



## Discovering the Relationship Between Science Students' Critical Thinking and Collaborative Problem Solving in Higher Education Theoretical, Empirical, and Determining Factors

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### Abstract

This study investigates the robust positive correlation between critical thinking (CT) and collaborative problem-solving (CPS) in science education. Employing a convergent parallel mixed methods design, the study involved a sample of 231 undergraduate students from Islamic higher education. Linear regression analysis demonstrated that CT accounted for 74.20% of the variance in CPS. The study underwent three complementary analytical phases. In the theoretical phase, prior literature was reviewed to contextualize CT and CPS. In the empirical phase, quantitative data were analyzed using regression, confirming the strong association between CT and CPS in the context of science education. In the factor-identification phase, qualitative coding revealed enabling and constraining factors. Enablers included AI tools (e.g., ChatGPT), conducive environments, hands-on practice, and targeted training, while barriers included personal biases, time constraints, and team conflicts. This research contributes by employing a convergent mixed-methods design in the Islamic higher education science context, integrating regression with qualitative factor analysis. These findings provide actionable guidance for designing integrated pedagogical strategies that promote both CT and CPS.

**Keywords:** Critical Thinking; Collaborative Problem Solving; Science Learning; Higher Education

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## INTRODUCTION

Critical thinking and collaborative problem-solving (CPS) abilities have become increasingly important in Indonesia's rapidly evolving information era, particularly in the context of science education. Science education is not merely about transferring knowledge but also about equipping students with the skills necessary to face real-world challenges. Critical thinking enables student to analyze information, evaluate arguments, and make reasonable decisions (Carmona, 2023). Meanwhile, CPS teaches student to collaborate, sharing ideas, and finding innovative solution (OECD, 2018). Critical thinking is one of the key competencies and characteristics emphasized in Indonesia's educational objectives and 21st-century learning frameworks. It is regarded as an essential skill for individuals to explore knowledge deeply, which can then be collaboratively applied within groups to solve problems in science education. (Nurdiana et al., 2023). Critical thinking skills and collaborative problem-solving abilities have become two essential competencies, particularly in the context of higher education (Bandura, 1999). Higher education institutions have a critical responsibility to prepare their students not only with religious knowledge and life skills but also with deep analytical thinking and relevant abilities to address contemporary challenges. Students are expected to develop critical thinking and collaborative problem-solving skills to effectively

navigate the increasing complexity of modern issues and adapt to the rapid advancements in science and technology (Haroky et al., 2019).

The lecturers noted that many students face barriers such as a lack of confidence or insufficient interpersonal skills required for effective collaboration. Additionally, factors such as the learning environment, access to resources, and task structure can significantly impact students' ability to develop these essential skills. The inability of many students to apply critical thinking while collaborating in groups is reflected in their low performance on project-based tasks in science education, where collaboration and critical analysis are crucial (van Zundert et al., 2010). These interview findings are further supported by research indicating that integrating critical thinking skills into collaborative contexts presents several challenges.

One of the primary difficulties lies in balancing individual critical reflection with group dynamics during collaboration (Orhan, 2022). The necessity to work cohesively in many team settings can sometimes diminish the space required for individuals to deeply reflect on their ideas before presenting them to the group. This dynamic may lead to premature consensus or "groupthink," where the team prioritizes agreement over thoroughly exploring diverse perspectives from all members. (Nisa et al., 2023). Another significant challenge is ensuring equal contribution from all team members. In collaborative problem-solving, some participants may dominate discussions, while others may hesitate to voice their critical insights (Fleckney et al., 2025). This imbalance can hinder the emergence of diverse critical thinking within the group, as valuable perspectives from more passive members may be overlooked. Furthermore, the integration of technology into collaboration, such as in computer-supported collaborative learning (CSCL), presents both opportunities and challenges (Stahl et al., 2022). While technology can enhance critical thinking by facilitating more structured dialogue and analysis, it can also introduce distractions or reduce the personalization of interactions, thereby diminishing the depth of critical engagement. (Tedla & Chen, 2024b).

Critical thinking is a systematic mental process used to solve problems, pose questions, and identify appropriate solutions by leveraging skills in evaluating available information (Motukeeva et al., 2024). A critical thinker examines issues from multiple perspectives, assesses situations based on reasoning and scientific evidence, and engages in active thought by organizing ideas to logically explore and analyze through higher-order reasoning activities (Khusna et al., 2024). Critical thinking in the context of science education enables students to evaluate information objectively, make evidence-based decisions, and explore various alternative solutions. Research indicates that students with strong critical thinking skills are generally better equipped to tackle complex problems in science learning, including making decisions grounded in empirical data (Karunarathne & Calma, 2024). These skills also assist students in assessing the validity of scientific arguments and establishing a strong logical foundation in group discussions, which is a crucial factor in Collaborative Problem Solving (CPS). The CPS model is an educational model aimed at fostering collective creative thinking used by groups to solve problems (Fathonah et al., 2024). CPS requires students to work together in identifying problems, sharing responsibilities, and integrating ideas to achieve effective solutions. Each group member in Collaborative Problem Solving (CPS) is expected to contribute through a critical understanding of the issues at hand and to provide creative ideas supported by scientific evidence (Rodriguez-Salvador & Castillo-Valdez, 2023). This indicates that Collaborative Problem Solving (CPS) requires not only collaboration skills but also critical thinking, as each group member must be able to evaluate and filter ideas that emerge during the problem-solving process. However, despite the recognition of critical thinking and CPS as essential skills in science education, the relationship between these two competencies still warrants further exploration.

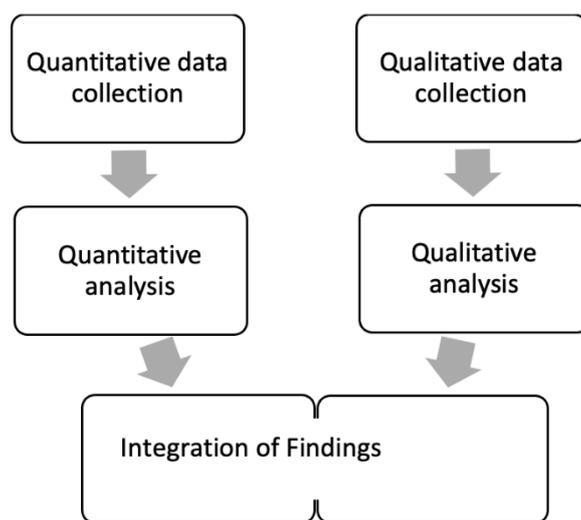
In the educational context, the ability to collaborate in problem-solving not only enhances students' skills but also prepares them to become constructive and contributive individuals within society (Apdoludin & Martinisyamin, 2022). In-depth empirical research on the relationship

between critical thinking and Collaborative Problem Solving (CPS) will provide better insights into how students utilize these skills in the context of science education. This understanding will also assist educators in designing more effective learning strategies to develop both skills simultaneously (Campos & Scherer, 2024). Given this rationale, it is crucial to investigate the relationship between critical thinking and collaborative problem-solving skills in science education. This study aims to explore the connection between critical thinking and collaborative problem-solving while identifying the factors that determine success in both areas. Consequently, the findings are expected to offer valuable insights for educators in developing more effective teaching strategies to train and enhance students' critical thinking and collaborative problem-solving skills.

To address the research gap, this study employs a convergent parallel mixed-methods design to empirically examine the association between cognitive transfer (CT) and cognitive processing speed (CPS) within the context of Islamic higher education science programs. By integrating regression analysis with qualitative factor analysis, this study fills the void in existing research. Key Contributions: (1) Identification of Contextual Enablers and Barriers: The study elucidates the factors that facilitate or hinder CT and CPS in science learning, (2) Demonstration of Linkage between CT and CPS: The findings provide evidence of the relationship between CT and CPS in the science learning domain. The study was conducted at a single institution, utilizing cross-sectional survey data and self-report instruments. Consequently, the findings should be interpreted as associations rather than causal effects, and their generalizability to broader contexts remains uncertain.

## METHOD

The research method employed in this study is a mixed methods approach, utilizing a Convergent Parallel Design as one of the primary frameworks within this methodology. This design allows the researcher to collect quantitative and qualitative data simultaneously (in parallel), analyze them separately, and then compare the results to gain a more comprehensive understanding (Creswell, 2012).



**Figure 1.** Convergent Parallel Workflow

### Participant, Sample, or Subject

The quantitative data collection for this study was conducted through a survey, utilizing a questionnaire that included both closed and open-ended statements and questions. Closed statements were designed for quantitative data, while open-ended questions were employed for qualitative data collection. The population for this research comprised all higher education science students, totaling 545 students. The sample for this study was selected using random

sampling techniques, with the sample size determined using Slovin's formula and a margin of error of 0.05. The calculation for the sample size is presented in

$$n = \frac{N}{1+Ne^2} \text{ (Creswell \& Plano, 2018). (Eq.1)}$$

$$n = \frac{N}{1 + Ne^2} = \frac{545}{1 + 545 \times 0,05^2} = \frac{545}{2,3625} = 230,69 = 231 \text{ students}$$

Equation 1 illustrates the minimum sample size utilized in this study, which comprises 231 higher education students. The data analysis techniques employed in this research consist of three main stages: theoretical-based examination, empirical-based examination, and factor determination (Ojo, 2015). Instruments A questionnaire was developed with two subscales: Critical Thinking (CT): 12 items adapted from validated CT indicators (analysis, evaluation, inference, reasoning). Collaborative Problem-Solving (CPS): 10 items measuring communication, teamwork, perspective-taking, negotiation. Responses used a 5-point Likert scale. Content validity was checked by 3 experts (CVI > 0.80). Exploratory factor analysis confirmed construct validity. Reliability coefficients: CT ( $\alpha = 0.88$ ), CPS ( $\alpha = 0.85$ ). Procedures Quantitative surveys and qualitative open-ended responses were collected simultaneously. Data were anonymized.

## Instrument and Procedure

### *Theoretical Based Examining*

Theoretical-based examining is the stage of data analysis that involves a literature review, starting with the collection of relevant literature, organization of the literature, critical evaluation, synthesis of findings, and the integration of results with interpretations into the final report (Creswell, 2012). This approach aims to provide a holistic perspective on the topic under investigation.

### *Empirical Based Examining*

Empirical-based examining is the stage of analyzing quantitative data obtained from the survey. The data analysis techniques employed in this study include simple linear regression and the determination coefficient test.

#### *Simple Linear Regression Test*

The simple linear regression test is a statistical method used to understand the relationship between two quantitative variables: one independent variable (predictor) and one dependent variable (response). Simple linear regression aims to identify the best-fit line that describes the linear relationship between these two variables. In this study, this test was conducted to examine the relationship between critical thinking skills and collaborative problem-solving skills. Mathematically, the simple linear regression model can be expressed in the form of Equation 2.

$$Y = \beta_0 + \beta_1 X + \varepsilon \quad \text{(Eq. 2)}$$

Notation:

Y: CPS

X: CT

Assumptions (linearity, normality of residuals, homoskedasticity) were tested. Effect sizes ( $R^2$ ,  $r$ ) were reported.

#### *Coefficient of Determination test*

The test of coefficient of determination ( $R^2$ ) is a step to evaluate the extent to which a regression model can explain the variation in the dependent variable influenced by the independent variable (X). Technically, coefficient of determination represents the proportion

of variation in the dependent variable (Y) that can be accounted for by the independent variable (X).

### ***Determining Factors***

The process of determining factors is a critical step in analyzing the qualitative data for each competency derived from interview results, presented in the form of percentages. At the determining factors stage, an interactive method is employed, consisting of four components of data analysis: (1) data reduction, (2) data collection, (3) data display, and (4) drawing conclusions. Qualitative: Open responses were coded thematically, including enablers, barriers, and contextual factors. Credibility was enhanced with representative quotes. (Miles et al., 2014).

#### *Data reduction*

This stage represents the initial phase of data analysis, involving the data reduction through selection, focusing, simplification, and refinement of the collected information. The data can be presented qualitatively by summarizing or describing it in the researcher's own words, among other methods. Based on the reduced data, the researcher can determine the next steps, such as gathering additional data, presenting the findings directly, or moving forward to draw conclusions.

#### *Data collection*

This stage involves the activities conducted when the reduced data is incomplete or when the conclusions drawn are insufficient or misaligned with the research objectives, necessitating additional data collection. The techniques employed for data collection include interviews and documentation from sources relevant to the research focus. The collected data can either be directly presented or go through a reduction process before being displayed.

#### *Data display*

The data presentation stage follows data reduction or data collection. This stage aims to facilitate a clearer understanding of the research problems and to guide subsequent steps. In this study, data presentation is carried out by outlining the research findings in alignment with the formulated research questions, using clear and comprehensible language.

#### *Conclusions*

The conclusion-drawing stage is undertaken once the data has been reduced and presented, making it the final step in the process. This stage involves deriving conclusions based on the evidence or answers obtained from the research, a process referred to as conclusion drawing.

## **RESULTS AND DISCUSSION**

### **Theoretical Based Examining**

Recent studies highlight a strong relationship between critical thinking (CT) skills and collaborative problem-solving (CPS) skills, particularly in educational settings (Xu et al., 2023). Critical thinking involves the ability to objectively evaluate, analyze, and synthesize information, which is essential for addressing complex problems. Critical thinking expects students to draw accurate conclusions and provide causal explanations in various ways (De Klerk et al., 2025). Meanwhile, collaborative problem-solving requires individuals to work together, leveraging collective skills to effectively tackle challenges. Research in recent years has demonstrated how the development of these two skills is mutually reinforcing (Ramirez & Monterola, 2022). For instance, critical thinking enables individuals to engage more effectively in discussions, contributing higher-quality solutions during collaboration (Zaqiah et al., 2024). On the other hand, collaboration often challenges individuals to think more critically by exposing them to diverse perspectives and ideas (Ramdhani et al., 2023).

The relationship between critical thinking (CT) skills and collaborative problem-solving (CPS) skills is illustrated by the integration of generative artificial intelligence tools, such as ChatGPT, Canva, and Google Docs, within higher education contexts. Critical thinking involves the ability to objectively analyze and evaluate information, a crucial skill when students collaborate within a team (Ruiz-Rojas et al., 2024). Through critical thinking, individuals can contribute stronger ideas, construct logical arguments, and address problems from multiple perspectives. Collaborative problem-solving requires students to work together to identify effective solutions for complex issues (Yang et al., 2025). In this collaboration, emphasis is placed on the thinking stages, each individual is expected to contribute with their critical thinking, sharing ideas or providing feedback on solutions proposed by other team members to solve problems (Muhfahroyin et al., 2024). Critical thinking skills and collaborative problem-solving are mutually supportive (Ramdhani et al., 2023). By engaging in critical thinking, individuals are better prepared to evaluate and refine solutions that arise during group discussions. Conversely, collaborative work challenges individuals to think more critically by interacting with diverse perspectives from their team members. The use of AI tools in education enhances this process by providing a platform for students to discuss and analyze problems collectively (Ruiz-Rojas et al., 2024).

Students are presented with the challenge of collaboratively addressing problems in a collaborative problem-solving (CPS) environment. This process encourages them to explore a variety of solutions and strategies. Active engagement in CPS enhances critical thinking skills, as students must continually evaluate, assess, and modify the solutions proposed by their team. Social interactions during the collaborative problem-solving (CPS) process enrich critical thinking abilities. Each individual has the opportunity to provide input, critique ideas, and listen to and respond to the perspectives of others during collaboration (Stahl, 2023). This process significantly deepens the analysis of problems and solutions, thereby enhancing critical thinking skills. Collaborative problem-solving provides a practical environment that encourages students to apply critical thinking skills in real-world situations. Since the problems encountered are often complex and require creative solutions, students are compelled to employ logic, weigh evidence, and make decisions based on critical assessment. Feedback from other team members offers new perspectives that can enhance students' critical evaluation of a problem during collaboration. This not only enriches their critical thinking skills but also broadens their understanding of how different approaches can influence the outcomes of solutions. Findings confirm that CT and CPS are strongly linked, consistent with prior work (Xu et al., 2023; Ruiz-Rojas et al., 2024). CT equips students with analytical judgment, enhancing group contributions; CPS contexts expose students to diverse perspectives, deepening CT.

The conclusions drawn from the theoretical framework presented above indicate that the integration of critical thinking and collaborative work enables students to effectively address the complex challenges of the 21st century, both in educational settings and the workforce. Therefore, collaborative problem-solving (CPS) is highly effective in developing critical thinking skills, as it requires students to actively engage in thinking, discussing, and evaluating solutions in an environment that emphasizes cooperation and exploration of ideas from diverse perspectives.

### **Empirical Based Examining**

The table presents the coefficient values used to construct the simple regression equation, as illustrated in Equation 3 that indicates that for every one-unit increase in critical thinking skills, collaborative problem-solving skills increase by 0.9165 units, assuming all other factors remain constant. The constant value of 1.818 represents the baseline level of collaborative problem-solving when critical thinking skills are zero. The coefficient for critical thinking is 0.9165, which signifies a strong positive relationship between critical thinking and collaborative problem-solving. This means that higher critical thinking skills correlate with

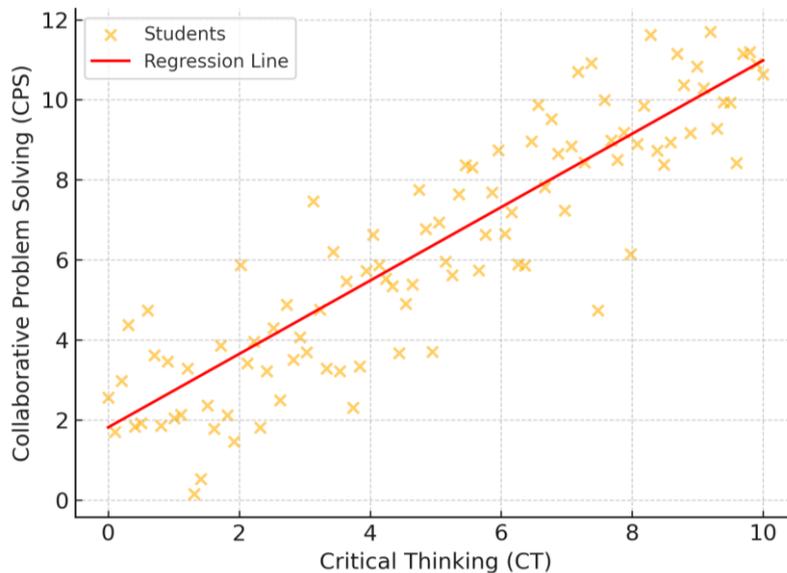
improved performance in collaborative problem-solving. The p-value is 0.000, which is significantly lower than the threshold of 0.05 (<0.05), indicating that the relationship between critical thinking and collaborative problem-solving is statistically significant. Additionally, the  $R^2$  value suggests that critical thinking skills account for 74.20% of the variance in collaborative problem-solving skills, illustrating a robust relationship between these two variables. Empirical data analysis confirms that critical thinking skills have a strong positive correlation and a significant impact on collaborative problem-solving abilities.

$$Y = 1.818 + 0.9165 X \tag{Eq. 3}$$

**Table 1.** Results of Regression Analysis

Term	Coef	SE Coef	T-Value	P-Value	VIF	R-Squared
Constant	1,818	0,747	2,43	0,016		
Critical Thinking Skill	0,9165	0,0345	26,55	0,000	1,00	74,20%

Figure 2 shows the regression fit between Critical Thinking (CT) and Collaborative Problem Solving (CPS). The scatterplot represents student data, and the red line indicates the regression model  $CPS = 1.818 + 0.9165(CT)$ .



**Figure 2.** Regression Fit: CT vs CPS

**Determining Factors**

The results of an open survey conducted with 195 participants regarding critical thinking skills indicate that the majority of science students in higher education describe critical thinking as encompassing the ability to analyze, evaluate, and synthesize information deeply. This skill is essential for understanding concepts, making logical decisions, and seeking innovative solutions. In the learning process, critical thinking involves not only the passive reception of information but also questioning, analyzing, and rigorously evaluating material. This approach facilitates a broader understanding of concepts and their application in various contexts, both in education and everyday life.

Many science students in higher education often face challenges in critical thinking due to various factors. Personal or emotional biases can hinder objectivity, especially when individuals tend to seek information that reinforces existing beliefs (Şimşek, 2025). Additionally, a lack of information or deep understanding complicates the evaluation process. Time pressure and excessive information can lead to confusion, while insufficient experience

or practice in critical thinking further exacerbates these difficulties (Williams & Juliano, 1985). Furthermore, stress, mental health conditions, and social pressures can negatively impact critical thinking abilities.

**Table 2.** Example of questions and student answer

Statement	Question	Respon
When studying the potential natural disasters caused by climate change in group discussions in class, some students underestimated the risks posed by rising sea levels or extreme weather because they had never experienced a major disaster firsthand. They found it difficult to comprehend or assess long-term global risks, even though data showed an increased likelihood of natural disasters.	How do you approach understanding rare but high-impact scientific risks, enabling you to make more accurate assessments of long-term threats?	In understanding rare but high-impact scientific risks, it is crucial to rely on existing data and scientific evidence, even in the absence of direct experience. Utilizing simulation models or case studies of similar events can help estimate the risks. Educating ourselves about climate change and its contributing factors is essential to becoming more aware of potential long-term impacts. This enables us to make informed decisions and take preventive measures, even without firsthand experience.

However, a supportive environment, quality education, practical experience, and self-reflection can contribute to the development of critical thinking skills (Manousou, 2025). Science students in higher education approach problem-solving and challenges by deeply analyzing issues, breaking them down into smaller components to grasp the core problem. They then seek relevant information from various sources to strengthen their analysis. When faced with complex issues, they engage in discussions with others to gain additional perspectives and new ideas (Bos et al., 2025). Once all information is gathered and analyzed, they make evidence-based decisions and ultimately reflect on the outcomes for future evaluation and improvement.

The results of an open survey conducted with 195 informants regarding collaborative problem-solving skills indicate that 94% of science students in higher education view collaborative problem-solving as a critical competency encompassing several crucial aspects, including effective communication, teamwork, creative and analytical thinking, as well as negotiation and mediation (Medina et al., 2024). These skills enable individuals to share ideas, listen to others' opinions, and collaboratively develop solutions. In the context of learning, collaboration enhances the ability to identify problems, gather information, engage in discussions, and collectively evaluate alternative solutions (Hu & Shu, 2025). By mastering these skills, teams can achieve more comprehensive and effective solutions while enriching the learning process through synergy and improved relationships among members.

The majority of science students in higher education describe the development of collaborative problem-solving skills as influenced by various factors, including a supportive learning environment, practical experience in teamwork, and access to feedback (Hobenu et al., 2025). Open and inclusive discussions facilitate constructive idea exchange, while involvement in group projects strengthens adaptability and cooperation. Training or workshops focused on communication and teamwork, as well as the use of collaborative technology, also enhance these skills. Other contributing factors include self-reflection, effective communication skills, and openness to receiving feedback and criticism (Palavan et al., 2025). The combination of these factors significantly boosts the ability to solve problems collaboratively and productively.

Furthermore, 85% of science students in higher education have experienced challenges and conflicts in collaborative problem-solving. Common issues arise from differing opinions, a lack of clear communication, and ambiguities in role distribution (Nolan & Zeidler, 2025). Differences in work styles and perspectives among team members can create tension, especially when there is a lack of compromise or willingness to listen to alternative viewpoints. Poor communication often leads to misunderstandings, confusion, and frustration. Navigating such situations underscores the importance of effective communication, active listening, and clearly defined roles in achieving optimal solutions.

Additionally, 93% of science students in higher education recognize challenges in collaboration stemming from varying communication styles, unclear roles, and differing perspectives among team members. Some individuals prefer direct and open communication, while others tend to be more cautious or formal. This imbalance can lead to confusion and tension within the team. However, 75% of science students in higher education believe that resolving conflicts through open discussion and active listening is crucial. Establishing clear roles and pursuing compromise solutions facilitates more effective teamwork, fostering an environment where diverse ideas are valued and collaboration can proceed smoothly.

Our qualitative findings corroborate the significant role of critical thinking skills in determining collaborative problem-solving abilities, as also evidenced by the quantitative results. This study offers insights into how critical thinking influences collaborative problem-solving through qualitative analysis based on participants' experiences within the context of higher education. Enablers: AI tools, supportive environments, teamwork practice, reflection. Barriers: biases, time pressure, team conflicts. Sample quotes: "Utilizing simulations facilitated my assessment of risks that I had not encountered in real-world scenarios" (Student 14). "Engaging in open discussions with peers enhanced my reasoning abilities" (Student 88). 85% reported challenges in teamwork, 93% noted communication issues, 75% valued open discussion as key to conflict resolution.

The significant contribution of critical thinking to collaborative problem-solving can be explained by three key factors: analytical communication among group members, a supportive learning environment that encourages immediate feedback, and open discussions. However, challenges such as differing communication styles, unclear roles, and conflicting perspectives also surfaced. These qualitative findings align with (Ying & Tiemann, 2024), who argue that indicators of collaborative problem-solving encompass not only cognitive skills but also social skills, including participation, perspective-taking, and social regulation.

Communication plays a pivotal role in solving collaborative problems. Each group member is expected to contribute ideas effectively and it requires good communication skills. Analytical communication involves articulating ideas with clear, logical reasoning and backing them with credible evidence or relevant experience. This kind of communication ensures that each contribution is well-founded and contributes meaningfully to problem-solving or decision-making processes. Critical thinking serves as a bridge to connect and evaluate interrelated ideas, ensuring they are acceptable and effective in addressing the given problem. Therefore, Communication, critical thinking, and problem-solving are interconnected and should be key priorities in the learning instruction of school education (Cheruiyot & Molnár, 2025)

The learning environment is another critical factor in collaborative problem-solving. According to Bandura's (1969) Social Learning Theory, the environment and surrounding individuals play a crucial role in shaping the learning process through interaction (Zhang et al., 2025). Rigorous interaction, characterized by the active exchange of ideas and prompt feedback, is vital for effective collaboration. Individuals with strong critical thinking skills excel in self-regulation, allowing them to articulate their reasoning clearly and adjust their approaches as ideas evolve and circumstances change (Zielińska et al., 2024). In the term of environment, for example, generative AI can act as a facilitator, supporting self-regulation by

providing immediate, tailored feedback, thereby enhancing critical thinking and collaborative problem-solving capabilities (Memon & Kwan, 2025).

Open discussions are particularly important in collaborative problem-solving, especially during decision-making processes. Group discussions often involve deliberations to reach consensus. Critical thinkers can analyze problems by breaking them down, evaluating proposed ideas based on evidence, and drawing conclusions from collected information. Using critical thinking in decision-making helps prevent errors and results in better outcomes than relying solely on intuition (Pawlicki et al., 2024).

While this study elucidates factors that mediate the relationship between critical thinking and collaborative problem-solving, certain aspects warrant further exploration. For instance, variations in participants' initial scientific and mathematical aptitudes, as well as the role of gender in collaborative problem-solving processes, present opportunities for additional investigation (Almulla, 2023). Potential Influences and Moderators Factors such as prior grade point average, discipline, gender, and team composition may influence the association between critical thinking and collaborative problem-solving. Future studies should incorporate these variables. (Campos & Scherer, 2024). Limitations of the Study This study employed surveys and self-reports, lacking classroom observations or instructor evaluations. Multi-source triangulation is recommended to enhance the reliability of the findings.

## CONCLUSION

The conclusions derived from the analysis and discussion presented in this study suggest that critical thinking and collaborative problem-solving skills mutually reinforce each other in the scientific learning process. Students who possess proficiency in critical thinking tend to make more substantial contributions within collaborative teams, while collaborative problem-solving challenges individuals to think more critically through social interactions and discussions. The development of these skills is influenced by several key factors, including a supportive learning environment, access to technology, practical experience, and training. The utilization of artificial intelligence technology further enhances the learning process by providing platforms for discussion and analysis in scientific education. Conflicts in collaborative problem-solving frequently arise from discrepancies in communication styles and a lack of well-defined roles. Implementing open discussion approaches, structured task division, and effective communication development can significantly improve collaboration outcomes. The integration of critical thinking and collaborative problem-solving in higher education equips students with the ability to address contemporary challenges with innovative, logical, and collaborative solutions, which are pertinent in both academic and professional contexts. This study underscores the strong association between critical thinking and collaborative problem-solving in scientific learning. Enabling conditions include AI-supported collaboration and structured teamwork, while barriers include biases and communication breakdowns. Implications for practice include incorporating critical thinking rubrics into collaborative problem-solving tasks, rotating group roles, and utilizing AI-assisted reflection prompts.

## RECOMMENDATION

This section provides a description of the actions that will be taken in relation to the next research idea. It also identifies potential barriers or problems that could influence the research results. Future Research Recommendations: Longitudinal Tracking: Track the development of CT↔CPS over time. Interdisciplinary and Institutional Comparison: Compare CT↔CPS across different disciplines and institutions. Gender and Prior Achievement Moderation: Examine the moderating effects of gender and prior achievement on CT↔CPS outcomes. Classroom Observations and Teacher Ratings: Include classroom observations and teacher

ratings in the research. Experimental Testing of AI-Scaffolded CPS Interventions: Test AI-scaffolded CPS interventions experimentally.

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#### AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
A.N. Maulida Fauziah	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Wahyu Budi Sabtiawan		✓				✓		✓	✓	✓		✓		
Angela Boey	✓		✓	✓			✓			✓	✓		✓	✓

#### CONFLICT OF INTEREST STATEMENT

The authors state that they have no conflict of interest related to the research, authorship, or publication of this article.

#### INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

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