

Optimizing Student Collaborative Learning through Artificial Intelligence Integration: An Innovative Approach

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Abstract: This study examines the role of Artificial Intelligence (AI) in enhancing student collaborative learning, with a particular emphasis on AI-driven feedback mechanisms and patterns of student interaction in developing effective collaborative skills. Unlike prior studies, this research highlights the mediating effect of AI-driven feedback on teamwork efficiency and overall learning outcomes in collaborative environments. An explanatory quantitative approach was applied using Partial Least Squares Structural Equation Modeling (PLS-SEM) to ensure robust data analysis. Data were collected from 112 university students who were actively engaged in AI-assisted collaborative learning activities, using a structured online survey instrument. The data were subsequently analyzed using SmartPLS software. The results reveal that AI significantly enhances student interaction ($\beta = 0.534$, $p < 0.000$) and improves problem-solving feedback ($\beta = 0.620$, $p < 0.000$), both of which contribute to significantly strengthening collaborative skills ($\beta = 0.716$, $p < 0.000$). However, the findings also indicate that AI alone does not directly improve collaboration without the support of structured pedagogical design and guidance. Therefore, universities should strategically integrate AI-driven feedback into Learning Management Systems (LMS) and strengthen digital literacy initiatives to optimize the effectiveness and sustainability of AI in collaborative learning contexts.

Keywords: Artificial Intelligence; Collaborative Learning; Collaborative Skills; Student interaction; Teamwork Efficiency.

1. Introduction

Advancements in artificial intelligence (AI) technology have created significant prospects in the realm of education, with extensive applications in administration, learning, and instruction (Chen et al., 2020). Artificial Intelligence is employed to enhance the efficiency of administrative functions, tailor curricula and content to meet student requirements, and create intelligent learning systems and tutors that offer individualized and adaptive educational assistance (Ahmad et al., 2021; Chen et al., 2020; Hamal et al., 2022). It gives rise to a new role for librarians, who must be skilled in supporting this new phenomenon in promoting lifelong learning (Mutia et al., 2024; Sugihartati et al., 2025). The use of AI in education has grown rapidly, enabling more effective personalization of learning, improving accessibility, and enriching the learning experience (Castro et al., 2024; Murtaza et al., 2022). AI supports learning by adapting teaching materials and methods according to individual needs, providing real-time feedback, and creating a more inclusive learning environment (Tapalova & Zhiyenbayeva, 2022). The application of AI in global education is expected to increase rapidly, with an annual growth rate of 45.12% between 2021 and 2027 (Marisa et al., 2024). AI has numerous advantages in education,

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such as tailored learning experiences, enhanced administrative efficiency, and improved global accessibility (Lin et al., 2024; Marisa et al., 2024; P. Duterte, 2024; Zhang & Aslan, 2021). AI is employed across various disciplines at all educational levels, including mathematics (Hwang & Utami, 2024) and medical science (Pudjiadi et al., 2024).

AI has an important role in supporting learning collaboration in the academic environment, especially in improving student collaboration. Providing students with cooperative assignments is a well-known and effective way to improve their learning process (Pinandito et al., 2021). Several ways AI supports learning collaboration with a multimodal approach by integrating data streams to provide a holistic view of the state of students Cohn et al. (2025), adaptive and intelligent systems and creativity development (Mena-Guacas et al., 2023). The application of AI in collaborative learning can increase the efficiency of student cooperation in solving problems and achieving common goals. AI can support collaborative learning in a variety of ways, including analysis of collaborative patterns Ouyang et al. (2023), improved conceptual understanding Canonigo (2024) and development of creative thinking skills (X. Hu et al., 2022). AI can substantially enhance collaborative learning by delivering immediate feedback, promoting debates Celik et al. (2024), Cohn et al. (2025), and aiding collaboration in both synchronous and asynchronous formats (Ifenthaler & Schumacher, 2023). This technology is crucial for cultivating collaborative abilities, which are essential competencies of the 21st century, especially for the advancement of higher education in Indonesia (Isnaini & Muslimin, 2024).

The utilization of AI in collaborative learning within higher education in Indonesia has not reached its full potential. Despite the significant promise of AI to enhance education, some hurdles persist, including limitations in functionality and disparities in access (Henny Sutrisman et al., 2024; Utami et al., 2023). AI presents significant promise for customizing education and enhancing collaboration between humans and machines (Liu et al., 2023). Investigations on the role of AI in facilitating student collaboration remain underexplored relative to the emphasis on personalizing individual learning. However, several studies have begun to explore how AI can support collaboration in the context of education (Cohn et al., 2025; McLaren et al., 2010; Mena-Guacas et al., 2023; Tomić et al., 2023). Challenges in integrating AI in higher education include limited pedagogical adaptation Celik et al. (2024), Magnisalis et al. (2011), understanding of technology by educators Canonigo (2024) and the lack of empirical evidence regarding the direct impact of AI on students' collaborative skills (Canonigo, 2024; Celik et al., 2024).

2. Literature Review

The utilization of artificial Intelligence (AI) in collaborative learning has emerged as a central subject in numerous higher education studies. Deeper learning is known to be important in the future (Valencia et al., 2023). AI can improve engagement, collaboration abilities, and the efficacy of feedback in team-based learning. An examination of the function of AI in collaborative learning through the analysis of pertinent ideas and empirical studies that endorse and refute each notion.

Hypothesis 1: The Use of AI in Collaborative Learning Increases Student Interaction

The application of AI in collaborative learning can augment student engagement by creating a more interactive and adaptive setting. AI can enhance the creation of more captivating educational experiences via gamification, AI-driven chatbots, and recommendation systems that customize content to meet individual requirements (Celik et al., 2024; Cohn et al., 2025). Some studies show that AI not only facilitates interaction but also provides in-depth analysis of students' learning patterns and recommends more effective learning strategies (Ouyang et al., 2023). Furthermore, AI has been proven to enhance engagement in academic discussions through the implementation of multimodal models that adjust interactions based on text, voice, and visual elements. Weber et al. (2025) asserted that

AI utilized in collaborative learning could evaluate student interactions in real-time and offer data-driven recommendations to improve the efficacy of conversations.

The social constructivism theory posits that social contact is a fundamental component of learning (Vygotsky, 1980). The learning process is more successful when individuals engage with their social surroundings. This approach is pertinent in AI-driven education, as AI functions as a learning agent that delivers feedback and advice customized to the student's comprehension level. In the realm of AI-driven collaborative learning, this technology facilitates an interactive environment that promotes student engagement in discourse, knowledge exchange, and collaboration in academic endeavours. Artificial Intelligence can facilitate interactions by delivering real-time feedback and conducting group interaction analysis (Chen et al., 2020).

Cohn et al. (2025) discovered that a multimodal AI-based system could improve student engagement in online discussion forums by utilizing technology for emotion recognition, communication pattern analysis, and automated answers to students' educational requirements. This study employs experimental methodologies involving control and experimental groups to evaluate the efficacy of AI in augmenting student engagement in academic discourse. The results demonstrate that the use of AI in collaborative learning enhances interactivity and facilitates more effective communication among students (Ouyang et al., 2023; Weber et al., 2025). Ouyang et al. (2023) have shown that AI enhances organized communication in collaborative learning settings. Facilitates pupils' engagement in their diverse opinions and debates. The study by Wang et al. (2022) indicates that while AI can augment student engagement, its effect on enhancing such contact is negligible without suitable pedagogical interventions. This study emphasizes the significance of structured teaching tactics, including project-based learning models integrated with AI help, to improve active student engagement. AI-supported personalized instruction and data-driven learning can be more effective when integrated with active faculty guidance and collaborative reflection activities (Ouyang et al., 2023). McLaren et al. (2010) also discovered that students continue to encounter communication difficulties despite the utilization of AI technologies.

Hypothesis 2: The Use of AI in Collaborative Learning Enhances Students' Collaborative Skills.

Collaborative skills have become vital competencies that students must acquire to confront the more intricate issues on the job. The use of AI in collaborative learning plays a role in creating an environment that supports cooperation, knowledge sharing, and joint problem-solving (Celik et al., 2024). AI not only serves as an aid in learning but also as a facilitator that can identify cooperation patterns and provide appropriate interventions to enhance team effectiveness (Ouyang et al., 2023).

The experiential learning hypothesis Kolb (1984) posits that collaborative skills are cultivated by active engagement in group interactions and subsequent reflection. AI can offer experience-driven simulations that enable students to cooperate within a dynamic digital setting. In this setting, AI functions as a supplementary instrument that facilitates collaborative experiences via scenario-based learning, gamification, and interactive simulations that mirror real-world issues (Celik et al., 2024; Ouyang et al., 2023).

A study by Canonigo (2024) showed that AI serves a more supportive function in enhancing collaboration skills rather than acting as the primary determinant in the development of students' collaborative abilities. Sanmas et al. (2024) demonstrated that students engaged in AI-based projects exhibit greater adaptability in executing group activities and possess a profound comprehension of each team member's responsibilities. Research by Ouyang et al. (2023) demonstrates that AI utilized in collaborative learning settings can enhance student interactions through data-driven recommendations that improve communication efficiency within groups.

Nonetheless, not all studies indicate that AI directly improves students' collaboration abilities. Jony & Hamim (2024) discovered that the implementation of AI can supplant some aspects of social interaction that ought to occur organically within an academic setting, enabling students to cultivate collaborative abilities through an adaptive AI-based system without engaging in direct teaming. Furthermore, the research by Xu et al. (2023) indicates that while AI can offer pertinent input, students still need instructor assistance to comprehend and implement that feedback in the context of collaborative efforts.

Hypothesis 3: The Use of AI in Collaborative Learning Enhances Feedback on Problem-Solving Skills

In the learning process, feedback plays an important role in helping students understand their mistakes and find more effective improvement strategies. Artificial Intelligence has been engineered to deliver data-driven feedback that is swifter, more precise, and more tailored than that of human educators (Celik et al., 2024). AI enables real-time analysis of student responses and provides adaptive suggestions that adjust to their level of understanding. This can boost efficiency in problem-solving and help pupils build superior analytical skills (Xu et al., 2023).

Social Cognitive Theory (Bandura, 1986) asserted that adaptive feedback is crucial for enhancing problem-solving abilities. AI can deliver depersonalized real-time feedback, allowing students to comprehend their faults more rapidly and develop more effective remedies. AI-based feedback enables more independent learning and encourages students to be more active in tackling academic challenges (Ouyang et al., 2023). Weber et al. (2025) discovered that AI systems can deliver more precise feedback than human instructions. The inis system aids problem-solving strategies. A study by Celik et al. (2024) demonstrates that multimodal data-driven AI enhances students' comprehension of their errors and refines their problem-solving skills. Xu et al., (2023) observed that students who receive AI-based feedback are more likely to propose inventive ways to complete their academic problems. Additionally, Porter & Grippa (2020) noted that AI providing personalized feedback enhances group work effectiveness by accelerating the identification of problems and solutions in collaborative discussions.

Nonetheless, particular academics have demonstrated that AI does not consistently enhance pupils' problem-solving abilities. Isaac et al. (2019) discovered that despite AI offering data-intensive input, students continue to have difficulties in converting that feedback into improved real-world activities. A study by Sarkheyli (2023) indicated that students occasionally lack confidence in utilizing AI as the principal source of feedback in the absence of direct instructor assistance.

Hypothesis 4: Student Interaction in Collaborative Learning Improving Collaborative Skills

Student engagement is a crucial component in the learning process for strengthening collaborative skills. Successful collaborative learning necessitates active student participation in discussions, teamwork, and joint problem-solving. (Zhang & Aslan, 2021). Engagement in study groups can promote the sharing of ideas, collaborative problem-solving, and an enhanced comprehension of concepts (Zhang et al., 2023). Consequently, well-organized student interactions are essential for improving collaborative abilities.

The social learning hypothesis Bandura (1986) posits that collaborative skills evolve in interactive settings characterized by social dynamics and collaboration. This idea posits that individuals acquire knowledge through observation, imitation, and interaction with their social milieu. In collaborative learning, students who actively interact with peers will more rapidly acquire skills in cooperation, communication, and problem-solving (Celik et al., 2024). Furthermore, the Zone of Proximal Development paradigm underscores the significance of interaction in collaborative learning. Vygotsky (1980) claimed that learners can attain a more profound comprehension through engagement with more knowledgeable individuals or by utilizing technical instruments such as artificial Intelligence. AI in collaborative learning serves as a facilitator, offering personalized feedback and assisting students in cultivating more effective collaboration tactics (Xu et al., 2023).

Isaac et al. (2019) demonstrate that student interactions facilitated by suitable instructional frameworks can markedly improve collaborative skills. This study found that students engaged in AI-facilitated discussion sessions had enhancements in communication and team collaboration relative to those who studied autonomously. Zhang et al. (2023) discovered that students with extensive group work experience had elevated collaborative skills, particularly when their interactions were augmented by AI offering data-driven recommendations. Conversely, researchers Qureshi et al. (2023) discovered that in the absence of explicit educational instruction, group interactions do not consistently enhance collaborative abilities. Students collaborating in groups without instructor supervision or a defined learning framework may encounter difficulties in meeting educational goals. The

study by Sarkheyli (2023) indicated that while AI can enhance student interactions, students find it challenging to effectively utilize the input from the AI system without further assistance from teachers.

Hypothesis 5: AI Feedback Has a Significant Impact on Students' Collaborative Skills

Feedback is crucial for enhancing pupils' collaboration skills. AI offers data-driven feedback that is more tailored, organized, and responsive than traditional techniques (Xu et al., 2023). AI feedback enables students to identify their deficiencies objectively and offers targeted suggestions to enhance team effectiveness (Weber et al., 2025). The adaptive and analytical capabilities of AI enable students to get instruction adapted to their particular requirements, hence improving group dynamics and collaborative interactions (Porter & Grippa, 2020).

The concept of the zone of proximal development Vygotsky (1980) demonstrated that technology-mediated assistance can facilitate the development of collaborative skills in students by offering contextual and specific feedback. Artificial Intelligence assists students in enhancing their collaborative skills through tailored feedback (Ouyang et al., 2023). Moreover, (Kolb, 1984)experiential learning theory posits that students are more likely to cultivate collaborative abilities when provided with pertinent reflection and feedback regarding their performance within project-based or group learning contexts (Celik et al., 2024). The research of Xu et al. (2023) demonstrates that individualized AI feedback can improve the efficacy of student group work. Porter & Grippa (2020) assert that AI feedback improves group dynamics and promotes collaborative efficiency in intricate tasks. Research conducted by Celik et al. (2024) indicates that AI utilized for multimodal feedback can improve students' comprehension of their roles in collaborative teamwork. Enhancing communication dynamics and augmenting understanding of each member's strengths and shortcomings within the group.

Sarkheyli (2023) observes that while AI can offer feedback, students frequently encounter difficulties converting that feedback into tangible activities without further assistance from educators. Isaac et al. (2019) have discovered that students receiving AI feedback without suitable pedagogical intervention often experience frustration and face challenges in adopting improved collaborative practices.

3. Research Method

This study uses explanatory quantitative approaches to examine the correlations among the application of artificial Intelligence (AI) in collaborative learning, student interactions, AI-generated feedback, and students' collaborative skills. This methodology was selected as it facilitates the statistical examination of both direct and indirect interactions among independent, mediating, and dependent variables. This method provides deep insights into the role of AI, student interactions, and feedback on problem-solving skills in supporting student collaboration in the learning environment.

Data analysis was undertaken using SmartPLS to assess the measurement model, examine the correlations between variables, and test hypotheses. The Partial Least Squares Structural Equation Modeling (PLS-SEM) method was selected for its capacity to manage intricate models featuring several latent variables and non-normally distributed data (F. Hair Jr et al., 2014). The choice of PLS-SEM is predicated on its advantages over other SEM methodologies like AMOS or LISREL, as it offers greater flexibility for datasets with constrained sample sizes and facilitates the examination of both direct and indirect relationships while also effectively managing multicollinearity among variables (F. Hair Jr et al., 2014; Khan et al., 2019).

The research population comprises active students from Universitas Murni Teguh Pematangsiantar who have experience with AI technologies, including Chat GPT, Google Workspace AI, Microsoft Teams AI, Wolfram Alpha, and Socratic in collaborative learning environments. Purposive sampling procedures obtained the sample according to the inclusion criteria: active students, utilization of AI in learning, participation in collaborative activities, and readiness to complete the questionnaire. One hundred twelve students met the criteria and were made respondents.

Data were collected using a 5-point Likert scale-based questionnaire in the context of AI variables in collaborative learning, namely AI1: Ease of use of AI technology in collaborative learning Chen et al. (2020), AI2: Provision of relevant learning materials, student interaction McLaren et al. (2010), AI3: Enhancing student engagement in group discussions Ouyang et al. (2023), AI4: Providing depersonalized recommendations according to student needs (Chen et al., 2020). The Student Interaction Variables are K1: Students are active in discussions when using AI Cohn et al. (2025), and K2: AI enhances student interaction with groupmates (Wang et al., 2022). The AI Feedback Variable on problem-solving is as follows: KK1: AI provides clear and relevant feedback on proposed solutions Celik et al. (2024); KK2: AI helps in identifying errors in problem-solving Awais Hassan et al. (2019); KK3: AI offers more effective alternative solutions (Xu et al., 2023). The variables of students' collaborative skills are H1: Students' ability to share ideas and information within a group (Vygotsky, 1980), H2: Students' ability to adapt to team dynamics Kolb (1984), H3: Improvement in group work effectiveness after using AI Bandura (1986), H4: AI helps students build trust within the team (Kolb, 1984). To ascertain validity and reliability, Outer Loading (>0.70), Composite Reliability (>0.70), and Average Variance Extracted (AVE >0.50) assessments were performed utilizing SmartPLS (F. Hair Jr et al., 2014). Measurement Model Testing and Structural Model Testing were performed for data analysis.

4. Results and Discussion

Characteristics Respondent

Data collected from 112 student respondents were analyzed using the PLS-SEM model with SMARTPLS 3 software. Table 1 describes the characteristics of the respondents.

Table 1. Characteristics of Respondents.

Question	Answer	Sum	Percentage
Gender	Man	22	19,64%
	Woman	90	80,36%
Age	<20 Years	43	38,39%
	20 – 24 years old	68	60,71%
	> 24 Years	1	0,9%

The characteristics of the study respondents were 19.64% male and 80.36% female. Based on age, respondents under 20 were 38.39%, 20-24 were 60.71%, and over 24 were 0.9%. The diversity of respondent characteristics affects the research results. This is related to the perspectives and interactions that occur during the learning process using AI. Previous research shows that gender and age diversity can influence communication patterns, technology adoption rates, and the effectiveness of feedback in collaborative learning (Ouyang et al., 2023; Xu et al., 2023). Younger respondents tend to be more adaptive in the use of AI technology compared to older respondents (L. Chen et al., 2020). Gender differences can influence interaction attitudes and the development of collaborative skills (Celik et al., 2024). Therefore, understanding the characteristics of respondents becomes very important in interpreting the research results and their implications for the application of AI in the context of collaborative learning.

Quantitative Analysis

Convergent Validity Test (Outer Loadings)

This measurement is carried out to ensure that each indicator in the construct adequately contributes to explaining the construct where the outer loading value considered to meet the convergence validity criteria is above 0.7. The results of the validity test are shown in the following Table 2.

Table 2. Validity Testing.

AI in Collaborative Learning	Student Interaction	Student Collaborative Skills	AI Feedback on Problem-Solving Capabilities
0.863			
0.775			
0.877			
		0.873	
		0.898	
		0.875	
		0.867	
	0.882		
	0.898		
			0.856
			0.768
			0.885

From Table 2 above, all indicators have relatively high outer loading values (> 0.7). Each indicator for measuring AI learning, Student Interaction, Student Collaborative Skills, and AI Feedback on problem-solving ability has a good convergent validity score. The research results show that each indicator can effectively measure the construct. High convergent validity indicates that the indicators in the study have a strong alignment with the constructs that have been measured. The data explains that the value of convergent validity strengthens the reliability of the research results (F. Hair Jr et al., 2014; Khan et al., 2019). Previous research states that an outer loading value above 0.7 indicates that the indicator can effectively represent the latent variable in the PLS-SEM analysis (Fornell & Larcker, 1981). The results of the study support the validity of the research measurements conducted and reinforce the conclusions regarding the relationship between AI in collaborative learning, student interaction, and collaborative skills.

Reliability Test

Cronbach's Alpha analysis measures each construct's internal consistency. A value above 0.7 indicates good reliability. The results are shown in Table 3.

Table 3. Construct Reliability and Validity.

	Cronbach's Alpha	rho_A	Composite Reliability	Average Variance Extracted (AVE)
AI in Collaborative Learning	0.792	0.814	0.877	0.705
Student Interaction	0.737	0.740	0.884	0.792
Student Collaborative Skills	0.901	0.903	0.931	0.771
AI Feedback on Problem-Solving Abilities	0.787	0.799	0.876	0.702

From Table 3, it can be concluded that AI in collaborative learning has a score of 0.792 (reliable), Student Interaction 0.737 (reliable), Student collaborative skills 0.901 (reliable), and AI feedback on problem-solving ability 0.787 (reliable). It means that all constructs have strong internal consistency and are reliable for this study. The Average Variance Extracted (AVE) value with an AVE value above 0.5 explains that each construct can explain the variability of its indicators well. According to F. Hair Jr et al. (2014), a Cronbach's Alpha value above 0.7 indicates that a construct has good reliability, while a value above 0.9 indicates very high reliability (Fornell & Larcker, 1981). The Average Variance Extracted (AVE) value above 0.5 confirms that each construct can adequately explain the variability of its indicators, indicating that each latent variable has sufficient convergence with each of its measurement items (Khan et al., 2019). Therefore, the research results support the validity and reliability of the research model and have ensured that the instruments used are reliable for evaluating the relationship between AI in collaborative learning, student interactions, and students' collaborative skills.

Model Fit

SRMR is a measure of model fit that assesses the difference between the observed correlation matrix and the one predicted by the model. Lower SRMR values indicate a better model fit. SRMR below 0.08 is considered good, while SRMR below 0.10 is still acceptable.

Table 4. Fit Summary.

	Saturated Model	Estimated Model
SUMMER	0.079	0.114
d_ULS	0.493	1.018
d_G	0.297	0.343
Chi-Square	199.097	210.512
NFI	0.769	0.756

Table 4 shows that the saturated model's Standardized Root Mean Square Residual (SRMR) of 0.079 is below the threshold of 0.08, indicating that this model has a good and acceptable fit. Although values such as NFI are below 0.9 and Chi-Square is relatively high, these results are still within acceptable limits, so the model remains worthy of further analysis. SRMR is an important element for assessing model fit in PLS-SEM. If the value is below 0.08, it indicates a minimal difference between the observed correlation matrix and the one predicted by the model (L. Hu & Bentler, 1999). Although the Normed Fit Index (NFI) value is below 0.9 and the Chi-Square value is relatively high, these results are still within an acceptable range and do not directly indicate any issues with the model (F. Hair Jr et al., 2014). Previous research shows that in PLS-SEM, the assessment of Model fit using SRMR is more relevant compared to other indices, because the approach is more flexible in handling the complexity of structural models with non-normal data (Henseler & Fassott, 2010). Although there are several indicators with suboptimal values, overall the model is considered adequate for further analysis and can be used to test the research hypothesis.

Mean, STDEV, T-Values, P-Values

Based on the output results from Mean, STDEV, T-Values, and P-Values in Table 5 and Figure 1. The following is an analysis of the relationship between the variables studied:

Table 5. Mean, STDEV, T-Values, P-Values.

Path	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (O/STDEV)	P Values	Supported
AI in Collaborative Learning -> Student Interaction	0.534	0.538	0.092	5.788	0.000	Yes
AI in Collaborative Learning -> Students' Collaborative Skills	0.054	0.056	0.071	0.751	0.453	No
AI in Collaborative Learning -> AI Feedback on Problem-Solving Abilities	0.620	0.625	0.061	10.199	0.000	Yes
Student Interaction -> Student Collaborative Skills	0.109	0.118	0.085	1.277	0.202	No
AI Feedback on Problem-Solving Skills -> Students' Collaborative Skills	0.716	0.710	0.087	8.200	0.000	Yes

Analysis of the path coefficients from Table 5, the mean value of the sample, the standard deviation, the T-statistic, and the p-value for each relationship between variables in the model:

AI in Collaborative Learning -> Student Interaction, where the Original Sample is 0.534 with T-Statistics 5.788 and P-Value 0.000. The influence of AI in collaborative learning on student interaction is significant and positive. Thus, the use of AI in collaborative learning has proven effective in increasing student interaction. Several previous researchers have shown that AI contributes to enhancing student engagement and communication in online learning environments through automatic feedback features and discussion pattern analysis (Celik et al., 2024; Cohn et al., 2025). Strengthening AI-based technology in learning can enhance student engagement by providing real-time feedback and adjusting interaction methods based on data collected from student activities (Weber et al., 2025). AI can also optimize group interactions by identifying communication patterns and providing more personalized recommendations for group dynamics (Ouyang et al., 2023).

AI in collaborative learning -> Students' collaborative skills were insignificant, with the Original Sample 0.054, T-statistics 0.751, and P-value 0.453. Thus, the direct use of AI on students' collaborative skills is not significant. This means that AI may not immediately improve collaborative skills without additional mediation. This shows that the direct use of

AI does not significantly affect the improvement of students' collaborative skills, where AI may not automatically enhance collaborative abilities without other mediating factors. The findings of this study are supported by previous research. Although AI can enhance efficiency in collaborative learning, collaborative skills still depend on the pedagogical structure implemented by Celik et al. (2024) and Jony & Hamim (2024). AI can provide feedback that reinforces problem-solving and interaction but does not automatically replace the social experiences necessary to develop collaborative skills (Xu et al., 2023).

AI in collaborative learning -> AI feedback on problem-solving skills where the Original Sample is 0.620, the T-Statistic is 10.199, and the P-Value is 0.000. Thus, the use of AI in collaborative learning significantly influences AI feedback on problem-solving. These findings are consistent with previous research that shows AI can provide more specific and data-driven feedback compared to traditional methods (Weber et al., 2025; Xu et al., 2023). AI also allows students to quickly understand their mistakes and develop more effective problem-solving strategies through adaptive recommendations (Celik et al., 2024).

Student interaction -> on students' collaborative skills where Original Sample 0.109, T-Statistics 1.277, and P-Value 0.202. The influence of student interaction on student collaboration is not significant. This may be due to the need for additional components, such as AI feedback, to improve students' collaborative skills effectively. These findings are in line with previous research that emphasizes that although interaction is an important factor in collaborative learning, its impact often depends on other supporting factors such as the learning structure or feedback provided (Celik et al., 2024; Ouyang et al., 2023). Without the presence of structured facilities or feedback, student interactions in groups can become less effective and do not always result in improved collaboration skills (Ouyang et al., 2023).

Problem-Solving -> students' collaborative skills where the Original Sample was 0.716, T-Statistics 8.200, and P-Value 0.000. Problem-solving has a significant influence on students' collaborative skills. These findings are in line with previous research emphasizing that problem-solving skills and collaboration have a close relationship in the context of team-based learning (Porter & Grippa, 2020). In collaborative learning, students with better problem-solving skills tend to be more active in discussions, able to manage group conflicts, and more effective in devising cooperation strategies to achieve common goals. The process of problem-solving in groups not only enhances individual understanding but also strengthens the social and communication skills necessary for team cooperation (Ouyang et al., 2023).

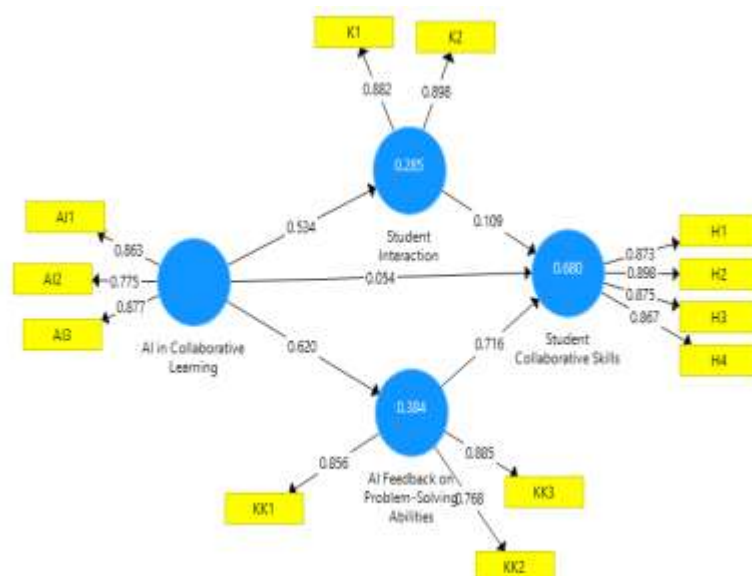


Figure 1. PLS Modeling.

Table 6. Path Coefficients.

AI in Collaborative Learning	Student Interaction	Student Collaborative Skills	AI Feedback on Problem-Solving Capabilities
AI in Collaborative Learning	0.534	0.054	0.620
Student Interaction		0.109	
Student Collaborative Skills			
AI Feedback on Problem-Solving Capabilities		0.716	

The Influence of AI in Collaborative Learning on Student Interaction

The research results show that AI in collaborative learning significantly affects student interactions ($\beta = 0.534, p = 0.000$). These findings suggest that AI technology can improve the quality of social connections in learning by creating a more dynamic and responsive conversation environment, therefore fostering student interactions. This aligns with research indicating that AI technology can improve the quality of social interactions in online learning through adaptive and structured collaboration platforms (Seo et al., 2021; Wang, 2022). AI technology is crucial in enhancing social connections that promote student collaboration. Numerous research studies indicate that AI can improve collaborative learning experiences and social relations within educational settings. There is an enhancement in communication and collaboration with non-personalized content and more intelligent recommendations (Bashiri & Kowsari, 2024). AI is used to support collaborative learning by facilitating group discussions and collaborative problem-solving(Cai et al., 2024; Pedersen, 2024). AI facilitates social interaction in online learning, helping students build social connections (Wang, 2022). The findings indicate that AI technology can enhance the quality of social connections in learning by establishing a more dynamic and responsive conversational environment, hence promoting student interactions. This corresponds with studies demonstrating that AI technology enhances the quality of social interactions in online learning via adaptive and structured collaboration platforms (Cohn et al., 2025; Seo et al., 2021; Wang, 2022; Weber et al., 2025). AI technology is essential for fostering social ties that facilitate student collaboration. Extensive research indicates that AI can enhance collaborative learning experiences and social interactions inside educational environments. Communication and teamwork have improved through non-personalized content and more sophisticated recommendations (Bashiri & Kowsari, 2024; L. Chen et al., 2020; Weber et al., 2025).

The Influence of AI in Collaborative Learning on Students' Collaborative Skills

The research results indicate that AI in collaborative learning does not have a significant direct impact on students' collaboration skills ($\beta = 0.054, p = 0.453$). These findings suggest that while AI can facilitate learning activities, it does not immediately improve students' collaboration skills without suitable social interaction and pedagogy. There is a need for additional mechanisms, such as pedagogical support or motivation-based interventions, to strengthen the relationship. In the context of experiential learning theory, collaborative skills (Kolb, 1984) are more effectively developed through direct interaction and active involvement in group activities compared to the mere use of technology (Lee et al., 2015). Previous studies explain that AI functions as a facilitative tool and is unable to replace the social aspects in collaborative learning activities (Canonigo, 2024). Collaboration skills require elements such as interpersonal communication Sanmas et al. (2024) and complex teamwork skills (Jony & Hamim, 2024). While AI can facilitate collaboration, the incorporation of additional learning methodologies is essential for achieving optimal outcomes. Enhanced pedagogical methods, including comprehensive project-based learning strategies, are required to maximize the effectiveness of AI in fostering collaborative abilities (Xu et al., 2023).

The Influence of AI in Collaborative Learning on AI Feedback on Problem-Solving Skills

The application of AI in collaborative learning significantly affects the provision of AI feedback on problem-solving skills ($\beta = 0.620, p = 0.000$). These findings indicate that AI can effectively provide relevant and focused feedback to help students develop problem-solving skills. Some studies show that AI technology can help solve complex problems (Jia et al., 2020). AI in Higher Education can support the development of students' collaborative skills by providing targeted feedback and facilitating problem-solving skills, which are key

components of effective teamwork (Weber et al., 2025; Xu et al., 2023). The purposeful incorporation of AI in education can foster a more inclusive and efficient learning environment (Jony & Hamim, 2024; Olabisi Oluwakemi Adeleye et al., 2024). AI implementation is more prevalent in the plan, do, and check stages with a focus on performance measurement (Hariyanti et al., 2023).

The Influence of Student Interaction on Students' Collaborative Skills

The research results indicate that student interaction does not have a significant impact on collaborative skills ($\beta = 0.109$, $p = 0.202$). These findings indicate that although social interaction theory is important in the context of learning (Bandura, 1986), the results of this study suggest that student interaction alone is not sufficient to develop collaborative skills without the support of a clear learning structure and facilities provided by the instructor. Student interaction in collaborative learning is a crucial factor that can improve learning results. Nonetheless, the efficacy of these connections frequently necessitates technical assistance, such as systems based on artificial Intelligence (AI), to steer interactions toward more defined learning goals. Artificial Intelligence can improve interactions between students and teachers by delivering non-personalized and prompt support on a broad scale (Cohn et al., 2025; McLaren et al., 2010; Seo et al., 2021). Consequently, AI feedback can operate as a catalyst that enhances the relationship between interaction and steers student engagement towards more effective learning.

The Effect of AI Feedback on Problem-Solving Ability on Students' Collaborative Skills.

This study shows that AI-based feedback has a significant impact on students' collaborative skills ($\beta = 0.716$, $p = 0.000$). This affirms that AI is more efficacious as an instrument for assessment and direction than as a promoter of social engagement. Research indicates that targeted and pertinent feedback from AI can improve students' collaborative skills in executing group activities or challenges. Research indicates that real-time AI input can improve group dynamics and collaborative performance in complicated activities (Porter & Grippa, 2020). Artificial Intelligence can mitigate issues in collaborative tasks, like poor communication and disproportionate contributions, by offering customized feedback (Sarkheyli, 2023). Artificial Intelligence enhances group formation by analyzing student characteristics and can improve engagement and communication abilities through the feedback offered (Garshasbi et al., 2023).

Tabel 7. Specific Indirect Effects.

	Specific Indirect Effects
AI in Collaborative Learning -> Student Interaction -> Student Collaborative Skills	0.058
AI in Collaborative Learning -> AI Feedback on Problem-Solving Ability -> Students' Collaborative Skills	0.443

Based on Table 7, the specific indirect effects shown in Table 7, the analysis of the indirect influence of the AI variable in collaborative learning on students' collaborative skills through mediation variables.

The Indirect Influence of AI on Students' Collaborative Skills through Student Interaction.

The research results indicate that the indirect influence of AI in collaborative learning on students' collaboration skills through student interaction has a coefficient value of 0.058. This score signifies that the mediating effect of student contact is comparatively minimal, and its impact on strengthening collaborative skills is not substantial. This arises from the nature of the interaction, which cannot directly cultivate collaborative abilities without supportive mechanisms such as feedback or targeted learning procedures. While vital, student interactions necessitate supplementary catalysts to impact the cultivation of collaborative skills substantially. Student engagement in collaborative learning is crucial, although it frequently necessitates supplementary catalysts to enhance the cultivation of collaborative skills substantially. Various elements can augment effectiveness, including conflict aspects and social competencies Lee et al. (2015), cooperative learning Premo et al. (2018), technological integration Chen et al. (2018), social dynamics Qureshi et al. (2023), and team skills development (Sjolie et al., 2021).

In this context, AI can enhance student interactions via features like learning analytics and individualized feedback. These findings underscore the significance of incorporating technology that might facilitate and augment the efficacy of interactions in collaborative learning. Consequently, while the indirect influence of student interactions is minimal, the findings suggest that the creation of more structured AI-driven collaborative learning models can significantly improve students' collaboration skills.

The Indirect Influence of AI on Students' Collaborative Skills through Feedback on Problem-Solving Skills.

The results of this study indicate that the indirect influence of AI in collaborative learning on students' collaboration skills through AI feedback on problem-solving skills has a coefficient value of 0.443. This value signifies that the mediating effect of pertinent input from AI enhances students' ability to identify and resolve issues more effectively during group work.

AI-driven feedback emphasizing problem-solving abilities is essential in collaborative learning. Artificial Intelligence can deliver adaptive feedback that facilitates skill enhancement, including problem-solving, by utilizing multimodal data from users (Celik et al., 2024; Ouyang et al., 2023). Prior studies indicate that technology-driven feedback offers tailored and adaptable advice to tackle learning obstacles, hence enhancing students' individual competencies and collaborative skills (Awais Hassan et al., 2019; Celik et al., 2024; Er et al., 2021). The findings suggest that educational institutions emphasize the incorporation of AI systems aimed at delivering problem-solving feedback. This method improves personal learning results and fortifies the collaboration abilities essential in contemporary education.

Research limitations

The integration of AI in Indonesian higher education remains nascent, with its efficacy contingent upon the accessibility of technological infrastructure, teacher preparedness, and students' learning behaviors (Razmerita, 2024). This research shows that the integration of AI can enhance efficiency and student engagement but also faces challenges in its implementation (Trilaksana et al., 2024). Studies show that the adoption of AI in education can enhance material comprehension, technical literacy, and learning methods, although it faces challenges such as technological dependence, uneven access, and the need for teacher (Henny Sutrisman et al., 2024). The integration of AI-based feedback systems in education can enhance personalization and learning effectiveness by providing adaptive feedback and supporting project-based learning. Educational institutions need to develop AI-based feedback systems that can provide personalized recommendations to students to improve collaborative skills. AI can create a more dynamic and responsive learning environment that meets the individual needs of students. The development of AI-based curricula must also consider digital literacy and pedagogical strategies to maximize the benefits of this technology (Celik et al., 2024; Magnisalis et al., 2011). Governments and universities need to promote digital literacy and technological readiness to make the integration of AI into education more effective.

This research has several limitations that need to be considered, including the limited population and sample that only come from one university, so the research results cannot be generalized to all students in Indonesia. Additionally, it does not control for external variables such as literacy levels, learning motivation, and students' communication skills, which can affect the effectiveness of collaborative learning. The use of a quantitative approach may not be sufficient to explore the mechanisms of collaborative skills, so a mixed-methods approach is needed to obtain a more in-depth understanding and analysis.

5. Conclusions

This research demonstrates that artificial Intelligence (AI) significantly enhances student interactions in collaborative learning environments. Nonetheless, AI does not inherently improve collaboration skills without an accompanying instructional framework. This research indicated that AI-driven feedback significantly enhances the development of students' collaboration abilities. The AI-driven automated assessment system enhances pupils' cooperation abilities.

Furthermore, this research confirms that student interactions alone are not sufficient to enhance collaborative skills without additional support. AI in collaborative learning has been proven to enhance problem-solving skills through more accurate and specific feedback, which ultimately strengthens cooperative skills in an academic environment.

AI improves student interaction by creating a more dynamic and responsive learning environment, hence substantially enhancing student participation in debates and collaborative efforts. Nonetheless, AI indirectly improves collaborative skills, as its efficacy in collaborative learning necessitates more pedagogical intervention. AI-driven feedback is crucial in cultivating collaborative skills by delivering personalized and pertinent responses, thereby assisting students in refining their teamwork and problem-solving abilities. Student interactions in collaborative learning are inadequate for improving collaborative skills without a defined learning framework, highlighting the necessity for instructor leadership in the educational process. The integration of AI in higher education in Indonesia encounters numerous hurdles, including inconsistent technological infrastructure, faculty preparedness, and disparate degrees of digital literacy among students.

Based on the results of this research, several recommendations can be made: (a) the development of an AI-based feedback system within the Learning Management System (LMS) to provide personalized recommendations to students, (b) the enhancement of digital literacy for lecturers and students to improve the effectiveness of AI implementation in learning, (c) further research using a mixed-methods approach, combining quantitative and qualitative data, to gain a deeper understanding of how AI can facilitate collaborative learning, (d) cross-country comparative studies to understand the challenges and opportunities in the application of AI in various educational systems, and (e) the integration of AI in project-based learning (PBL) to provide automatic feedback and support the dynamics of student teamwork

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