

# Collaborative Learning Approaches in Secondary School STEM Education: A Systematic Literature Review

Khaled Saufi Bin Raisin<sup>1</sup>, Nurazidawati Binti Mohd Arsad<sup>2</sup>

<sup>1</sup>Faculty of Education, Universiti Kebangsaan Malaysia, Malaysia, <sup>2</sup>Faculty of Education, Universiti Kebangsaan Malaysia, Malaysia

Corresponding Author Email: khaledsaufi@gmail.com

DOI Link: <http://dx.doi.org/10.6007/IJARPED/v15-i1/27603>

*Published Online:* 21 February 2026

## Abstract

STEM education plays a critical role in preparing students to become competitive, innovative, and future-ready citizens equipped with 21st-century skills. This study aims to conduct a Systematic Literature Review (SLR) on the use of collaborative learning approaches in secondary school STEM education. A total of 51 empirical studies were selected from an initial pool of 938 articles retrieved from major databases based on strict inclusion and exclusion criteria. Through a systematic analysis and synthesis of existing evidence, this review identifies the core characteristics, implementation strategies, and educational impacts of collaborative learning in STEM contexts. Findings indicate that such approaches enhance academic achievement, higher-order thinking skills (HOTS), communication, motivation, and teamwork among students. Based on these findings, a conceptual framework was developed to integrate the key features, strategies, and outcomes of collaborative learning for STEM education. This review provides valuable insights for educators, researchers, and policymakers seeking to strengthen collaborative pedagogical practices in STEM classrooms.

**Keywords:** Collaborative Learning, STEM Education, Secondary School, Higher-Order Thinking Skills (Hots), Student Motivation, Communication Skills

## Introduction

Science, Technology, Engineering, and Mathematics (STEM) education plays a vital role in developing human capital that is highly knowledgeable and technologically skilled. This educational approach not only nurtures scientific literacy and critical thinking but also promotes creativity, innovation, and problem-solving abilities among students. In Malaysia, efforts to strengthen STEM education have been initiated through the Malaysia Education Blueprint (2013–2025), followed by the National STEM Education Policy (2021), which establishes a systematic and integrated direction for STEM implementation across all levels of education.

STEM education remains one of the key priorities in 21st-century learning. Teaching approaches that focus on higher-order thinking skills, problem-solving, and collaboration are

essential in preparing students to face real-world challenges. Collaborative learning, as an active pedagogical approach, emphasises student interaction, idea sharing, and collective responsibility in achieving learning goals (Abu Kassim & Tasir, 2022).

### **Research Problem**

Although numerous initiatives have been introduced to promote the implementation of STEM learning approaches, teacher-centred instruction still dominates classroom practice. Students often remain passive recipients of information rather than active participants in the learning process. As a result, opportunities for students to develop collaboration and communication skills are limited.

There is an increasing need to systematically identify the effectiveness of collaborative learning approaches within the secondary STEM context. Despite the growing body of literature on collaborative learning in STEM education, existing systematic reviews often examine learning features, instructional strategies, and educational outcomes in isolation, resulting in a lack of an integrated conceptual synthesis that connects these elements, particularly at the secondary school level. Addressing this issue is crucial in ensuring that STEM education fulfils its goal of producing creative, innovative, and problem-solving learners.

### *Research Objectives*

The objectives of this study are as follows:

1. To identify the key characteristics of effective collaborative learning.
2. To determine the collaborative learning strategies utilised in STEM education.
3. To examine the impact of collaborative learning on students' academic achievement and overall development.
4. To develop a conceptual framework based on the synthesis of research findings.

### *Research Questions*

This study is guided by the following research questions:

1. What are the main characteristics of collaborative learning approaches in the context of secondary school STEM education based on previous studies?
2. What collaborative learning strategies have been identified in the implementation of STEM education at the secondary school level?
3. What is the impact of implementing collaborative learning approaches on students' learning outcomes in STEM education at the secondary school level?

### **Methodology**

This study employed a Systematic Literature Review (SLR) approach to identify, analyse, and synthesise previous research related to the implementation of collaborative learning approaches in STEM education. The review focused on three main aspects — the characteristics, implementation strategies, and impacts of collaborative learning on students' learning outcomes.

The SLR method enables researchers to develop a comprehensive understanding based on existing empirical evidence in a structured and transparent manner. This process involves the

systematic identification, selection, and critical evaluation of studies relevant to the research questions.

The review in this study was conducted in accordance with the ROSES (Reporting Standards for Systematic Evidence Syntheses) protocol, which ensures a rigorous and transparent process in reporting systematic reviews. The protocol involves five major steps: (1) review protocol development, (2) screening, (3) eligibility assessment, (4) quality appraisal, and (5) data extraction.

#### *Review Protocol – ROSES*

The ROSES protocol was adopted to ensure transparency, replicability, and reliability in the implementation of the systematic review. This protocol structures the review process into clearly defined and sequential phases, ensuring that all procedures are systematically reported (Shaffril et al., 2020).

ROSES provides explicit and comprehensive guidance for each phase of the review process, starting from the formulation of research questions to the analysis and synthesis of findings. Its structured format enhances the credibility and methodological consistency of the review, allowing other researchers to trace, validate, and replicate the process effectively.

#### *Screening Process*

The screening process was carried out through a systematic search of relevant articles from reputable academic databases, namely Scopus and Web of Science (WoS). These databases were selected because they provide access to peer-reviewed, high-impact publications that ensure the quality and credibility of sources included in the review. The combination of keywords and databases used in this systematic search is summarised in **Table 1** below.

Table 1

#### *Keywords and Databases Used in the Screening Process*

<b>Keywords</b>	<b>Database</b>
("collaborative learning") AND ("STEM" OR "science" OR "chemistry" OR "physics" OR "biology") AND ("secondary school" OR "high school" OR "middle school")	Scopus
("collaborative learning") AND ("STEM" OR "science" OR "chemistry" OR "physics" OR "biology") AND ("secondary school" OR "high school" OR "middle school")	Web of Science (WoS)

A consistent search string was applied across both Scopus and Web of Science (WoS) to ensure comparability of results. Boolean operators and quotation marks were used to refine the search and retrieve studies that explicitly focus on collaborative learning within the context of STEM education at the secondary school level.

#### *Eligibility Criteria*

The inclusion and exclusion criteria were carefully defined to ensure that only relevant and high-quality studies were selected for analysis. Table 2 presents the specific criteria applied in this review.

Table 2

*Inclusion and Exclusion Criteria*

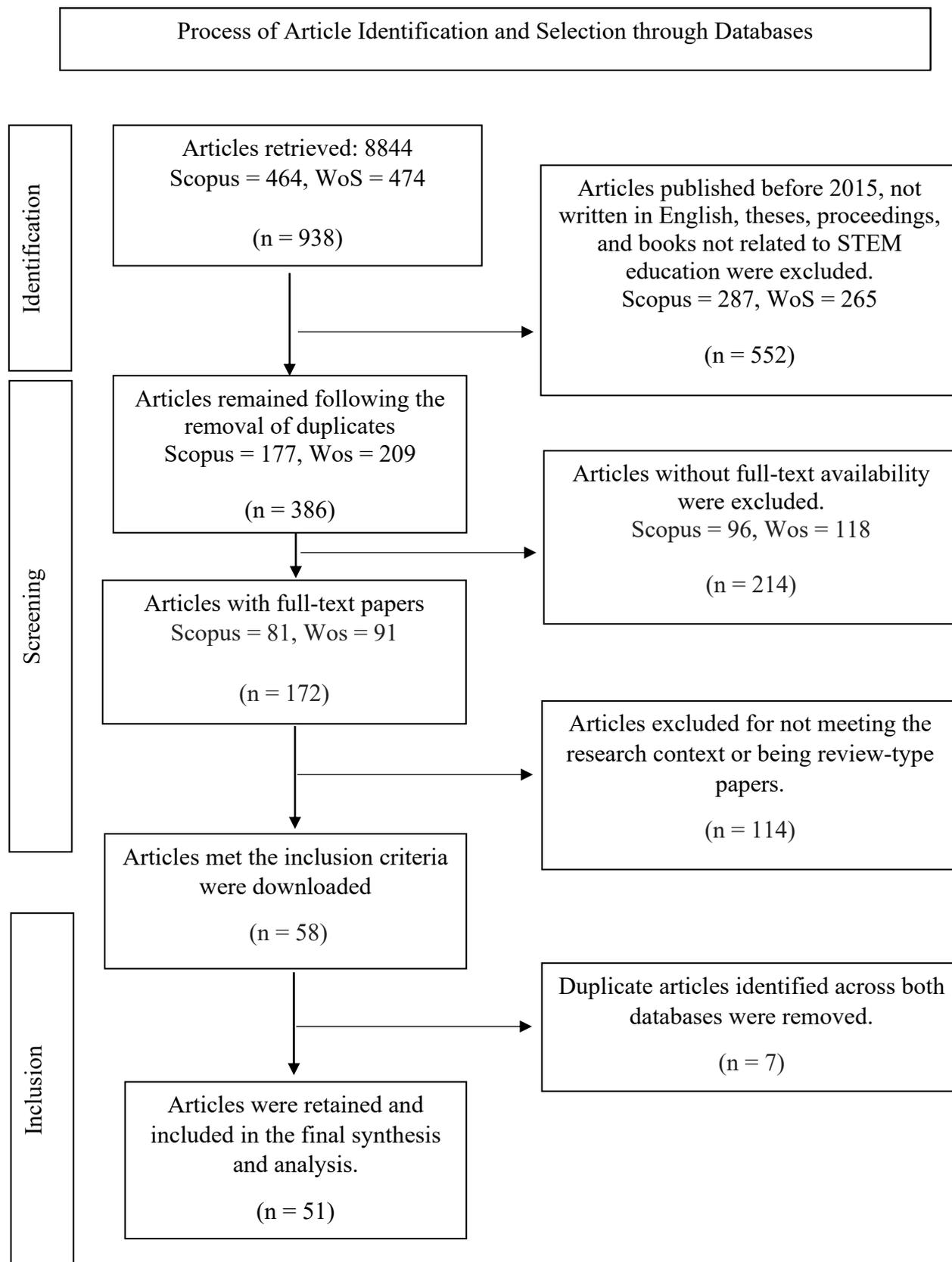
<b>Criteria</b>	<b>Inclusion</b>	<b>Exclusion</b>
<b>Year of Publication</b>	Articles published between 2015 and 2025	Articles published before 2015
<b>Type of Source</b>	Peer-reviewed journal articles	Theses, proceedings, conference papers, and books
<b>Language</b>	English	Non-English publications
<b>Type of Study</b>	Empirical research (qualitative, quantitative, or mixed methods)	Systematic literature reviews (SLR) or conceptual papers

*Quality Appraisal*

The primary purpose of the quality appraisal was to ensure that each selected study demonstrated methodological transparency and reliable findings (Shaffril et al., 2020). Each article was evaluated based on several key aspects:

1. Clarity of research objectives and questions
2. Appropriateness of research design in addressing the objectives
3. Transparency in data collection and analytical procedures
4. Accuracy and consistency of data interpretation
5. Conclusions supported by empirical evidence

The appraisal process involved a thorough examination of the title, abstract, keywords, and research focus of each identified article to determine its alignment with the aims of this review. Only studies meeting the minimum quality standards were included in the synthesis phase.



### *Data Extraction*

The data extraction process was conducted systematically using a specially designed extraction form developed for this study. The primary purpose of this process was to collect key information in a consistent and structured manner, enabling a more organised thematic analysis of the selected studies.

Information extracted from each article included the authors' names, year of publication, key findings, and thematic focus related to issues of STEM education in schools. The extraction process was conducted meticulously and underwent cross-checking among reviewers to ensure the accuracy and validity of the information obtained.

The extracted data were then subjected to thematic analysis to identify major themes and recurring subthemes that emerged from the reviewed studies. This thematic synthesis provided a comprehensive understanding of how collaborative learning approaches are implemented within the context of STEM education at the secondary school level.

### *Background of Selected Articles*

All articles selected for this review were empirical studies published between 2015 and 2025. These studies encompassed various research designs, including qualitative, quantitative, and mixed-method approaches, reflecting methodological diversity in exploring collaborative learning within STEM education.

The studies were conducted across multiple countries, including developed nations such as the United States and the United Kingdom, providing a broad and comparative perspective on the implementation of STEM education in schools. This international representation enhanced the generalisability of findings and offered valuable insights into best practices in collaborative learning.

All selected studies focused specifically on secondary school education, with particular emphasis on the implementation of collaborative learning approaches. The studies examined three key dimensions:

1. The characteristics of collaborative learning;
2. The implementation strategies used in classroom settings; and
3. The impact of collaborative learning on students' engagement, understanding, and skill development.

A majority of the studies provided detailed explanations covering all three dimensions, allowing for a comprehensive synthesis of evidence on how collaborative learning contributes to effective STEM instruction at the secondary level.

### *Characteristics of the Collaborative Learning Approach*

The implementation of collaborative learning within STEM education involves various features that are adapted to the classroom context, students' levels, and intended learning outcomes. Based on the literature analysis, four major characteristics were identified as the core of the collaborative learning approach in secondary education:

- a) discussion and interaction in small groups,
- b) joint problem-solving,

- c) shared responsibility, and
- d) the teacher's role as a facilitator.

### **Discussion and Interaction in Small Groups**

Small-group discussions provide opportunities for students to exchange ideas, express opinions, ask questions, and respond in an open and comfortable environment (Laakso et al., 2018; Sun et al., 2017). This strategy supports the constructivist pedagogical paradigm, which builds understanding through social interaction (Laws et al., 2015). Studies by de Araujo et al. (2024) and Alp and Bulunuz (2023) revealed that students are better able to analyse and synthesise information when given opportunities for in-depth group discussions. Moreover, collaborative learning emphasises peer interaction as a vital source of information, guidance, and formative assessment (Malazoaia, 2023; Cuesta, 2017). Techniques such as peer tutoring, peer feedback, and peer discussion help foster an inclusive learning environment while strengthening individual accountability towards collective success (Reychav & MacHaney, 2017; Mallick & Singh, 2016). According to Gaad (2022) and Zhan et al. (2024), students tend to be more motivated when trusted to share knowledge with their peers, thereby increasing their confidence and engagement in the learning process.

#### *Joint Problem-Solving*

In the context of secondary school STEM education, collaborative learning enables students to actively interact and work together to complete tasks or solve problems (Zhan et al., 2024). This finding is further supported by Koretsky et al. (2021) and Andrew-Todd et al. (2023), who argue that collaborative learning not only enhances conceptual understanding but also develops authentic problem-solving skills. Several studies (e.g., Adjei et al., 2022; Gaad, 2022) demonstrated that students involved in collaborative activities requiring them to plan, negotiate, and implement shared solutions exhibited improvements in achievement and self-confidence when dealing with complex topics. Cognitive and metacognitive engagement were also widely emphasised in related studies (Järvenoja et al., 2025; Malmberg et al., 2021).

Typically, students collaborate in heterogeneous groups to encourage inclusivity and the sharing of diverse perspectives (Tatiana et al., 2022). Joint problem-solving goes beyond mere task distribution — it involves deep discussion, critical thinking, and justification of arguments that help build collective understanding among learners (Abubakar & Arshad, 2015). Additionally, collaborative problem-solving activates both metacognitive and social regulation processes among students (Malmberg et al., 2021; Vuorenmaa et al., 2023). Learners not only contribute individual ideas but also monitor and support one another's cognitive processes while solving problems (Sukmawati et al., 2019). This integrative process combines cognitive, emotional, and social dimensions, transforming problem-solving activities into a holistic developmental experience (Olaniyan & Govender, 2018).

Furthermore, Petersen et al. (2023), in a study involving virtual reality learning environments, highlighted how digital collaboration fosters higher learning outcomes when problem-solving tasks are carried out jointly. Overall, collaborative problem-solving emerged as a dominant feature that reinforces the effectiveness of collaborative learning in STEM education (Mallick & Singh, 2016).

### *Shared Responsibility*

One of the dominant characteristics of collaborative learning is the existence of shared responsibility among students for the success of their group (Zabalotna et al., 2025; de Jesus & Silveira, 2022; Koretsky et al., 2021). This feature involves the active participation of every group member in contributing ideas, monitoring progress, and ensuring that learning objectives are achieved collectively (Mallick & Singh, 2016). According to Tee et al. (2019), students are not only responsible for their individual tasks but also for the overall performance of their peers, leading to enhanced interaction, social competence, and motivation. This finding is supported by McDougall and Philips (2024) and Alp and Bulunuz (2023), who found that collaborative strategies encourage students to take ownership of both their own and their peers' learning through meaningful and reflective small-group interactions.

Furthermore, shared responsibility reinforces the effectiveness of teamwork when students recognise that the success of the group depends on each member's cooperation. Malmberg et al. (2021) emphasised that structured small-group learning promotes active collaboration and effective problem-solving. This characteristic creates a socially supportive and interactive learning environment in which knowledge sharing and mutual assistance become the foundation of improved academic performance (Malazonia et al., 2023; Patandean & Baharuddin, 2018; Lee et al., 2018). Thus, the presence of shared responsibility in collaborative learning not only contributes to cognitive achievement but also fosters a sense of collective learning identity among students in the context of secondary school STEM education (Cuesta, 2017; Olaniyan & Govender, 2018).

### *The Teacher as Facilitator*

In collaborative learning environments, the teacher acts as a facilitator who guides the learning process without dominating it (Sukmawati et al., 2020). This role emphasises providing support, encouraging learner autonomy, and ensuring that group interactions are purposeful and meaningful (Agwu & Nmadu, 2023). According to Peterson et al. (2023), when teachers serve as facilitators, students are more likely to explore ideas, ask questions, and construct their own understanding — promoting active, reflective, and student-centred learning (Abubakar & Arshad, 2015). Sukmawati (2020, 2019) highlighted that teachers often provide incentives as motivational tools, enhancing student focus during collaborative sessions. This demonstrates that teachers play a key role in designing motivational strategies without compromising learner autonomy (Olaniyan & Govender, 2018; Ke & Carafano, 2016). Ting et al. (2018) further noted that teachers create structured learning environments that embed critical thinking, communication, and teamwork skills throughout classroom activities.

The teacher's role in designing socially engaging activities is crucial to ensure the effectiveness of collaborative learning (Tatiana et al., 2022). Mallick and Singh (2016) found that teachers facilitate the formation of structured small groups and guide students to maintain consistent and effective interaction throughout the learning process. Continuous assessment also reinforces the teacher's function as a facilitator, ensuring that all students remain actively engaged (Zabalotna et al., 2016). Similarly, Cohn et al. (2025) reported that teachers help students generate higher-order thinking (HOTS) ideas and build confidence in answering complex questions. Such outcomes are achieved when teachers provide strategic scaffolding and opportunities for learners to expand their critical thinking in an open and supportive

environment (de Jesus & Silveira, 2022). Sukmawati et al. (2020) further affirmed that teachers play an essential role in nurturing values of cooperation, interaction, and knowledge sharing among students, leading to more meaningful and sustainable collaborative learning experiences.

### **Collaborative Learning Implementation Strategies**

#### *Problem-Based Collaborative Learning (PBCL)*

Problem-Based Collaborative Learning (PBCL) has been identified as one of the most consistent and effective strategies for enhancing STEM learning at the secondary school level (Sukmawati et al., 2020; Sukmawati, 2019; Cuesta, 2017). This strategy emphasises active student engagement in solving real-world problems collaboratively, thereby directly strengthening critical thinking and problem-solving skills (Olaniyan & Govender, 2018). According to Adjei et al. (2022), the use of problem-based collaborative approaches in teaching redox reactions significantly improved students' achievement through experiment-driven problem-solving activities and peer discussions. Similarly, Sukmawati et al. (2019) demonstrated that the application of PBCL in biology enabled students to construct knowledge collectively through field projects and group presentations. This approach not only enhanced conceptual understanding but also cultivated social skills and shared group responsibility.

In another study, Petersen et al. (2023), supported by Abubakar and Arshad (2015), found that implementing generative collaborative learning activities in a virtual reality environment strengthened knowledge construction through the interactive exploration of challenging problems. Effective PBCL implementation requires well-structured task design. For instance, Patandean and Baharuddin (2017) reported that using reciprocal teaching techniques in physics classes allowed students to solve problems more effectively when they were assigned specific roles within their groups. This finding aligns with Ke and Carafano (2016), who demonstrated that employing flight simulation scenarios as problem contexts in physics lessons significantly improved both collaboration and conceptual comprehension. As noted by Sprowls (2020), the PBCL strategy encourages students to apply STEM knowledge contextually while engaging in communication, negotiation, and joint problem-solving. This approach supports the development of 21st-century competencies through the integration of cognitive, social, and metacognitive dimensions within the learning experience (Ahola et al., 2024; de Jesus & Silveira, 2022).

#### *Project-Based Learning (PBL)*

Project-Based Learning (PBL) is one of the most dominant collaborative learning strategies in STEM education, where students actively work together to complete projects based on real-world problems within a defined period of time (Malazonia et al., 2023). Through PBL, students not only develop conceptual understanding but also enhance their communication, teamwork, and time-management skills (Sprowls, 2020). The study by Sukmawati et al. (2020) found that the implementation of PBL in biology topics related to fungi led to significant improvements in concept mastery, research abilities, and presentation skills. Students demonstrated deeper engagement when they were given autonomy to plan, implement, and present their projects collaboratively.

The problem-based nature of PBL allows students to explore real-world issues collaboratively and construct solutions through interdisciplinary inquiry (Ellianawati et al., 2025). Within the STEM context, this approach not only encourages critical thinking and problem-solving but also enhances students' engagement with complex scientific topics. Järvenoja et al. (2025) and Haataja et al. (2022) reported that students participating in problem-oriented learning tasks displayed high levels of creativity and an increased ability to make meaningful conceptual connections. In the context of STEM collaboration, a well-structured PBL approach helps students integrate cross-disciplinary knowledge with real-life applications (Järvenoja et al., 2025). Sukmawati et al. (2019) also emphasised that social skills and teamwork effectiveness improved when PBL tasks were designed collaboratively. This finding aligns with Ellianawati et al. (2025), whose study on a STEAM project related to renewable energy demonstrated that students not only worked together to solve problems but also developed critical thinking and creativity through model building and solution design.

Furthermore, Petersen et al. (2023) showed that integrating PBL into virtual learning environments through generative activities strengthens both self-directed and collaborative learning. Students engaged with content through simulation-based project design, thereby fostering technological competence and deep cognitive engagement (Du & Dewitt, 2024; Wongta et al., 2021; Le et al., 2018; Ting et al., 2018). Similarly, Cohn et al. (2025) demonstrated the effectiveness of PBL in STEM+C (Computing) environments, where collaboration among students, teachers, and AI-based systems effectively supported the resolution of complex challenges. PBL also enhances group accountability by assigning specific roles to students and granting them autonomy to steer the direction of their projects (Gaad, 2022). Throughout the project duration, students are guided to plan, review, and evaluate their work continuously, promoting reflective learning and collective decision-making skills (Haataja et al., 2022; de Jesus & Silveira, 2022).

### **Online Collaborative Learning (OCL)**

The advancement of educational technology has transformed the landscape of collaborative learning, giving rise to Online Collaborative Learning (OCL) as a significant pedagogical approach within STEM education. According to Laakso et al. (2018), OCL refers to an online, activity-based learning process involving communication, information sharing, and collective problem-solving through digital platforms. In secondary school contexts, OCL provides a flexible and connected learning environment that promotes continuous interaction among students regardless of time and physical constraints (Sun et al., 2017; Cuesta, 2017).

Studies by Gaad (2022) and Zabalotna et al. (2025) revealed that OCL significantly enhances academic performance and student engagement, particularly when tasks are collaboratively designed and delivered through user-friendly virtual environments. In such settings, students actively engage in online discussions, peer assessment, and group reflection, which strengthen conceptual understanding and foster proactive learning attitudes (Alp & Bulunuz, 2023; Wongta et al., 2021). Du and DeWitt (2023) examined the use of collaborative augmented reality systems in chemistry education, demonstrating that the integration of OCL with immersive technologies increases student motivation and engagement in complex topics. Similarly, Webb et al. (2022) found that haptic and virtual reality technologies within collaborative activities enhance student interaction and allow for the simulation of scientific experiments that are otherwise difficult to conduct in traditional classrooms.

OCL has also been shown to support the development of metacognitive skills and self-regulation. Järvelä et al. (2023) found that students collaborating online via platforms supporting emotional and motivational regulation exhibited higher performance and reflective engagement. Moreover, Li et al. (2024) highlighted that multimodal interaction in OCL enables students to better manage their learning processes when guided by real-time behavioural and emotional data analytics. A key element of OCL effectiveness lies in the design of meaningful tasks and virtual facilitation support. de Araujo et al. (2024) introduced an analytics-based collaborative conversational agent to facilitate productive dialogue during online inquiry sessions. Likewise, Cohn et al. (2025) proposed an integrated OCL model that combines the roles of teachers, researchers, and AI-driven systems to optimise collaboration in STEM+C environments. de Jesus and Silveira (2022) further demonstrated that online collaborative programming effectively enhances students' computational thinking and teamwork skills.

The benefits of OCL are also evident in hybrid STEM instruction. Ke and Carafano (2016) employed online flight simulations to support collaborative science learning, allowing students to conduct virtual experiments as groups and construct understanding through realistic interactions. Ting et al. (2018) utilised mobile video conferencing as a tool for real-time scientific collaboration, stimulating discussion and reflection on optical science topics. However, the effectiveness of OCL is highly dependent on interaction quality, technological infrastructure, and students' digital competence. Studies by Le et al. (2018) and Loes (2022) emphasised the importance of teacher guidance and well-structured online learning design to prevent role imbalance or digital social isolation during collaboration. Overall, OCL has emerged as a flexible and highly promising approach in STEM collaborative learning, provided that pedagogical and technological supports are strategically integrated. Its application not only broadens access to learning resources but also cultivates digitally competent collaborators equipped for the demands of the 21st century.

### *Jigsaw Learning Method*

The Jigsaw Learning Method is a collaborative learning strategy that organises students into small groups, where each member is responsible for mastering a specific portion of the learning material (Le et al., 2018). Each student becomes an "expert" in their assigned section before returning to their home group to share their understanding and collectively complete a group task. In a study by Zhan et al. (2024), a jigsaw-integrated task-driven learning (jigsawTDL) approach was implemented in a secondary school programming course. Students were divided into expert groups to explore a particular aspect of the topic in depth before returning to their original groups to teach their peers and collaboratively complete programming assignments.

This approach was found to enhance student motivation, computational thinking skills, and teamwork capacity, compared with control groups that used conventional collaborative learning structures without the jigsaw framework (Patandean & Baharuddin, 2018; Vuorenmaa et al., 2023). Furthermore, students in jigsaw groups demonstrated better performance in less complex programming tasks and provided positive feedback regarding the collaborative structure (Zhan et al., 2024). Although not explicitly referring to the jigsaw method, Le et al. (2018) supported its underlying principles of positive interdependence, individual accountability, and shared group responsibility. Similarly, Abubakar and Arshad

(2015), supported by Olaniyan and Govender (2018), reported collaborative practices such as group discussions and joint presentations that implicitly align with jigsaw principles. Overall, these findings reinforce the pedagogical value of the jigsaw approach in strengthening STEM learning through a structure that promotes active engagement, deep understanding, and clearly defined role distribution among secondary school students (Malmberg et al., 2021; Niyigena et al., 2021).

#### *Reciprocal Teaching Technique in Collaborative Learning*

The reciprocal teaching technique in collaborative learning refers to an instructional strategy that emphasises two-way interaction among students through explanation, questioning, and cognitive support (de Araujo et al., 2024; Haataja et al., 2022). In this approach, students not only act as recipients of knowledge but also serve as facilitators for their peers, which has been found to effectively enhance conceptual understanding and higher-order thinking skills (Ahola et al., 2024; Alp & Bulunuz, 2023). In a study by Patandean and Baharuddin (2017), the reciprocal learning technique was implemented in a secondary school physics classroom, focusing on shared problem-solving strategies among peers. The results indicated that this approach not only increased student participation but also strengthened their ability to explain concepts in their own words, leading to deeper understanding.

According to Sukmawati et al. (2020), the use of reciprocal learning in biology project-based activities had a positive impact on students' social development. Students were more comfortable exchanging ideas and collaboratively verifying understanding within their groups, thereby enhancing their ability to reflect on their own and others' learning. Similarly, Ke and Carafano (2016) found that applying reciprocal teaching in flight simulation environments improved student motivation and conceptual comprehension in science through bidirectional communication. Students actively provided feedback to one another, resulting in increased self-awareness and mastery of key scientific ideas (Agwu & Nmadu, 2023; Peterson et al., 2023).

Moreover, Adjei et al. (2022) demonstrated that reciprocal, collaborative strategies in chemistry experiments, particularly in redox reactions, enabled students not only to understand theoretical concepts but also to connect them to practical applications. The learning experience became more meaningful as students were required to re-explain findings and justifications to their group members (Li et al., 2018; Laws et al., 2015). Overall, the reciprocal teaching technique within collaborative learning supports the development of communication competence, reflective thinking, and deeper conceptual understanding in STEM content (Vuorenmaa et al., 2023; Koretsky et al., 2021). It also allows students to build learning agency and strengthen group dynamics through alternating roles as "teachers" and "learners" (Malmberg et al., 2021).

#### *Impact of the Collaborative Learning Approach*

The implementation of collaborative learning approaches within the context of STEM education has demonstrated comprehensive impacts on students' cognitive, affective, and social development. A review of the literature reveals that these effects extend beyond conceptual understanding, encompassing the enhancement of Higher-Order Thinking Skills (HOTS), student engagement, self-confidence, motivation, teamwork, and leadership values, all of which are essential competencies for 21st-century learning.

*Enhancement of Conceptual Understanding*

Collaborative learning has been consistently shown to have a significant impact on students' conceptual understanding in secondary school STEM education. Through social interaction, group discussion, and collective problem-solving activities, students develop a deeper grasp of the concepts being taught (Agwu & Nmadu, 2023; Sukmawati et al., 2020). The process of explaining ideas and constructing arguments collaboratively helps reinforce students' cognitive structures and makes abstract concepts more concrete and meaningful (Mallick & Singh, 2016; Adjei et al., 2022). Several studies have reported that the use of collaborative strategies, such as Project-Based Learning (PBL) and Problem-Based Collaborative Learning (PBCL), accelerates students' mastery of science and mathematics concepts by encouraging exploration and joint knowledge construction (Sukmawati et al., 2019; Gaad, 2022). Wongta et al. (2021) further demonstrated that a STEM-based collaborative orientation contributes to improved conceptual and creative understanding through structured exploration activities. Similarly, the Jigsaw learning approach (Zhan et al., 2024) enables students to study specific topics in depth before sharing their expertise with peers, thereby reinforcing both individual and collective understanding. This exchange of knowledge fosters not only conceptual clarity but also interdependence and accountability, creating a more holistic learning experience within STEM classrooms.

*Enhancement of Higher-Order Thinking Skills (HOTS)*

Collaborative learning has been proven to be an effective strategy for stimulating and strengthening Higher-Order Thinking Skills (HOTS) among secondary school students in STEM education, particularly at the levels of analysis, evaluation, and creation (Alp & Bulunuz, 2023; Malmberg et al., 2021; Gaad, 2022; Zhan et al., 2024; Sukmawati et al., 2019, 2020). HOTS encompasses a range of cognitive abilities, including critical reasoning, creative thinking, complex problem-solving, and the capacity to make informed decisions based on evidence analysis and open dialogue (Ellianawati et al., 2025; Wongta et al., 2021).

Findings from Gaad (2022) indicate that in online collaborative learning environments, students tend to adopt active cognitive roles, particularly when given opportunities to voice opinions and evaluate peers' arguments. This is further supported by Cohn et al. (2025), Zabalotna et al. (2025), Webb et al. (2022), Ting et al. (2018), Laws et al. (2018), and Sun et al. (2017), who emphasised that structured group interactions not only accelerate conceptual understanding but also enhance students' ability to evaluate information critically and creatively. In addition, instructional strategies such as the Jigsaw method (Zhan et al., 2024) and Reciprocal Teaching (Patandean & Baharuddin, 2017) have demonstrated significant impacts on HOTS development. Within the Jigsaw framework, students must understand and teach specific subtopics to their peers, thereby fostering analytical depth and the synthesis of complex information. This is further supported by Alp and Bulunuz (2023) and de Jesus and Silveira (2022), who found substantial improvement in students' ability to construct evidence-based scientific arguments through digital collaborative learning.

In the context of Project-Based Learning (PBL), Ellianawati et al. (2025) showed that students were able to build creativity and problem-solving efficiency in addressing real-world issues related to renewable energy, when given the opportunity to explore and resolve challenges collaboratively. Similarly, Sukmawati et al. (2020) and Peterson et al. (2023) found that students demonstrated the ability to synthesise biological information critically, showing

competence in transferring knowledge to novel situations. Overall, collaborative learning serves as a robust pedagogical approach that cultivates students' higher-order thinking, reflective reasoning, and creative problem-solving—skills that are fundamental to success in STEM learning and innovation-driven education systems.

#### *Enhancement of Student Engagement*

Collaborative learning approaches have consistently been shown to enhance students' engagement in STEM learning, promoting active participation across emotional, social, and metacognitive dimensions (Vuorenmaa et al., 2024; Abubakar & Arshad, 2015; Zabolotna et al., 2025). Numerous studies have highlighted that students' active engagement is strengthened when they are directly involved in group discussions, idea sharing, and collective problem-solving activities. For instance, de Araujo et al. (2024) reported that pair and group work fostered meaningful interactions that supported students' emotional and cognitive engagement, while Sara Ahola et al. (2024) emphasised the importance of structured tasks and self-regulation in sustaining active participation during collaborative learning activities.

Project-oriented and task-based learning approaches have also been found to maintain students' focus and interest, as teamwork within small groups encourages effective communication and inclusive participation (Sukmawati et al., 2020; Alp & Bulunuz, 2023). Such engagement is closely associated with increased motivation and a stronger sense of ownership over learning, as reported by Gaad (2022) and Mallick & Singh (2016).

Furthermore, technology-enhanced collaborative environments, such as intelligent collaborative systems (Cohn et al., 2025) and virtual learning platforms (Kuanbayeva et al., 2024), have demonstrated significant potential in fostering deeper and more interactive engagement among students. These digital tools not only facilitate communication and reflection but also create immersive contexts that sustain cognitive and emotional involvement in STEM learning processes. Overall, collaborative learning provides a dynamic framework that cultivates active, sustained, and meaningful student engagement, which is essential for fostering inquiry-driven, reflective, and participatory learning in contemporary STEM education.

#### *Enhancement of Confidence and Motivation*

Collaborative learning approaches have been shown to exert a significant positive influence on students' self-confidence and motivation within STEM education contexts (Agwu & Nmadu, 2023; Patandean & Baharuddin, 2018). A synthesis of the reviewed literature reveals that students who engage actively in group discussions, idea sharing, and collective problem-solving demonstrate higher levels of self-efficacy, a stronger willingness to express opinions, and greater sustained interest in learning activities (Loes, 2022; Gaad, 2022). Studies by Gaad (2022), Laakso et al. (2018), and Sun et al. (2017) examining online collaborative learning environments indicate that group-based participation enhances students' affective engagement, thereby fostering confidence in reflective dialogue and classroom discussions. Similarly, Loes (2022) and Cuesta (2017) found that collaborative learning improves academic motivation, as students feel socially supported by peers and experience incremental achievements through ongoing group interactions.

Furthermore, Zhan et al. (2024) reported that the implementation of the jigsaw-integrated task-driven learning model in secondary-level programming courses not only improved academic performance but also boosted intrinsic motivation among learners. This finding aligns with Ting et al. (2018), who demonstrated that the use of mobile video conferencing in collaborative science lessons increased students' confidence when they assumed active roles in discussions. The emphasis on individual accountability within group structures has also been identified as a key contributor to students' confidence development (Järvenoja et al., 2025). When learners are assigned explicit roles and responsibilities within well-defined teams, they perceive their contributions as meaningful, resulting in stronger motivation and ownership over group achievements (Alp & Bulunuz, 2023; Tatiana et al., 2022; Loes, 2022). Overall, the literature supports that collaborative learning cultivates an empowering environment in which students gain confidence through interdependence, build mutual trust, and are intrinsically motivated to pursue shared academic goals within STEM learning contexts.

### *Teamwork Skills*

Teamwork is a foundational element of effective collaborative learning, particularly in STEM education, where group-based inquiry and problem-solving are central to the learning process. Empirical studies consistently demonstrate that collaborative approaches strengthen students' ability to work cooperatively, contribute meaningfully, and respect diverse perspectives within group dynamics (Peterson et al., 2023). According to Ellianawati et al. (2025), the implementation of mini-projects within STEAM environments supports contextual learning while enhancing students' communication and collaborative competencies. Similarly, Haataja et al. (2022) and Vuorenmaa et al. (2024) emphasised that incorporating socially shared regulation and co-regulation in collaborative learning encourages students to negotiate shared understanding, build cohesion, and pursue collective learning goals effectively.

Studies by Järvenoja et al. (2025) and Li et al. (2018) revealed that structured peer-support strategies — such as assigning interdependent tasks and rotating leadership roles — help reinforce shared responsibility within groups. This dynamic promotes accountability, trust, and cohesion among learners. In Järvelä et al. (2023), STEM-based group interactions were found to develop essential group dynamics such as empathy, conflict management, and evidence-based negotiation, all of which are integral to cooperative problem-solving. Additionally, Zabolotna et al. (2023) and Vuorenmaa et al. (2023) demonstrated that collaborative learning environments facilitate equitable task distribution and enhance students' decision-making and joint problem-solving abilities. Likewise, Le et al. (2018) reported that when teachers provided scaffolding during collaborative tasks, students displayed stronger peer interaction, clearer role comprehension, and improved coordination of group responsibilities. Collectively, these findings affirm that collaborative learning not only deepens academic knowledge and disciplinary understanding, but also nurtures interpersonal and teamwork skills — crucial attributes for students to thrive in STEM disciplines and future professional contexts.

### **Discussion and Recommendations**

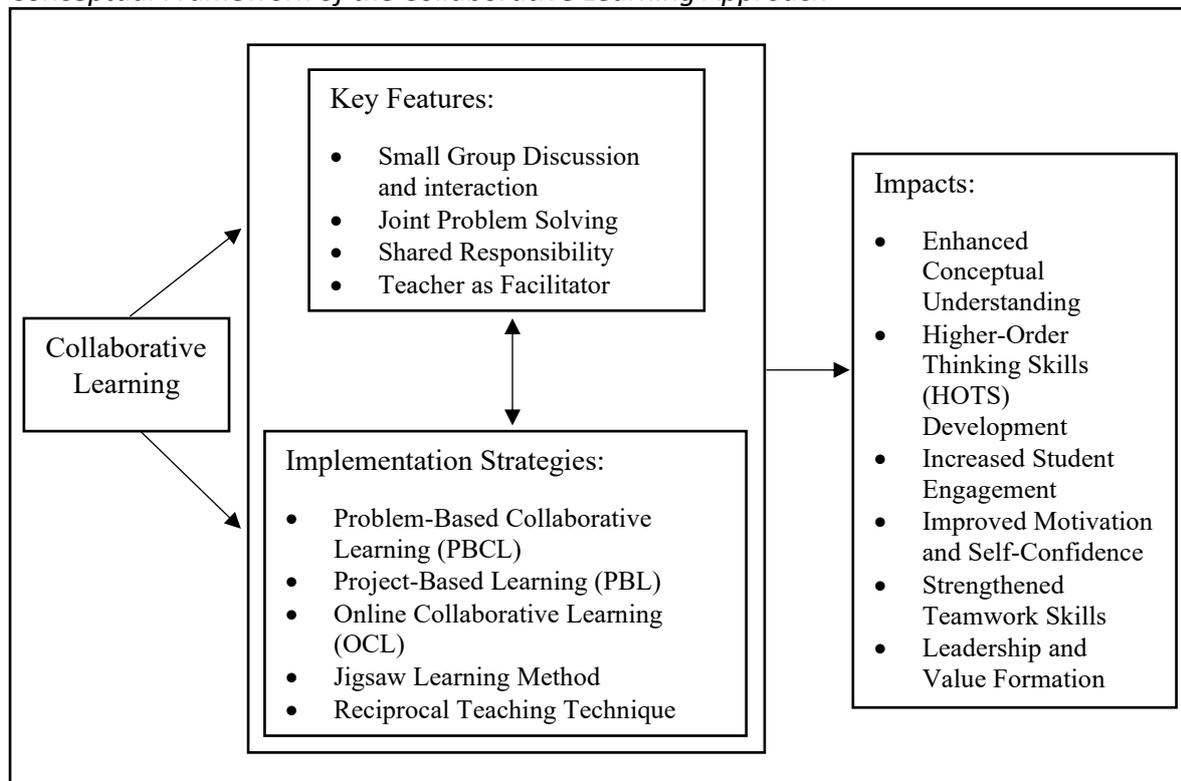
Collaborative learning approaches have increasingly been recognised as an essential pedagogical foundation within secondary STEM education, given their effectiveness in

cultivating students who can think critically, collaborate actively, and apply knowledge to real-world contexts (Sukmawati et al., 2019; Gaad, 2022). This study identified that key features — such as small-group discussions, joint problem-solving, shared responsibility, and the teacher’s role as facilitator — are crucial determinants of successful implementation (Zabolotna et al., 2025; Abubakar & Arshad, 2015; Alp & Bulunuz, 2023). Overall, instructional strategies such as Problem-Based Collaborative Learning (PBCL), Project-Based Learning (PBL), Online Collaborative Learning (OCL), Jigsaw, and Reciprocal Teaching Techniques have demonstrated positive impacts across the cognitive, social, and affective domains, including enhanced higher-order thinking skills (HOTS), motivation, self-confidence, and leadership values (Ellianawati et al., 2025; Malmberg et al., 2021; Vuorenmaa et al., 2023). Nevertheless, the implementation of collaborative learning in STEM education continues to face significant challenges. Key issues identified include student dependency on peers (commonly referred to as “free-riders”), time constraints in planning and conducting collaborative tasks, and the lack of adequate digital infrastructure to fully support online collaborative learning environments (Loes, 2022; Le et al., 2018; Peterson et al., 2023). Moreover, not all teachers receive sufficient training or professional support to effectively function as facilitators within collaborative classrooms (Ting et al., 2018; de Jesus & Silveira, 2022). Hence, greater emphasis should be placed on structured task design, active teacher facilitation, and comprehensive assessment mechanisms to strengthen the adoption of collaborative learning at both policy and classroom practice levels.

In this regard, it is recommended that schools and educational policymakers prioritise the development of teachers’ capacity in collaborative pedagogy through continuous professional learning and the establishment of professional learning communities (PLCs). The STEM curriculum design should allow space for student-centred collaborative strategies that emphasise exploration, creation, and collective reflection (Ke & Carafano, 2016; Cohn et al., 2025). In addition, technological infrastructure, including digital devices, interactive learning platforms, and stable internet access, is critical in supporting inclusive and effective OCL implementation (Du & DeWitt, 2024; Sun et al., 2017). Future research is encouraged to explore the longitudinal impact of collaborative learning approaches to understand their sustained effects on STEM students’ performance and character development. Scholars are also advised to conduct meta-analyses comparing digital and face-to-face collaborative environments, as well as investigate the influence of teacher training on the overall effectiveness of collaborative teaching practices.

**Conceptual Framework of the Collaborative Learning Approach**

Table 1

*Conceptual Framework of the Collaborative Learning Approach*

Overall, this systematic literature review affirms that the collaborative learning approach plays a pivotal role in strengthening the effectiveness of STEM education at the secondary school level. Through various implementation strategies such as Problem-Based Collaborative Learning (PBCL), Project-Based Learning (PBL), Online Collaborative Learning (OCL), the Jigsaw method, and Reciprocal Teaching techniques, students not only gain a deeper conceptual understanding but also demonstrate notable improvement in higher-order thinking skills (HOTS), active engagement, self-confidence, motivation, teamwork, and leadership values. The findings also highlight that the success of collaborative learning is largely determined by four key features: small group interaction, joint problem-solving, shared responsibility, and continuous teacher support as a learning facilitator.

Nevertheless, the effectiveness of collaborative learning does not occur automatically without careful planning and systematic support. Therefore, the implementation of collaborative strategies must be supported by a flexible curriculum design, continuous professional training for teachers, and a conducive learning infrastructure—including technological support to effectively implement online collaborative learning. This study recommends that educational stakeholders adopt a holistic and integrated approach to expand the use of collaborative pedagogy, ensuring comprehensive student development across the cognitive, social, and affective domains. Such integration aligns with the aspirations of 21st-century education and the Malaysia Education Blueprint (2013–2025). Furthermore, this review opens new avenues for future research to explore in greater depth the long-term effectiveness and equity of implementation of collaborative learning in STEM education contexts.

**Conclusion**

This systematic literature review synthesised empirical evidence on collaborative learning approaches in secondary school STEM education by analysing 51 selected studies published between 2015 and 2025. The findings indicate that collaborative learning consistently enhances students' academic achievement, conceptual understanding, higher-order thinking skills (HOTS), engagement, motivation, self-confidence, and teamwork competencies. Key features such as small-group interaction, joint problem-solving, shared responsibility, and the teacher's role as a facilitator were identified as fundamental elements that determine the effectiveness of collaborative learning implementation. In addition, instructional strategies including Problem-Based Collaborative Learning (PBCL), Project-Based Learning (PBL), Online Collaborative Learning (OCL), the Jigsaw method, and Reciprocal Teaching were found to provide meaningful learning experiences that support holistic student development. From a theoretical perspective, this study contributes to the existing body of knowledge by integrating fragmented findings from previous research into a comprehensive and systematic conceptual framework. The proposed framework establishes clear relationships between the core features, implementation strategies, and learning outcomes of collaborative learning in STEM education. By synthesising cognitive, social, and affective dimensions of learning, this study extends current theoretical understandings of collaborative pedagogy and provides a structured foundation for future empirical and experimental investigations in secondary STEM contexts.

Contextually, this review offers valuable insights for educators, school leaders, and policymakers, particularly within the context of secondary education systems such as Malaysia. The findings provide evidence-based guidance for designing collaborative instructional practices that align with national educational aspirations and 21st-century learning goals. The proposed framework may serve as a practical reference for teachers in planning, implementing, and evaluating collaborative STEM lessons, as well as for curriculum developers in embedding student-centred and inquiry-oriented approaches into STEM programmes. Furthermore, this study highlights the importance of continuous professional development and adequate technological infrastructure in supporting sustainable collaborative learning practices. Overall, this study underscores the pivotal role of collaborative learning in strengthening the quality and effectiveness of secondary school STEM education. By offering an integrated theoretical model and contextually relevant pedagogical implications, this review contributes to the advancement of collaborative learning research and practice. Future studies are encouraged to validate the proposed framework through longitudinal and intervention-based research, as well as to explore its applicability across diverse educational settings and learner populations.

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