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Collaborative Learning in Science Education: A Systematic Review on Enhancing 21st Century Skills and Overcoming Implementation Barriers

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ABSTRACT.
An abstract is a summary of the contents in a scientific article, starting with a brief background, then proceed with the research objectives, research models/approaches, methods of taking and number of samples, instruments and methods of data collection, and methods of data analysis. The abstract closes with research results, conclusions and inferentials/impacts. In summary, it is also recommended to write down recommendations for future research. The length of the abstract is a maximum of 250 words, there is no formula, there are no references/references and there are no pictures/tables, using the font Times New Roman with a font size of 10 without bold and italic. Abstract writing is recommended to combine several activities in one sentence. For example, the research used a quantitative approach, quasi-experimental methods and a two-group pretest-posttest design or other examples. Quantitative data collected through multiple choice tests were analyzed using the t-test formula. On the left side of this abstract are written keywords of about 4-7 words, which are the focus and important words in the research. The order or arrangement of the sub-activities in the abstract is the same as the sub-activities in the body or contents of the article.

INTRODUCTION

Science education in Indonesia is currently confronted with complex challenges in preparing the younger generation to remain competitive in the era of globalization and the Industrial Revolution 4.0. This situation necessitates a transformation in learning that goes beyond the mastery of conceptual knowledge to include the development of 21st-century competencies such as critical thinking, creativity, effective communication, and collaboration (Andayani & Agustina, 2025; Henukh et al., 2024; Islamiyati et al., 2023). However, empirical evidence shows that science learning in Indonesian schools is still dominated by teacher-centered approaches, limiting active student participation and inquiry-based practices. This has contributed to relatively low achievements in science competencies, as reflected in international assessments such as the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS), where Indonesian students' scores consistently fall below the global average (Harto et al., 2025; Nandang Mustafa, 2023; Trianung et al., 2024)

One of the primary problems in science learning in Indonesia is the lack of student engagement and insufficient development of collaborative skills, which are essential for both workplace readiness and social life (Karno et al., 2024; Suharyat et al., 2022) Students often struggle to understand abstract science concepts due to traditional, individualistic teaching methods that fail to promote meaningful peer interaction. Comparative studies demonstrate that classrooms implementing collaborative learning models tend to show more significant improvements in student achievement compared to those using conventional approaches (Biasutti, 2011; Tint & Nyunt, 2015; Vijayalakshmi & Kanchana, 2020)

Collaborative learning significantly enhances science education through various mechanisms and approaches. The urgency of adopting collaborative learning strategies in science education aligns with global perspectives, emphasizing that such approaches foster critical thinking, creativity, communication, and problem-solving (Shaik, 2025; Tint & Nyunt, 2015; Wicaksono, 2024). Collaborative learning encourages students to work in heterogeneous groups, promoting interaction, knowledge-sharing, and collective problem-solving through structured dialogue and teamwork (Shaik, 2025; Tint & Nyunt, 2015; Wicaksono, 2024). Beyond academic performance, collaborative learning also fosters motivation, responsibility, and a sense of community among students (Biasutti, 2011; Guajardo et al., 2025; Vijayalakshmi & Kanchana, 2020)

Despite these benefits, the implementation of collaborative learning in Indonesian science classrooms remains inconsistent. Many studies focus on its theoretical advantages but overlook contextual factors such as teacher readiness, classroom dynamics, curriculum alignment, and institutional support. This gap indicates the need for a systematic review of recent empirical studies to synthesize existing findings, identify the key enablers and barriers, and offer evidence-based recommendations for effective practice. Accordingly, this study aims to evaluate the effectiveness and challenges of collaborative learning in science education in Indonesia through a systematic review of recent literature. Based on these objectives, the study addresses the following research questions, how effective is collaborative learning in improving student outcomes in Indonesian science education? and what strategies and policy recommendations can strengthen the application of collaborative learning in line with 21st-century education demands?.

RESEARCH METHODS

Research Approach

This study uses a qualitative approach because it focuses on the analysis of the content and meaning of secondary data sourced from scientific articles. This approach was chosen to explore in depth a range of empirical findings related to the effectiveness of collaborative learning in science education. Qualitative is suitable for use in literature studies because it can describe trends, patterns, and themes that emerge from previous studies without involving direct statistical measurement.

Systematic Literature Review (SLR) with reference to the PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) protocol. This design consists of four main stages, namely identification, screening, feasibility assessment, and inclusion of articles. The application of this design allows the selection and analysis process of literature to be carried out in a systematic, transparent, and planned manner. By using the SLR design, the researcher can filter and organize information thoroughly, resulting in a synthesis of data that can be scientifically accounted for the research process refers to four systematic stages: identification for initial search, screening criteria, quality assessment (eligibility), and data extraction (included) for information collection (Das & Halder, 2024).

Research Instruments

The instruments used in this study consist of several tools that support the selection and analysis process of the literature. First, the PRISMA protocol is used as a procedural guideline in systematically selecting articles. Second, data extraction tables are used to document important information from each article, such as the author's name, year of publication, title, method, and key findings. Third, the VOSviewer software application is utilized to map and visualize the relationships between keywords from the reviewed articles. The use of this instrument allows the analysis to be carried out in a more in-depth and organized manner.

Data Collection

The implementation of the collection of journals/articles as material for the literature study of this research uses scopus. The number of articles obtained was then filtered using the PRISMA method with inclusion and exclusion criteria.literature that had been filtered then became the subject of in-depth study. The next stage is to use the VOS Viewer software application. Use this app to see the keyword relationships of all the collected articles. This literature selection process is a very important stage. A search for articles with the keywords: Collaborative Problem, Collaborative Learning, Science and Teacher.

Data Analysis

The data collected from the Systematic Literature Review (SLR) was then analyzed using the PRISMA method, The steps in this literature review are presented in Figure 1. The article screening process begins by examining the relevant literature for inclusion and exclusion criteria. These criteria are presented in Table 1. After determining these criteria, the article will be reviewed and selected for research.

Tabel 1. Inclusion and Exclusion Criteria

Criteria Inclusion
Literature review comes from journal articles/proceedings
The database used is sourced from scopus
Journals/articles published in 2015-2025
Main topic: collaborative learning, science education dan effectiveness
Criteria Exclusion
1. Literature review in the form of books, final courses, theses, papers and reports
2. The article is inaccessible and the abstract is incomplete
3. Research topics that are not with the topics covered
4. Journals/articles published before 2015

RESULTS AND DISCUSSION

Results of the Systematic Literature Review (SLR) Using Prisma

Based on the research method with guidelines using PRISMA, there are 188 articles from Scopus that are relevant to the keywords used. After going through the selection and screening process according to the inclusion and exclusion criteria, 6 articles were obtained for further review. The 6 journals will be analyzed based on the author's name, title, journal name, research method and research results, which will be presented in Table 2.

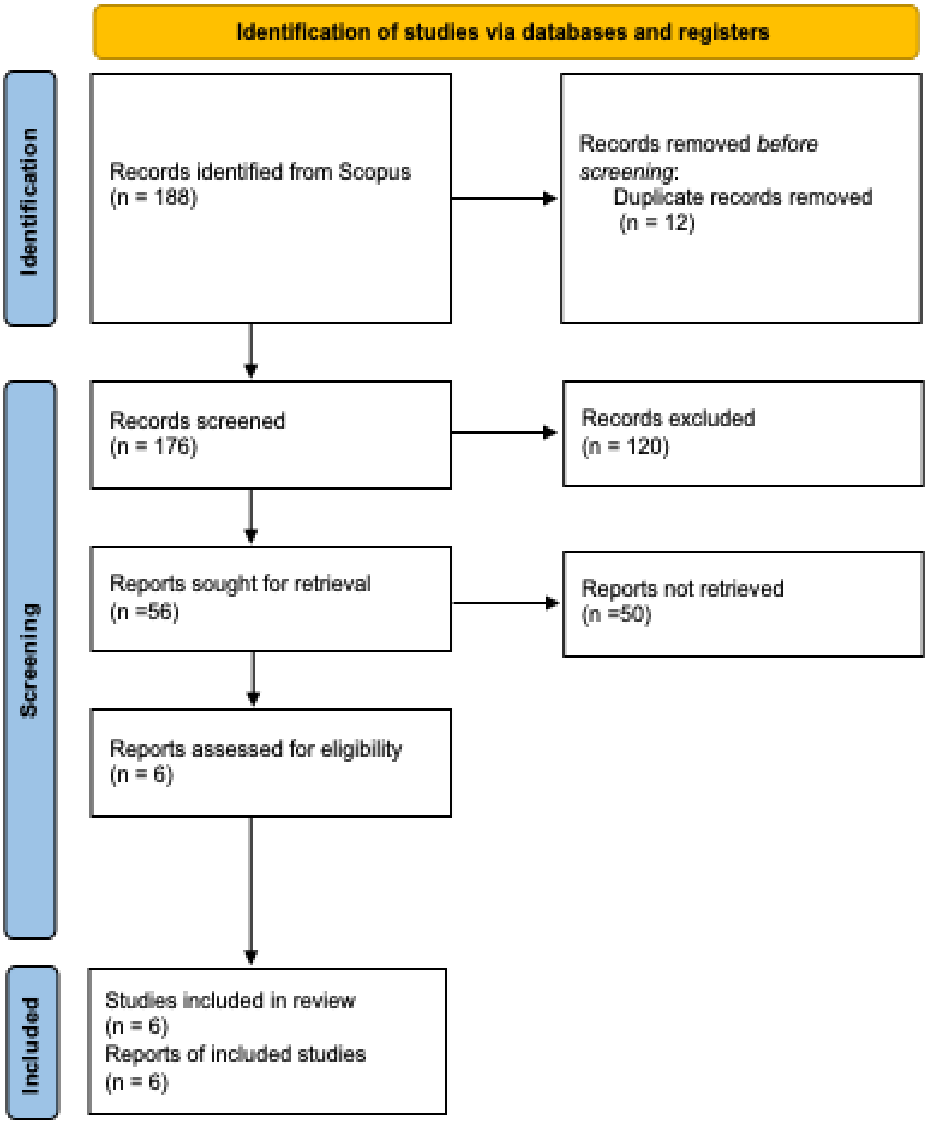

Figure 1. Literature Review Flow Diagram

A literature analysis conducted through SLR approach using the PRISMA method showed that out of the 188 articles found, only six met the inclusion criteria and merit further analysis. This entire article examines the effectiveness of collaborative learning in the context of science, both at the secondary school and tertiary levels. By integrating a variety of innovative approaches such as STEM, STEAM, and online learning, the collaborative model shows a real contribution to improving student learning outcomes.

Table 2. Analysis of Journal Articles

No	Author	Title	Journal	Method research	Result
1	(Chen et al., 2024a)	Exploring the behavioral and strategic factors	Journal Sage Open	This study used a mixed method with	CPS-based STEM learning directly

		that affect the learning performance of high school students in collaborative problem-solving-based STEM lessons		106 students as participants.	improves student learning performance.
2	(Ellianawati, Subali, Putra, Wahyuni, Dwijananti, Adhi, & Yusof, 2025a)	Understanding Critical Thinking and Creativity in Steam-Based Collaborative Learning	Journal of Education and Learning (EduLearn)	The method used in this study is a quasi-experimental one-group pretest-posttest design involving 36 students.	Collaborative learning has been shown to improve students' critical and creative thinking skills in renewable energy materials, while the STEAM approach effectively integrates local resources into Education.
3	(Le et al., 2018a)	Collaborative Learning Practices: Perceived Barriers by Teachers and Students to Effective Student Collaboration	Cambridge Journal of Education	This study uses a qualitative approach through interviews.	The results obtained are 4 main obstacles: lack of collaborative skills, free-riding, competency status, and the influence of friendship.
4	(Köpeczi-Bócz, 2020b)	Proactive learning and learning portfolio in higher education pedagogue	International Journal of Engineerig Pedagogy (iJEP)	This study uses a design-based research method through an experiment for 4 years.	The use of portfolios can increase student engagement, motivation, and reflective skills, as well as support competency development.
5	(E et al., 2021)	Collaborative Problem-Based Learning	International Journal of	This study uses a post-test-only quasi-	The results showed that collaborative problem-based

		Integrated with Online Learning	Emerging Technologies in Learning	experimental design with a quantitative approach.	learning (CPBL) integrated with online learning significantly improved collaborative and problem-solving skills compared to conventional online learning.
6	(Akhigbe & Adeyemi, 2020a)	The Use of Gender-Responsive Collaborative Learning Strategies to Improve Students' Achievement and Attitudes to Science Learning in Virtual and In-Person Laboratory Environments	Journal of Pedagogicl Research	This study used a quasi-experimental design of factorial with GR-CLS treatment in 218 students, analyzed using ANOVA to test the influence based on gender, school type and learning environment.	GR-CLS is effective in improving students' learning achievement and attitudes towards biology, without significant differences between genders, but more optimal in female students and homogeneous schools. A virtual lab is also as effective as a live lab.

Of the six main articles reviewed, the collaborative STEM-based learning reviewed by (Chen et al., 2024b) showed a direct improvement in student learning performance. This suggests that when students are exposed to a collaborative problem-solving context, they are more motivated to actively build knowledge. The increase is not only influenced by interaction between students, but also by learning strategies that emphasize collective decision-making. In parallel, the application of the STEAM approach in a collaborative context has also been shown to improve students' critical thinking skills and creativity, as explained by (Ellianawati, Subali, Putra, Wahyuni, Dwijananti, Adhi, & Yusof, 2025b) The integration of art elements into science learning encourages students to explore concepts in a more contextual way, while providing space for the emergence of original ideas in solving problems.

Although the results of the study show the positive impact of collaborative learning, its implementation is inseparable from a number of obstacles. Research by (Le et al., 2018a) identified the existence of significant obstacles such as students' low collaborative skills, dominance of certain individuals in the group, and differences in competency status. This suggests that collaboration in learning is not just about bringing students together in groups, but requires pedagogical strategies that effectively regulate the distribution of roles, responsibilities, and social dynamics. These barriers show the importance of teacher intervention in guiding, facilitating, and evaluating group interactions in a structured manner so that the collaboration that occurs is truly meaningful.

Another aspect that is also an important highlight is the role of technology in supporting collaborative learning. Research by (E et al., 2021) emphasizes that the application of Collaborative Problem-Based Learning (CPBL) integrated with online learning is able to significantly improve students' collaborative skills and problem-solving compared to conventional online approaches. These findings confirm that technology is not just an auxiliary medium, but an important element that can strengthen collaborative scenarios in the context of distance learning. This has become especially relevant in the post-pandemic era, where the education system is increasingly reliant on digital flexibility.

In addition to the technological aspect, the dimension of inclusivity is also a concern in the research studied. (Akhigbe & Adeyemi, 2020b) propose a gender-responsive collaborative learning strategy as an approach that can address inequality of participation. Their findings suggest that this approach not only improves students' academic achievement, but also reinforces positive attitudes towards science learning in a variety of learning environments, both virtual and in-person. This strategy has proven effective in accommodating the learning needs of female students, who have tended to be marginalized in science subjects.

Results of the Systematic Literature Review (SLR) by Vos Viewers

The results of connectivity (network) and density using vos viewers conducted using keywords from each article/journal used as source material for the literature review found that out of 188 articles and 6 articles used, only five keywords showed relevance to each other. The visualization is shown in figure 2 and figure 3.

Figure 2. Visualization of the Article Keyword Network used

The results of the analysis of connectivity (network) and keyword density, visualized using the VOSviewer software, reveal patterns of thematic interaction in the collection of articles/journals used as literature review materials. Out of a total of 188 articles and 6 articles analyzed, only five major keywords showed significant relevance to each other.

The network visualization (Figure 2) shows the existence of two main thematic clusters. The first cluster centers on the relationship between "learning" and "science", indicating that these two concepts are often discussed simultaneously or have a strong connection in the literature reviewed (van Eck & Waltman, 2010) The keyword "collaborative problem" also appears to have a connection to this cluster, implying that collaborative problem-solving may often be associated with the context of science learning. The second cluster, which is relatively separate, highlights the keyword "collaborative learning." Although "collaborative learning" identifies fragmentation in research or a lack of integration of these topics within the corpus analyzed, its connection to the "learning" and "science" clusters appears to be less strong, or even isolated in these network visualizations. This may indicate that while "collaborative learning" is a relevant topic, the focus may be on a slightly different domain or has not been extensively integrated with the discussion of "learning" and "science" in the corpus being analyzed. The limitation of only five keywords that indicate linkage indicates that there may be fragmented in the research or some concepts that are still stand-alone, which require further exploration to find a more comprehensive relationship (Cheung et al., 2020; Xia et al., 2017).

This visualization helps to clarify that the literature analyzed extensively discusses the effectiveness of collaborative learning in science, problem-based learning strategies, and the role of teachers in supporting their implementation. These results also support the finding that the implementation of collaborative learning still requires pedagogical support from teachers.

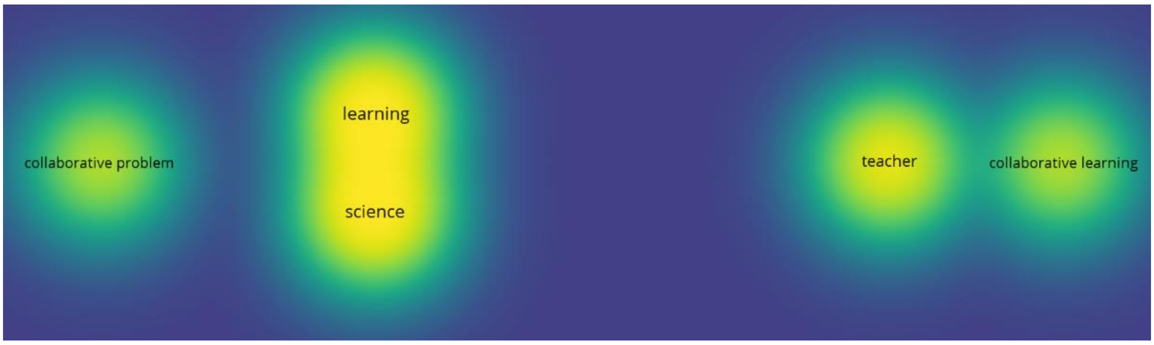

Figure 3. Visualization of the density of the article/journal keywords that Used

The visualization of keyword density in Figure 3 presents a thematic distribution in the corpus of journal articles analyzed. This visual analysis indicates the existence of three main clusters that reflect different research focuses. The first cluster, which is characterized by the highest intensity of yellow in the upper left, shows the dominance of the concept of "pedagogical knowledge." This indicates that this topic is a central theme with a very high frequency of keyword occurrences, demonstrating the maturity and depth of exploration in the literature (Müller & Mildenberger, 2021)

The second cluster, located in the upper center and also bright yellow, represents the keyword "learning." The high density of these clusters confirms that "learning" is a fundamental concept and is often discussed in the context of these articles, placing it as one of the main pillars of research.

In contrast, the third cluster, located on the upper right side, displays a more muted color gradient. This cluster is associated with the keyword "collaborative learning." Visual observations of the lower color intensity in this cluster indicate that, although relevant, the concept of "collaborative learning" has not received equal or intensive research attention compared to the previous two clusters. This relatively low density implies the potential for a significant research gap on the topic of collaborative learning, opening up opportunities for further exploration to enrich understanding and applications in related fields. This visualization comprehensively illustrates the thematic landscape of the journal article while also highlighting areas that require more in-depth scientific investigation.

Discussion

The findings of this study provide important insights into the effectiveness, challenges, and implications of collaborative learning models within science education. This discussion interprets the results in light of previous research and theoretical frameworks, and situates the outcomes within the broader discourse of 21st-century learning competencies.

Discussion of Effectiveness of Collaborative Learning

Collaborative learning (CL) is an educational approach where students work together to achieve common goals, solve problems, or create products. The effectiveness of this approach has been widely studied and generally shows positive outcomes across various educational contexts. The review confirms that collaborative learning approaches substantially enhance student learning outcomes, including academic achievement, critical thinking, creativity, and problem-solving. These results are consistent with prior studies demonstrating that collaborative environments foster deeper cognitive engagement and promote higher-order thinking skills (Hsieh et al., 2019; Rau & Wu, 2017). The integration of STEM and STEAM approaches within collaborative settings appears particularly beneficial. For example (Chen et al., 2024) found that collaborative problem-solving in STEM contexts directly improved student performance, while (Ellianawati et al., 2025) demonstrated that STEAM-based collaboration enhanced students' critical thinking and creativity by connecting scientific content with artistic and local cultural elements. These findings support the constructivist perspective, which emphasizes that knowledge is co-constructed through social interaction and contextual application.

Challenges and Barriers In Implementation

While collaborative learning offers significant educational benefits, its implementation is fraught with challenges that require careful consideration and strategic planning to overcome. Addressing these barriers through effective instructional design, technological support, and socio-cultural sensitivity is essential for successful CL integration. (Le et al., 2018) highlighted barriers such as low collaborative skills, free-riding, uneven participation, and the influence of friendship dynamics within groups. These findings indicate that collaborative learning does not automatically occur simply by grouping students together; rather, it requires intentional design, clear role allocation, and teacher facilitation to ensure equitable participation. This aligns with the work of (Slavin, 2014), who noted that poorly structured collaboration can exacerbate inequalities and reduce group effectiveness. Therefore, teacher training in group facilitation and conflict management is crucial to realizing the full potential of collaborative models.

Technology-Enhanced Collaborative Learning

Technology-Enhanced Collaborative Learning offers numerous benefits for enhancing student engagement and learning outcomes. By incorporating co-creation, effective grouping strategies, innovative digital tools, and careful pedagogical planning, educators can create dynamic and collaborative learning environments. (Hendarwati et al., 2021) showed that Collaborative Problem-Based Learning (CPBL) combined with online platforms significantly improved students' collaborative and problem-solving skills compared to traditional online methods. This finding echoes global post-pandemic trends emphasizing the role of digital tools in supporting flexible and interactive learning (Mgeladze & Kapanadze, 2025) The evidence suggests that technology should be positioned not merely as a delivery medium, but as an enabler of collaborative processes, allowing students to co-construct knowledge synchronously and asynchronously.

Inclusivity and Equity

Inclusivity and equity in education are essential for creating environments where all students have the opportunity to succeed, regardless of their backgrounds or abilities. The study by (Akhigbe & Adeyemi, 2020c) underscores the importance of inclusivity through gender-responsive collaborative strategies (GR-CLS). Their findings demonstrate that GR-CLS improved both achievement and attitudes toward science, particularly among female students, and were effective in both virtual and in-person laboratories. This is significant because girls have historically been underrepresented in STEM-related fields (Chai, 2020). Designing collaborative environments that are sensitive to gender dynamics and other aspects of diversity can help bridge participation gaps and foster equity in science education.

Role of Assessment and Reflection

Assessment and reflection are pivotal components in enhancing collaborative learning environments. They serve to improve both the learning process and outcomes by fostering deeper understanding, engagement, and accountability among learners. The work of (Köpeczi-Bócz, 2020) highlights that incorporating reflective tools such as learning portfolios can reinforce collaborative learning by enhancing motivation, engagement, and self-regulation. This aligns with (Gau, 2026; Khoo & Hsu, 2026), who emphasized the importance of self-regulated learning strategies for sustained academic success. The integration of authentic assessment tasks thus appears essential to deepen learning and to hold students accountable for their collaborative contributions.

Future Research Directions

The VOS viewer keyword density analysis revealed that while “learning” and “science” are dominant and well-connected research areas, “collaborative learning” appears relatively isolated, suggesting a research gap. This underlines the need for future studies to position collaborative learning as a central construct in science education research. Specifically, longitudinal studies are needed to examine long-term impacts on higher-order thinking, while experimental studies could explore how teacher professional development influences the quality of collaboration. There is also potential to investigate how emerging technologies such as artificial intelligence (AI) and adaptive learning systems could support personalized yet collaborative science learning environments.

The synthesis of literature confirms that collaborative learning is a potential approach to answer the demands of 21st century education. This model is not only effective in improving learning outcomes, but also strengthens students' critical thinking, cooperation, and creativity skills. However, its success relies heavily on student readiness, teacher facilitation skills, appropriate use of technology, and assignment design that encourages authentic interaction. Therefore, it is important for educators and researchers to continue to explore pedagogical innovations that support the implementation of collaborative learning in an adaptive, contextual, and inclusive manner.

CONCLUSION

This literature review concludes that collaborative learning significantly contributes to the improvement of science learning outcomes, particularly in enhancing students’ critical thinking, creativity, cooperation, and problem-solving skills. The effectiveness of this model is further strengthened when integrated with innovative pedagogical approaches such as STEM, STEAM, problem-based learning, and gender-responsive strategies.

Nevertheless, its implementation still faces several challenges, including students’ limited collaborative skills and insufficient active involvement of teachers as facilitators.

Therefore, effective pedagogical support is essential, including structured training in collaborative methods, the use of appropriate learning tools, and the implementation of contextual and inclusive teaching strategies.

Collaborative learning is not merely an instructional technique but a transformative pedagogical approach capable of equipping students with the essential skills for the 21st century. Its successful implementation requires pedagogical innovation, technological support, and a strong commitment to inclusivity. Strengthening these aspects can help position collaborative learning as a central strategy for advancing science education in Indonesia and beyond.

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