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The Influence of Critical Thinking, Collaborative Skills on Learning Outcomes of Sensor and Actuator Competency of Electrical Engineering Collegers in Indonesia

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***Abstract*— Critical thinking is a competency essential for collegians in both personal and professional contexts. For this reason, universities should integrate it effectively into their curricula, programs, and courses. Collaboration is a key factor in advancing both educational theory and technology. This study examines how critical thinking and collaboration skills influence the learning outcomes of electrical engineering collegers in Indonesia when applied through Problem-Based Learning (PBL) and Project-Based Learning (PjBL). The research involved colleagues from five universities in Surabaya, with a specific focus on competencies related to sensors and actuators. Data were collected through questionnaires and written tests, then analyzed using SEM-PLS, employing path analysis and bootstrap methods to assess direct and indirect effects. The results indicate that critical thinking, mediated through collaboration, can improve collegers' abilities by 26.3% in the cognitive domain and 16.4% in the affective domain. Furthermore, critical thinking directly impacts cognitive and psychomotor learning outcomes, while indirectly influencing psychomotor outcomes through collaboration. These findings highlight the importance of fostering critical thinking and collaborative skills to enhance learning outcomes in engineering education.**

***Keywords*—Affective, Cognitive, Collaborative, Critical Thinking, Learning Outcomes, Psychomotor.**

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I. INTRODUCTION

The demands of the twenty-first century require university colleagues to take an active role in learning and continuously develop their intellectual capacity to adapt to social changes. Academic knowledge by itself is no longer enough. Collegers are also expected to build essential skills, including critical and creative thinking, problem solving, effective communication, collaboration, digital competence, and awareness of global challenges(Andrini, 2016).

Critical thinking is a crucial intellectual skill in everyday life. In today's fast-paced information era, it enables individuals to distinguish accurate and relevant information from misleading or biased sources. Critical thinking involves evaluating, analyzing, and concluding using logic and reason. It helps people avoid deception, manipulation, and the spread of false information while identifying strengths and weaknesses in arguments or approaches. This skill also enhances communication, allowing individuals to present ideas clearly and logically. Critical thinking requires recognizing underlying assumptions, avoiding stereotypes and unfair biases, and seeking evidence that supports or challenges a claim. It allows for decision-making based on objective analysis and supports effective problem-solving. For collegers, critical thinking fosters deep understanding and analytical skills when studying learning materials. The process involves connecting new knowledge with existing understanding and includes two levels: Lower Order Thinking Skills and Higher Order Thinking Skills (Kabeel & Eisa, 2016). High Order Thinking Skill is the part that has to be acquired by a colleague. However, the fact is collegers have not trained their High Order Thinking Skills yet (Taghva, Rezael, Ghaderi, & Taghva, 2014).

Critical thinking trains someone to identify inconsistent or contradictory arguments. By thinking critically, one can identify deficiencies or errors in a process or system. Critical thinking helps one face challenges with confidence and independence. In complex decision-making, critical thinking allows one to consider all relevant factors before making a final decision. Critical thinking allows one to analyze and evaluate ideas and information. In addition, critical thinking relies heavily on reasoning and logic. This means connecting ideas clearly and rationally, identifying patterns, and recognizing assumptions or weaknesses in arguments. By doing so, individuals can decide what to believe or what action to take (Redifer, Bae, & Zhao, 2021). Critical thinking helps a person become a more independent individual and is not easily influenced by other people's opinions and thoughts. Critical thinking skills are essential for making wise and rational decisions because they allow individuals to carefully analyze situations, evaluate possible options, and consider the

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consequences of their choices. Instead of reacting impulsively or relying solely on assumptions, critical thinkers use evidence, logic, and reasoning to arrive at well-informed decisions. Critical thinking allows one to look at problems from multiple perspectives and find the most effective solutions. Individuals who are able to think critically can adapt more effectively to different situations by identifying, understanding, and analyzing problems in a systematic way. Instead of focusing only on surface issues, critical thinkers examine the root causes of a problem and consider all relevant factors that may influence the outcome (Ulger, 2018). As a benchmark, critical thinking shows whether an individual can actively engage with their environment by observing details, recognizing problems, and responding thoughtfully. It measures a person's ability to use logical reasoning, evidence, and established principles to make sense of what is happening around them (Mursid, Saragih, & Hartono). By thinking critically, one can develop strong analytical skills and relate information from various sources. Critical thinking helps one overcome cognitive biases and consider different points of view. In the business world, critical thinking allows one to more accurately identify opportunities and risks. Critical thinking involves the ability to construct cohesive and well-organized arguments. By thinking critically, one can overcome reasoning errors and logical biases in their thinking. Critical thinking involves skills in asking relevant questions and challenging the status quo. In group decision-making, critical thinking allows for more effective collaborative thinking. Critical thinking helps in developing sensitivity to social and ethical issues. By thinking critically, one can identify errors in other people's reasoning and convey criticism constructively. Critical thinking enables one to deal with complexity and ambiguity in uncertain situations. In making decisions that involve long-term implications, critical thinking helps one consider the long-term impact of the decision. Critical thinking involves the ability to identify and overcome confirmation bias. By thinking critically, one can evaluate the reliability and validity of information sources. Critical thinking helps one develop a deep and comprehensive understanding of a topic. In solving complex problems, critical thinking allows for more efficient and effective problem-solving. Critical thinkers consider different ideas, experiences, and methods, recognizing that complex problems often require more than one way of thinking. By thinking critically, one can identify and overcome weaknesses in their own argument. Critical thinking helps one develop a critical sense of unreasonable authorities and leaders. Critical thinking is becoming increasingly important in education because it helps individuals develop skills that go beyond memorization and simple learning. Critical thinking enables individuals to question assumptions, examine information carefully, and use knowledge in purposeful ways. This way of thinking also fosters creativity, as it opens space to explore new ideas and develop innovative solutions to existing problems. (Syahrin, Dawud, Suwignyo, & Priyatni, 2019).

Critical thinking is essential in learning because it helps collegers improve their understanding and achieve better learning outcomes (Subuh, Ekohariadi, Munoto, Lilik, & Fendi, 2022). When learning, it's not enough to just memorize facts; critical thinking allows collegers to analyze information, understand connections between ideas, and evaluate the accuracy and relevance of what they are studying. (Jia, Li, & Cao, 2019). Critical thinking benefits both teachers and colleagues because it helps make the learning process more effective and meaningful. For collegers, critical thinking allows them to process their thoughts clearly and find learning methods that work best for them personally. It encourages them to understand the true meaning of what they are learning, rather than just memorizing facts, and to identify the main points or key ideas of a lesson, which makes studying more focused and efficient (Huang, Chang, & & Chou, 2020). Critical thinking allows one to identify the long-term implications of their decisions or actions. By thinking critically, one can recognize and overcome contradictions in their own thinking. Critical thinking helps one understand the difference between fact and opinion, so that one can make decisions based on valid information. In dealing with complex problems, critical thinking allows one to break them down into smaller and more easily solved parts. Critical thinking involves the ability to identify and evaluate the underlying premises of an argument. By thinking critically, one can develop skills in substantiating their arguments with relevant evidence. Critical thinking helps a person recognize deficiencies in their own knowledge and look for ways to improve them. In learning, critical thinking allows collegers to develop analytical skills that are important in understanding subject matter. Critical thinking involves the ability to identify and evaluate the assumptions underlying a statement. By thinking critically, one can recognize logical fallacies in other people's thinking and ask relevant questions. Critical thinking helps a person become more open to new ideas and different perspectives. In the research process, critical thinking allows one to collect and analyze data objectively. Critical thinking involves the ability to identify and understand complex arguments. By thinking critically, a person can recognize and overcome biases that may affect their thinking. Critical thinking helps a person develop the ability to convey opinions persuasively and effectively. In solving problems, critical thinking allows one to consider various possible solutions and choose the most optimal one. Critical thinking involves the ability to recognize and evaluate arguments that contradict our own views. By thinking critically, one can recognize and overcome weaknesses in their own reasoning. Critical thinking helps a person become more independent in processing information and making decisions based on rational thinking (Farid, Bambang, Lilik, & Yuyun, 2023). In interpersonal relationships, critical thinking allows one to understand and appreciate the viewpoints of others. Critical thinking is not just useful in school, but it is also important throughout life, especially in work and social situations. It supports ongoing professional development by enabling individuals to assess situations, compare available options, and make decisions based on clear and logical reasoning (Gube & Lajoie, 2020) (Sumarni & Kadarwati, 2020). A cross-sectional correlational study involving 209 university collegers in Hong Kong was conducted to measure their critical thinking, cognitive ability, and disposition toward critical thinking, aiming to determine the factors that affect critical thinking (Segundo Marcos, López Ferández, Daza González, & & Phillips-Silver, 2020).

Collaboration is a process of cooperation between individuals or groups that aims to achieve a common goal. In the world of education, collaboration is a key element in creating an effective learning environment. Collaboration allows colleagues to learn together and support each other in achieving a deeper understanding. Through collaboration, colleagues can develop social skills, such as the ability to communicate, work in teams, and listen to the opinions of others. Collaboration in education promotes an inclusive environment where all colleagues feel heard and valued. By collaborating, colleagues can combine their skills and knowledge to solve problems effectively. Collaboration also helps collegers broaden their horizons through interactions with people with different backgrounds and perspectives (Sandhya, Ramananda, Jagadeesha, Rajesh, & Reni, 2021). Through collaboration, colleagues learn to respect each other and respect differences, thus forming an inclusive and tolerant attitude. Collaboration in education allows teachers and colleagues to share knowledge, experiences, and innovative ideas. By collaborating, teachers can enrich colleagues' learning experiences through the use of various teaching methods and strategies. Collaboration enables teachers to join forces and share ideas to improve the teaching and learning process. Collaborating teachers can support and inspire each other in improving the quality of their teaching. Collaboration also involves the involvement of parents and guardians in their children's education. Through collaboration between schools and families, collegers receive consistent support in developing their potential. Collaboration between teachers and parents allows important information to be exchanged about colleagues' development, so that appropriate steps can be taken to support them. In the digital era, collaboration also occurs through online learning platforms, where colleagues and teachers can interact and share knowledge virtually. Collaboration in education allows collegers to learn from their peers, developing important social and emotional skills. Through collaboration, colleagues learn to work in teams and build healthy relationships with others. Collaboration allows colleagues to feel satisfaction in achieving a common goal, increasing their motivation and involvement in learning (Farid, Bambang, Lilik, & Yuyun, 2023).

Collaboration skills can be assessed through self-evaluation. These skills cover two main areas. First, personal skills related to managing one's own work, such as preparation, motivation, work quality, and time management. Second, teamwork skills that reflect how someone functions in a group, including flexibility, active contribution, interaction with others, understanding team roles and dynamics, and providing support to teammates. Together, these competencies help individuals perform effectively both independently and in collaboration with others (Hinyard, Eliot, Toomey, & Breitbach, 2018).

One of the competencies of college graduates that can describe the real-world learning process is sensors and actuators (Baskoro, B, et al., 2025; Baskoro, Rohman, et al., 2025). Using sensors can support the learning process (Elstermann, Betz, Lederer, Schmidt, & & Bührer, 2021). A reference model focused on the subject of commissioning virtual factory operations (Yang, et al., 2020). This study uses PjBL and PBL based on the above background, to explore the indirect and direct relationship of collaboration, critical thinking, to sensor and actuator capabilities of cognitive, affective, and psychomotor in electrical engineering colleagues. The purpose of this research is to serve as an assessment system for integrated learning models within the curriculum, helping collegers develop content proficiency through real-life situations.

II. Method

This study employs a quantitative research methodology, which involves collecting and analyzing numerical data to examine relationships between variables and draw objective conclusions (Johnson & Christensen, 2017). A quantitative approach helps researchers make objective conclusions. This method was chosen to check if the measurement model for the study variables is valid and practical. The study looks at critical thinking using the IAEIE model, which stands for Interpretation, Analysis, Evaluation, Inference, and Explanation, with five indicators to measure each part (Facione, 2015). Collaboration skills are measured using the CCIF model (Cooperate, Contribute, Interaction, Flexibility), which includes four indicators (Hinyard, Eliot, Toomey, & Breitbach, 2018). Finally, learning outcomes are measured using the CAP model (Cognitive, Affective, Psychomotor), which includes nine indicators. Together, these models provide a structured approach to evaluating the relationship between critical thinking, collaboration, and learning outcomes (Rao, 2020). All variables and indicators can be seen in Table I.

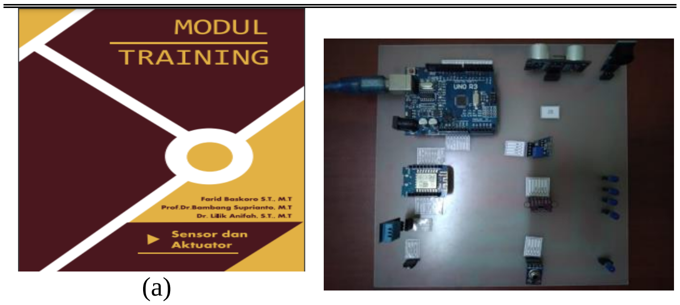
This study involved 206 electrical engineering students from five universities in Surabaya, Indonesia. We recognize that the sample may not fully represent all electrical engineering colleagues in Indonesia. Collegers were selected based on accessibility and voluntary participation, which may have introduced response bias and limited the generalizability of the findings. As a result, the conclusions may not fully reflect the broader college population. Future studies should involve more diverse and representative samples to enhance the robustness and validity of the results. In this research, learning activities were conducted using Project-Based Learning (PjBL) and Problem-Based Learning (PBL) approaches, supported with sensor and actuator trainer kits, as shown in Figure 1, to help collegers learn through practical, hands-on experiences.

Collegers work in teams to solve problems and find solutions. The training combines PBL and PjBL skills, including understanding content, communication, presentations, time management, organization, self-assessment, reflection, problem-solving, leadership, group participation, and critical thinking. Independent learning is supported through the https://faridbaskoro.wixsite.com/sensordanaktuator. The site offers structured materials on sensors and actuators that can be accessed anytime. Learners can review key concepts at their own pace, reinforce what is covered in class, and build a stronger understanding through repeated practice.

This study took place from September 2022 to May 2023. Data were gathered through questionnaires to evaluate collaboration skills, written tests to measure critical thinking and cognitive abilities, and interviews to assess learning outcomes in the affective and psychomotor domains. According to Hair et al., SEM-PLS is a statistical method that allows multiple relationships to be analyzed simultaneously and is commonly used for prediction, exploratory analysis, and the development of structural models (Hair, Risher, & Sarstedt, 2019). SEM-PLS offers several advantages, including minimal requirements for data distribution, the ability to handle complex models, and flexibility for prediction, exploration, and model development. The analysis emphasizes latent variables that are represented through observed indicators. In this research, the latent variables are classified into two groups: exogenous variables, consisting of critical thinking and collaboration skills, and endogenous variables, comprising cognitive, affective, and psychomotor learning outcomes.

TABLE I
VARIABLES, SUB-INDICATORS, AND BENCHMARKS

Variable	Indicator	Code	benchmark
Critical Thinking Adoption from (Facione, 2015)	Interpreted	KR1	Skill to describe, explain, organize, and notice trends or patterns.
	Analysis	KR2	Ability to explain what something is clearly and study the information carefully to understand it or find patterns
	Evaluation	KR3	Ability to explain a problem
	Inferences	KR4	Ability to identify a problem with a sensor and find a different way to fix it or achieve the goal
	Explanation	KR5	The ability to clearly present what happened in the experiment and explain what it means
Collaboration Skills (Hinyard, Eliot, Toomey, & Breitbach, 2018)	Cooperate	KL1	Ability to share useful information with the team, help and support each other, and treat everyone politely and fairly.
	Contribute	KL2	Material readiness, work productively, and the ability to inspire
	Interaction	KL3	Ability to express your ideas clearly and confidently, and act on tasks or solve problems
	Flexibility	KL4	Adaptability, time management skills, and self-mastery
Learning outcomes (Rao, 2020)	Cognitive	KG1	The skill to clearly describe how motion sensors work
		KG2	Ability to connect sensors and actuators
		KG3	to clearly describe what light sensors are, how they work, and what they are used for.
		KG4	Ability to explain temperature sensors
	affective	AF1	Ability to work together
		AF2	Ability to be independent
		AF3	Responsible ability
	Psychomotor	PS1	Ability to describe processes
		PS2	Ability to describe products / Results



(a)

(b)

Fig. 1. Cover module Training, (b) Training Kit

III. RESULT

A. Outer Model Test Analysis

The evaluation of the measurement model focused on reliability, average variance extracted, and discriminant validity for each indicator. Convergent validity was first tested using standardized outer loadings, with a threshold of 0.70 to indicate acceptable validity. The outcomes of this analysis are presented in Table II. Based on the results, item KL1 shows an outer loading of 0.464, indicating that indicators with values below 0.70 were excluded from the model. For KR3 it has a value of 0.697 according to Chin (1998), the item is still allowed because its value is still above 0.6 (Chin & Marcoulides, 1998).

TABLE II.
OUTER MODEL

	Affective_Learning Result	Cognitive_Learning Result	Collaboration_Skills	critical_Thinking	psychomotorik_Learning Result
AF1	0.916				
AF2	0.892				
AF3	0.922				
KG1		0.701			
KG2		0.776			
KG3		0.769			
KG4		0.763			
KL1			0.464		
KL2			0.863		

KL 3	0.896		
KL 4	0.755		
KR 2		0.712	
KR 3		0.697	
KR 4		0.736	
KR 5		0.710	
PS1			0.928
PS2			0.946
KR 1		0.752	

B. *Convergent Validity Test and Composite Reliability*

Reliability at the construct level was evaluated using Cronbach's alpha to assess the internal consistency of the indicators. In addition, composite reliability was applied to measure the true reliability of each construct by considering the contribution of individual indicator loadings. Together, these measures provide a more comprehensive assessment of the consistency and reliability of the measurement model.

In general, composite reliability and Cronbach's alpha values above 0.70 are regarded as acceptable thresholds. When either of these measures exceeds 0.70, the construct is considered to demonstrate adequate reliability (Hair, Risher, & Sarstedt, 2019). The construct shows adequate reliability, indicating that it consistently captures the concept it is intended to measure. Convergent validity assesses the extent to which the indicators properly represent the construct. This evaluation is based on three aspects. Item reliability describes the strength of each indicator in measuring the construct. Composite reliability reflects the overall consistency of the indicators when considered together. Average Variance Extracted (AVE) indicates how much variance in the indicators is explained by the construct. High convergent validity means the indicators are strongly related and accurately reflect the underlying concept. Common criteria require factor loadings to be above 0.70 and AVE values to exceed 0.50. The results of the reliability and convergent validity analyses are shown in Table III and Figure 2. Table III presents the composite reliability results, where Cronbach's alpha values are above 0.70, confirming construct reliability. In addition, the AVE values exceed 0.50, demonstrating that the convergent validity requirements are met. Together, these results confirm that the measurement instruments are both reliable and valid.

TABLE III
RELIABILITY TEST RESULTS AND CONVERGENT VALIDITY

Variabel	Cronbach's Alpha	Test results	AVE	Test results
Affective_ learning result	0.896	Realibel	0.828	Valid
Cognitive_ learning result	0.745	Realibel	0.567	Valid
Collaboration_ skills	0.774	Realibel	0.583	Valid
Critical_ Thinking	0.774	Realibel	0.521	Valid
Psychomotorik_ Learning Result	0.863	Realibel	0.879	Valid

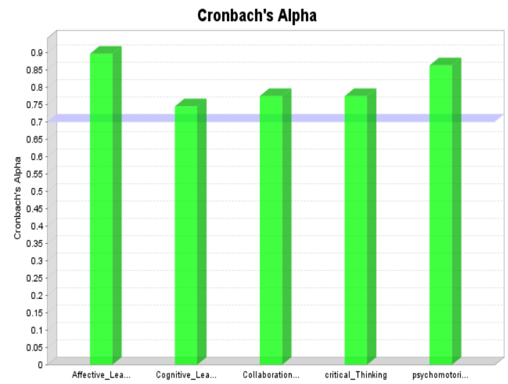


Fig. 2. Comparison of Cronbach's alpha

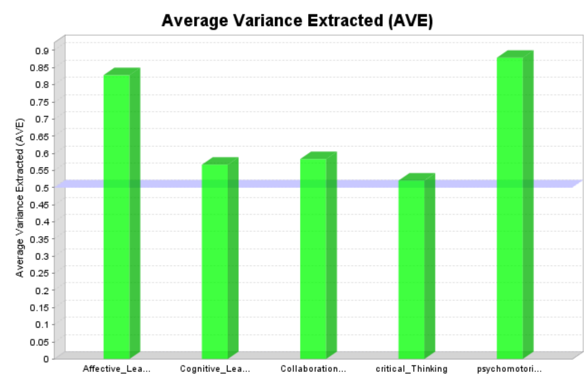


Fig. 3. AVE values

C. *Discriminant Validity*

Discriminant validity may be examined by applying the Fornell–Larcker criterion to determine whether each construct is conceptually and empirically distinct from the others included in the model. This approach focuses on comparing the relationships among latent variables. A construct is regarded as demonstrating sufficient discriminant validity when the square root of its AVE is higher than its correlations with other constructs. This condition indicates that the construct shares more variance with its own indicators than with external constructs. Furthermore, discriminant validity can also be evaluated using the Heterotrait–Monotrait (HTMT) ratio. HTMT values below the recommended threshold of 0.90 suggest that the constructs are not excessively correlated and therefore exhibit acceptable discriminant validity. As presented in Table IV, the results confirm that all constructs meet the discriminant validity criteria and are clearly distinct from one another.

TABLE IV
DISCRIMINANT VALIDITY HETEROTRAIT-MONOTRAIT RATIO

	Affective Learning Result	Cognitive Learning Result	Collaborative Skills	Critical Thinking	Psychomotorik Learning Result
Affective_Learning Result					
Cognitive_Learning Result	0.406				
Collaboration_Skills	0.340	0.400			
Critical_Thinking	0.424	0.625	0.398		
Psychomotorik_Learning Result	0.289	0.421	0.391	0.400	

D. Structure Test (Inner Model)

Evaluating the structural model involves testing the relationships between research variables to see how one variable affects another. The process is conducted in three steps. The first step is to check for multicollinearity, which occurs when variables are too closely related, making it difficult to determine their individual effects. This is done using the Variance Inflation Factor (VIF), where a value below 5 indicates no multicollinearity. In this study, all VIF values were below 5, confirming that the model estimates are reliable and unbiased. The second step tests whether the relationships between variables are significant, using a t-test or p-value. A t-value above 1.96 or a p-value below 0.05 indicates a significant effect, meaning the variable truly influences the other. The final step is presenting the results: Figure 4 shows the overall structural model, Figure 5 presents the significance of direct relationships between variables, and Figure 6 shows indirect effects. Together, these steps ensure that the model is correctly specified, the relationships are meaningful, and the results can be trusted.

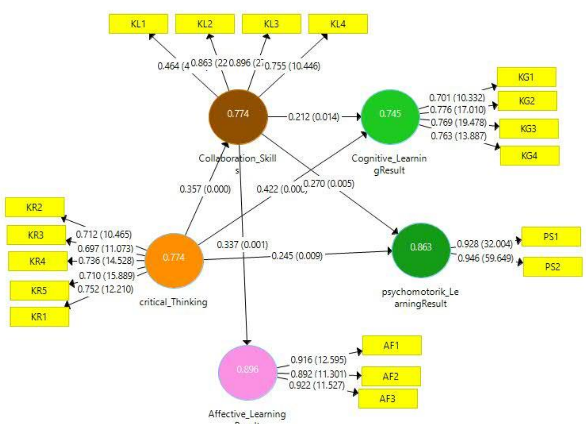
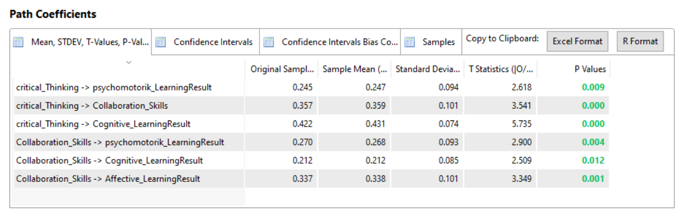


Fig. 4. Structure test results (inner model and outer model)

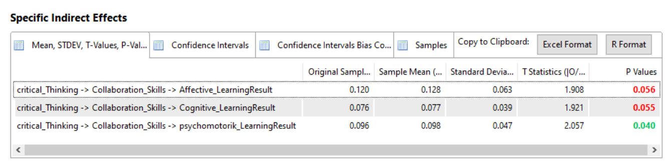


Path Coefficients

Mean, STDEV, T-Values, P-Val... | Confidence Intervals | Confidence Intervals Bias Co... | Samples | Copy to Clipboard: | Excel Format | R Format

	Original Sampl...	Sample Mean (...	Standard Devia...	T Statistics (|O/...	P Values
critical_Thinking -> psychomotorik_LearningResult	0.245	0.247	0.094	2.618	0.009
critical_Thinking -> Collaboration_Skills	0.357	0.359	0.101	3.541	0.000
critical_Thinking -> Cognitive_LearningResult	0.422	0.431	0.074	5.735	0.000
Collaboration_Skills -> psychomotorik_LearningResult	0.270	0.268	0.093	2.900	0.004
Collaboration_Skills -> Cognitive_LearningResult	0.212	0.212	0.085	2.509	0.012
Collaboration_Skills -> Affective_LearningResult	0.337	0.338	0.101	3.349	0.001

Fig. 5. Path coefficients direct relationship



Specific Indirect Effects

Mean, STDEV, T-Values, P-Val... | Confidence Intervals | Confidence Intervals Bias Co... | Samples | Copy to Clipboard: | Excel Format | R Format

	Original Sampl...	Sample Mean (...	Standard Devia...	T Statistics (|O/...	P Values
critical_Thinking -> Collaboration_Skills -> Affective_LearningResult	0.120	0.128	0.063	1.908	0.056
critical_Thinking -> Collaboration_Skills -> Cognitive_LearningResult	0.076	0.077	0.039	1.921	0.055
critical_Thinking -> Collaboration_Skills -> psychomotorik_LearningResult	0.096	0.098	0.047	2.057	0.040

Fig. 6. Path coefficients indirect relationship.

The construct in this study demonstrates strong reliability, indicating that it consistently measures what it is intended to measure. Reliability testing was conducted using Cronbach's alpha, where a value greater than 0.70 indicates acceptable internal consistency. The results show that all constructs achieved Cronbach's alpha values above this threshold, demonstrating that they meet the reliability criteria. Convergent validity was evaluated to determine whether the indicators (observable variables) effectively reflect their underlying dimensions. It was assessed using item reliability, composite reliability, and the AVE. Higher convergent validity indicates that the indicators are strongly related and effectively represent the latent variables. The study results show that the AVE values exceed 0.5 and factor loadings are above 0.7, meeting the criteria for convergent validity.

Discriminant validity was examined by employing both the HTMT ratio and the Fornell–Larcker criterion. The HTMT approach requires values below 0.90 to indicate that constructs are not overly correlated, while the Fornell–Larcker criterion states that the square root of each construct's AVE be greater than its correlations with other constructs. Based on the results reported in Table IV, the constructs in this study are clearly distinguishable and show no strong correlations, indicating adequate discriminant validity.

Evaluation of the structural model was carried out to test the proposed hypotheses on the relationships among variables. The analysis began with a multicollinearity check using the VIF, where values below 5 indicate the absence of multicollinearity. All VIF results were below this threshold, showing that the model estimates are stable and unbiased. Next, the significance of relationships between variables was examined using t-statistics and p-values, with t-values greater than 1.96 or p-values below 0.05 indicating significant effects. Both direct effects and indirect (mediating) effects were analyzed, and the mediating effects were evaluated using the upsilon v statistic. The f^2 value was used to assess the magnitude of direct effects, interpreted as 0.02 (small), 0.15 (medium), or 0.35 (large), while the upsilon v statistic indicated 0.02 (low), 0.075 (medium), or 0.175 (high) mediating effects. The R^2 value measures how much of the variance in endogenous variables is explained by exogenous variables, with 0.66 considered high, 0.33 moderate, and 0.19 low; in this study, the average R^2 was 0.277, showing moderate explanatory power. The Q^2 value evaluates predictive accuracy, with values of 0, 0.25, and 0.50 representing low, moderate, and high predictive relevance, respectively. Table 5 presents the f^2 values, illustrating the strength of influence of the latent variables. Direct and indirect relationships are visualized in Figures 4, 5, and 6, providing a comprehensive view of the model's structural relationships.

The model fit was assessed using the Standardized Root Mean Square Residual (SRMR), which compares the correlation matrix of the observed data with that of the estimated model. In this study, the SRMR was 0.077, indicating an acceptable fit. According to standard guidelines, values below 0.08 reflect a good fit, while values between 0.08 and 0.10 are still acceptable but may require improvement. In addition, the Goodness of Fit (GoF) Index was used to evaluate the overall fit of the measurement model, particularly for reflective constructs. Based on Table V, the average communality value is 0.676, and the average R^2 value is 0.277. Using these values, the calculated GoF Index is 0.432, which is considered a good fit. This indicates that the estimated model in this study meets the criteria for a strong overall fit, although there remains potential for further improvement in data analysis and the use of the unique dataset collected.

Overall, the results of the reliability tests, convergent and discriminant validity assessments, structural model evaluation, and model fit metrics demonstrate that the measurement instruments and structural model used in this study are both reliable and valid, providing a robust foundation for testing the research hypotheses.

TABLE V
R SQUARE, Q SQUARE, SRMR, NFI, CHI-SQUARE, AND GOF INDEX

	R square	Q square	RMSE	MAE	Q2_ Predict	SRMR	NFI	Gof Index
Affective_ LearningResult	0.214	0.158	0.984	0.799	0.161	0.077	0.679	0.432
Cognitive_ LearningResult	0.387	0.328	0.901	0.672	0.324			
Collaboration_ Skills	0.227	0.196	0.966	0.733	0.198			
Psychomotorik_ LearningResult	0.280	0.631	0.975	0.676	0.187			

TABLE VI
VALUE OF F-SQUARED

	Affective_ Learning Result	Cognitive_ Learning Result	Collaboration_Skills	Critical_ Thinking	Psychomotorik_ Learning Result
Affective_Learning Result					
Cognitive_Learning Result					
Collaboration_Skills	0.128	0.055			0.077
Critical_Thinking		0.218	0.146		0.064
Psychomotorik_Learning Result					

One possible reason for the relatively low R^2 values could be the complexity of the variables involved, where other unmeasured factors or latent variables may significantly influence learning outcomes. This suggests that while critical thinking and collaborative skills are important, they are not the only predictors of success in these domains. To address this limitation, future research could explore alternative models or include additional variables that better capture the multifaceted nature of learning outcomes in engineering education. For example, incorporating factors such as colleagues' prior knowledge, motivation, or learning environment might provide a more comprehensive explanation of the variance in learning outcomes. Moreover, the model fit indices, including the SRMR (0.077) and the GoF Index (0.432), indicate that while the model is generally acceptable, there is still room for improvement. Recognizing these limitations, further studies should aim to refine the model to enhance its explanatory power and more accurately capture the relationships among critical thinking, collaboration, and learning outcomes.

The practical implication of this finding is that other variables, such as prior knowledge, motivation, learning environment, and instructional methods, should also be considered when designing learning activities. For this study, this suggests that while Project-Based Learning and Problem-Based Learning effectively enhance sensor and actuator competencies as well as psychomotor skills, additional strategies may be needed to further improve cognitive and affective learning outcomes. Recognizing these factors can help educators and program designers develop more comprehensive, adaptive, and personalized instructional approaches, thereby optimizing the impact of critical thinking and collaboration on overall learning outcomes.

CONCLUSION

Based on the analysis findings, several conclusions can be drawn. Through Project-Based Learning (PjBL) and Problem-Based Learning (PBL), collegers are encouraged to analyze and solve real-world problems or engage in projects with direct practical relevance. This approach helps collegers gain a deeper understanding of sensor and actuator competencies while simultaneously developing critical thinking skills. In PBL and PjBL, colleagues work collaboratively in groups to achieve learning goals, which fosters the development of communication, teamwork, negotiation, and problem-solving skills in a team context.

The influence of critical thinking, mediated through collaborative skills, was found to improve learning outcomes in the psychomotor domain. However, the indirect effect of critical thinking through collaboration is less effective in enhancing learning outcomes in the cognitive and affective domains. Specifically, the 97.5% confidence interval for the effect of critical thinking through collaborative learning shows a value of 0.263 for the cognitive domain and 0.164 for the affective domain, with P-values of 0.055 and 0.056, respectively, indicating weak effects. These results suggest that with further improvements in collaborative learning strategies, the impact of critical thinking on cognitive and affective learning outcomes could be strengthened.

Overall, the development of critical thinking skills through collaboration benefits psychomotor learning outcomes by enhancing colleagues' ability to analyze and solve problems effectively in a team setting, contributing to a deeper understanding of sensor and actuator competencies.

Despite these findings, the study has some limitations. The relatively low R^2 values indicate that the model may not fully capture the complexity of how critical thinking and collaborative skills influence learning outcomes across cognitive, affective, and psychomotor domains. Additionally, the sample size and composition may not fully represent the diversity of electrical engineering collegians in Indonesia, which could affect the generalizability of the results. Future research should address these limitations by employing a more diverse and representative sample and refining the conceptual framework to better capture the interplay between these variables.

Nevertheless, this study provides valuable insights into the role of critical thinking and collaborative skills in enhancing technical competencies, laying the groundwork for future studies aimed at optimizing educational strategies in engineering education.

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