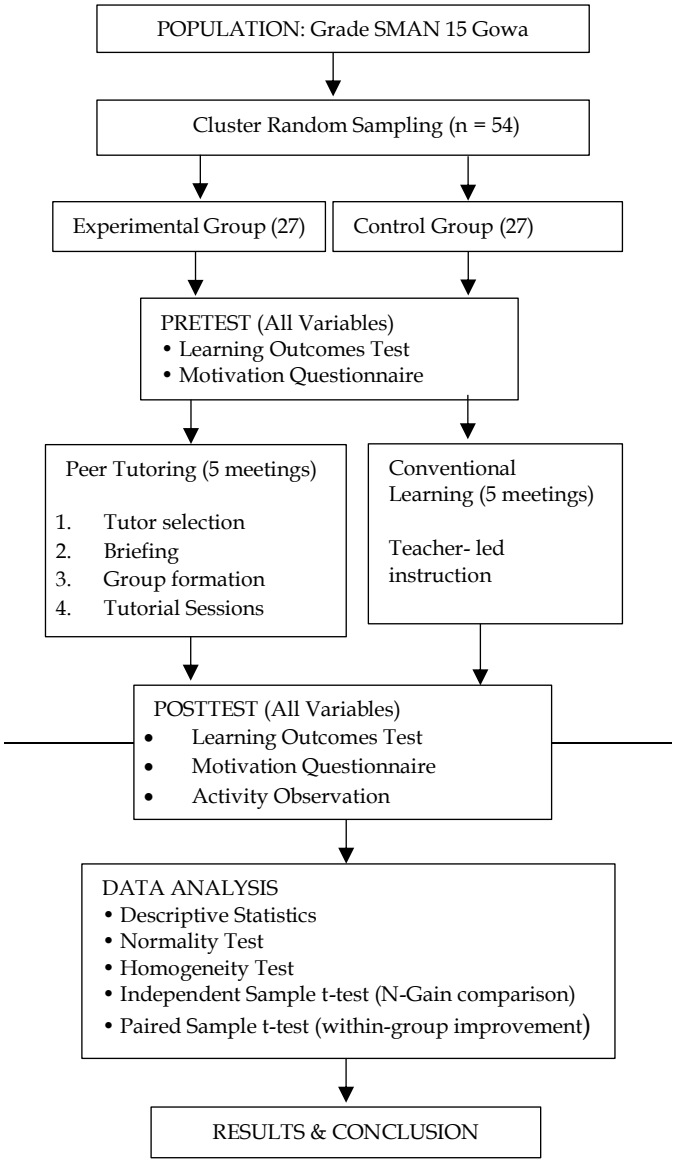

Figure 1: Research procedure

Research instruments included: a learning activity observation sheet consisting of 15 items based on Paul B. Diedrich indicators covering visual, oral, listening, writing, and mental activities with a scoring scale of 1–2; a learning motivation questionnaire consisting of 25 statements based on Keller's ARCS model (Attention, Relevance, Confidence, Satisfaction) with a Likert scale of 1–4; and a cognitive learning outcomes test consisting of 25 multiple-choice questions and 5 essay questions based on revised Bloom's taxonomy covering remembering, understanding, applying, analyzing, and evaluating levels.

Different scoring scales were used appropriately for each variable's nature: the activity observation used a dichotomous scale (1–2) for observable behaviors that could be directly seen and recorded during the learning process, the motivation questionnaire used a Likert scale (1–4) for measuring attitudes and perceptions regarding the learning experience, and the cognitive test combined multiple-choice (each worth 2 points) and essay questions (each worth 15 points before normalization) with a total possible score of 100. The weighting for the cognitive test was multiple-choice 50% (25 questions × 2 points = 50 points) and essay 50% (5 questions × 15 points normalized to 10 points each = 50 points), ensuring a balanced assessment of both recognition and constructed response abilities. For hypothesis testing, activity scores were directly compared between groups using the Independent Samples t-test, as this variable was only measured once at the end of the treatment; motivation analysis used both gain scores (posttest minus pretest) and N-Gain values for a standardized comparison accounting for the maximum possible improvement; and learning outcomes analysis focused on N-Gain values to control for initial differences between groups and provide a fair comparison of learning effectiveness.

Data were analyzed using descriptive and inferential statistics. Descriptive analysis calculated the mean, median, standard deviation, minimum and maximum values, and percentage distribution for each category. Inferential analysis included a normality test using Shapiro–Wilk, a homogeneity test using Levene's test, and hypothesis testing. The primary analysis employed the Independent Samples t-test to compare N-Gain values between the experimental and control groups, which appropriately tests the "effect" of the treatment while controlling for initial differences. The Paired Samples t-test was used supplementarily to analyze improvements within each group from pretest to posttest. All tests used a significant level of $\alpha = 0.05$. N-Gain was calculated using Hake's formula: N-Gain = (posttest score − pretest score) / (maximum score − pretest score), and categorized as high ($g \geq 0.70$), medium ($0.30 \leq g < 0.70$), or low ($g < 0.30$). Data analysis was performed using SPSS version 25. This approach aligns with established methodologies for measuring learning gains in pretest–posttest designs (Dimitrov & Rumrill, 2003).

Result and Discussion

The statistical analysis results showed that the peer tutoring method had a significant effect on student learning activity ($t = 2.510$, $df = 52$, $p = 0.015 < 0.05$). The experimental group's mean learning activity score (25.93 ± 2.29) was significantly higher than that of the control group (24.44 ± 2.04), with a mean difference of 1.49 points. The activity category distribution showed that 33.30% of the experimental group students were in the very active category, while only 11.10% were in the control group, with the remaining students in both groups being in the active category (Table 1).

Table 1. Distribution of learning activity categories

Category	Experimental Group	Percentage (%)	Control Group	Percentage (%)
Very Active (81-100%)	9	33.30	3	11.10
Active (61-80%)	18	66.70	24	88.90
Moderately Active (41-60%)	0	0.00	0	0.00
Less Active (21-40%)	0	0.00	0	0.00
Not Active (0-20%)	0	0.00	0	0.00
Total	27	100.00	27	100.00

These findings indicate that the peer tutoring method successfully increased student activity across all five activity dimensions. Visual activities improved as students paid more attention to peer tutor demonstrations regarding respiratory system models and gas exchange diagrams. Oral activities increased significantly with higher intensity in asking questions, discussing, and explaining concepts. Listening activities improved as students showed better attention when listening to peer tutor explanations using more aligned language. Writing activities became more active as students took notes, made summaries, and created process flow diagrams. Mental activities involved students in higher-order thinking such as analyzing differences between chest and abdominal breathing, evaluating the impacts of air pollution on respiratory health, and solving problems related to respiratory disorders.

These results align with Vygotsky (1978) social constructivism theory, which emphasizes that learning

is a social process where individuals build knowledge through interaction with their social environment. The Zone of Proximal Development (ZPD) concept was realized in this research when peer tutors with higher abilities helped tutees understand complex respiratory system concepts. According to Vygotsky, learning is most effective when students work within their ZPD with assistance from someone more competent, in this case, peer tutors (Suryani, 2023; Hidayat et al., 2023). The peer interaction in this study created scaffolding opportunities where tutors provided temporary support that gradually decreased as tutees developed independent mastery of respiratory system concepts, consistent with findings from Santrock (2018) regarding the importance of social interaction in cognitive development.

Figure 2. Students engaged in peer tutoring activity during respiratory system lesson

Learning Motivation

The analysis results showed that the peer tutoring method had a very significant effect on learning motivation ($p=0.000<0.05$). The experimental group's mean motivation score increased dramatically from 59.67 (pretest) to 84.33 (posttest), an increase of 24.67 points. In contrast, the control group only increased from 59.15 to 63.89, an increase of 4.74 points. The motivation increase difference between the two groups was 19.93 points (Table 2).

Table 2. Descriptive analysis of learning motivation

Statistics	Experimental Group		Control Group	
	Pretest	Posttest	Pretest	Posttest
N	27	27	27	27
Mean	59.67	84.33	59.15	63.89
Std. Deviation	2.774	3.43	4.78	2.64
Minimum	54	77	51	58
Maximum	64	93	72	69
Increase		24.67		4.74
N-Gain		0.61		0.12

The pretest scores of both groups (59.67 for the experimental group and 59.15 for the control group) demonstrate nearly identical initial motivation levels. This similarity is crucial as it confirms that improvements in the experimental group can be attributed solely to the peer tutoring method rather than pre-existing differences in student motivation. The dramatic increase in the experimental group (24.67 points), compared to the minimal increase in the control group (4.74 points), provides strong evidence of the effectiveness of peer tutoring in enhancing student motivation.

The motivation category distribution showed that 81.50% of the experimental group students reached the very strong motivation category, while all control group students (100%) remained in the strong category, with none reaching the very strong category. This shows that the peer tutoring method not only increases motivation quantitatively but also qualitatively transforms learning motivation characteristics and intensity.

The significant motivation increase can be explained through Keller (2010) ARCS model (Attention, Relevance, Confidence, Satisfaction) which became the theoretical framework for motivation measurement in this research. Peer tutoring successfully optimized all four ARCS components: first, Attention was enhanced by creating learning variation that attracted student attention more effectively through peer demonstrations and discussions, aligning with findings from Malik (2014) that varied instructional strategies increase engagement; second, relevance was strengthened by making the respiratory system material feel more relevant to student life through peer explanations using contextual examples; third, Confidence increased through two complementary mechanisms where tutees saw peers capable of mastering complex material and tutors felt valued and trusted in their teaching role, supporting self-efficacy development (Bandura, 1997) and fourth, Satisfaction was achieved as students obtained gratification from various learning aspects, both from finally understanding difficult concepts and from more relaxed yet productive learning atmosphere.

Figure 3. Peer tutors explaining respiratory system concepts to their group members

These findings are consistent with research by Rohim & Susanto (2012) and Hermawan (2018) which report that peer tutoring increases student motivation because they feel more responsible for their own learning and their peers' progress. Pratiwi et al. (2019) added that learning that integrates peer tutoring shows significant motivation increase in various aspects, including increased learning interest, persistence in following the learning process, and positive attitude development toward learning activities.

Learning Outcomes

The analysis results showed that the peer tutoring method had a very significant effect on learning outcomes ($p = 0.000 < 0.05$). The experimental group's mean learning outcomes increased from 67.00 (pretest) to 84.67 (posttest), an increase of 17.67 points with an N-Gain of 0.57 (medium category). Meanwhile, the control group only increased from 66.59 to 76.52, an increase of 9.93 points with an N-Gain of 0.29 (low category). The N-Gain difference of 0.28 shows that the effectiveness of peer tutoring learning was almost twice as high compared to the conventional method (Table 3).

The pretest scores of both groups (67.00 for the experimental group and 66.59 for the control group) demonstrate nearly identical initial abilities. This similarity is essential as it confirms that improvements in the experimental group resulted solely from the peer tutoring treatment rather than pre-existing differences in student capabilities. The substantially higher N-Gain in the experimental group (0.57, medium category) compared to the control group (0.29, low category) indicates that peer tutoring was almost twice as effective as conventional teaching in optimizing students' learning potential.

Table 3. Descriptive analysis of learning outcomes

Statistics	Experimental Group		Control Group	
	Pretest	Posttest	Pretest	Posttest
N	27	27	27	27
Mean	67.00	84.67	66.59	76.52
Std. Deviation	12.57	7.60	10.89	8.63
Minimum	43	74	46	60
Maximum	88	98	87	94
Increase		17.67		9.93
Mean N-Gain		0.57		0.29

The control group's low N-Gain (0.29) warrants explanation. Despite receiving instruction on the respiratory system material through conventional teaching methods, the passive nature of teacher-centered learning limited students' deep understanding of complex concepts. The respiratory system involves highly abstract processes like gas exchange at the molecular level, respiratory regulation by the nervous system, and the integration of multiple organ systems, which require active cognitive engagement and peer discussion for deep understanding. Conventional lecture-based teaching, where students primarily listen and take notes, was insufficient to facilitate the deep processing necessary for mastering these complex concepts, resulting in minimal improvement even though basic content was covered.

The mastery level category distribution showed that 25 experimental group students (92.60%) achieved the KKM (≥75), with 22.20% in the very high category and 70.40% in the high category, while only 2 students (7.40%) had not reached the KKM but were very close to the mastery limit with a score of 74. Conversely, in the control group there were still 33.30% of students (9 people) who did not reach the KKM, with only 3.70% in the very high category. These difficulties align with findings from Mardin et al. (2023) who identified common student learning challenges in complex biological concepts requiring abstract thinking. The fact that the experimental class mastery level (92.60%) was much higher compared to the control class (66.70%), with a difference of 25.90%, shows the superiority of the peer tutoring method in improving student learning achievement more evenly.

The N-Gain category distribution also showed very striking differences: 11.10% of experimental class students achieved a high N-Gain and 88.90% achieved a medium N-Gain, with no students in the low category. Conversely, in the control class, 70.40% of students only achieved a low N-Gain, 29.60% achieved a medium N-Gain, and no students achieved a high N-Gain.

The significant learning outcomes increase in the experimental class can be explained through several theoretical and pedagogical mechanisms. First, meaningful learning through peer interaction where students not only memorize respiratory organ structures but also built deep understanding through discussion, questions and answers, and explanations with peer tutors, consistent with constructivist learning theory (Slavin, 2018). Second, more effective language and communication where peer tutors can "translate" formal scientific language into everyday language that is easier to understand without reducing concept accuracy. Third, concept reinforcement through the teaching process (learning by teaching) where tutors demonstrate very deep understanding and high learning outcomes, as explaining to others requires higher-order cognitive processing (Fiorella & Mayer, 2013). Fourth, learning according to the revised Bloom's taxonomy where the experimental class students were superior at all cognitive levels from remembering to evaluating (Anderson & Krathwohl, 2001), indicating comprehensive cognitive development.

These findings are consistent with research by Sukrajh & Adefolalu (2021) which shows significant peer tutoring effects on learning improvement in several aspects: procedural skill improvement through direct practice, theoretical knowledge strengthening through the teaching and learning process, and higher effectiveness compared to conventional teaching methods.

Similarly, Duran & Topping (2017) in their meta-analysis found that peer tutoring consistently produces positive effects on academic achievement across diverse educational contexts and subject areas.

Positive Learning Cycle Model

A comprehensive analysis of the three research variables shows that the peer tutoring method effects on learning activity, learning motivation, and learning outcomes are not independent or separate, but interconnected in a synergistic positive cycle. The integrative model emerging from this research can be explained as follows: first, Learning Activity → Learning Motivation where increased student learning activity creates more engaging and meaningful learning experiences, which in turn increases students' intrinsic motivation; second, Learning Motivation → Learning Activity where conversely, increased motivation encourages students to be more active in learning; third, Learning Activity & Learning Motivation → Learning Outcomes, where the combination of high activity and strong motivation produces more effective learning, reflected in a significant learning outcomes increase; and fourth, Learning Outcomes → Motivation & Activity where the achievement of good learning outcomes provides positive reinforcement increasing motivation and encouraging higher learning activity.

This positive cycle explains why increases in all three variables in the experimental class are consistent, substantial, and mutually reinforcing. The peer tutoring method not only improves one learning aspect partially but also creates a holistic, synergistic, and sustainable learning ecosystem. This cyclical relationship aligns with the self-determination theory (Ryan & Deci, 2000) which emphasizes that the satisfaction of psychological needs for competence, autonomy, and relatedness leads to enhanced intrinsic motivation and engagement. This synergistic relationship demonstrates how each variable continuously strengthens the others in a sustainable learning ecosystem.

Conclusion

This research provides strong empirical evidence that the peer tutoring method significantly affects learning activity ($p = 0.015$), learning motivation ($p = 0.000$), and learning outcomes ($p = 0.000$) of grade XI students at SMAN 15 Gowa on the respiratory system material. The experimental group showed higher mean scores in all three variables: learning activity (25.93 vs 24.44), motivation with an N-Gain of 0.61 compared to the control group's 0.12 (medium vs low category), and learning outcomes with an N-Gain of 0.57 compared to the control group's 0.29 (medium vs low category). The mastery level achievement in the experimental class (92.60%) is much higher compared to the control class (66.70%). The three research variables are interconnected in a synergistic positive cycle where increased learning activity increases motivation, high motivation encourages higher activity, the combination of activity and motivation produces better learning outcomes, and the achievement of good learning outcomes subsequently increases motivation and activity. Overall, this research demonstrates that the peer tutoring method is a very effective learning alternative for improving biology learning quality at the senior high school level, particularly for complex and abstract materials like the respiratory system. Future research is recommended to conduct longitudinal studies observing the long-term impacts of the peer tutoring method; replicate this research in different contexts such as different schools, education levels, or biological materials; explore moderator factors affecting peer tutoring effectiveness, including teacher preparation, student characteristics, and organizational support; develop more systematic and structured tutor training models incorporating pedagogical content knowledge and communication skills; and compare peer tutoring effectiveness with other innovative learning methods such as problem-based learning or the flipped classroom to provide a comprehensive understanding of optimal collaborative learning approaches in biology education.

Acknowledgments

The authors would like to thank the principal, biology teachers, and grade XI students of SMAN 15 Gowa for their cooperation and support during this research.

Author Contributions

Conceptualization, methodology, formal analysis, investigation, resources, data curation, writing—original draft preparation, visualization, project administration, N.A.; validation, writing—review and editing, N.A., Y.H., R., F.D., and I.; supervision, Y.H. and R. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

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