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The Influence of Computational Thinking Skills, Critical Thinking Skills, and Collaborative Thinking Skills on the Learning Outcomes of Robotics Competence of Electrical Engineering Education Students

Fendi Achmad[1*], Agus Wiyono[1], M. Syariffuddien Z[1], Nur Kholis[1], Ali Nur Fathoni[1], Inaya Retno Putri[1], Daeng Rahmatullah[1], Yuli Sutoto Nugroho[2]
[1] Universitas Negeri Surabaya, Surabaya, Indonesia
[2] Queen Mary University of London, London, England

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ABSTRACT

Objective: This study aims to examine the influence of computational thinking skills, critical thinking skills, and collaborative thinking skills on the learning outcomes of robotics competencies of Electrical Engineering Education Students. **Method:** The sample in this study was 150 respondents, all of whom were students of the Electrical Engineering Education Study Program at Universitas Negeri Surabaya. The research data were obtained from filling out the questionnaire and analyzed quantitatively using the SEM PLS analysis technique with the help of the SmartPLS program. **Results:** This study shows that (1) Critical thinking skills have a positive effect on the educational robotics-based learning system, (2) computational thinking skills have a positive effect on the educational robotics-based learning system, (3) collaborative skills have a positive effect on the educational robotics-based learning system, (4) critical thinking skills have a positive effect on learning outcomes, (5) Computational Thinking Skills have a positive effect on learning outcomes, (6) Collaboration Skills have a positive effect on learning outcomes, (7) educational robotics-based learning systems have a positive effect on learning outcomes. **Novelty:** Educational robotics-based learning systems can be an ideal platform for developing computational, critical, and collaborative thinking skills among students. The use of robots as interactive and direct learning media through experiments and problem solving. This can help better understand technical concepts and increase confidence in facing complex challenges in the increasingly connected and rapidly changing real world.

INTRODUCTION

The topic of using robotics to support various needs has become commonplace over the past decade. In particular, using robotics in educational contexts has become the most researched topic (Chaidi et al., 2021; Conde et al., 2021; Schina et al., 2021) where most of the robots that have been tested in previous studies involve the use of the latest user interfaces and humanoid robots that attract users' attention and facilitate social interaction between the robot and the user.

Several studies have concluded that robot behavior leaves a strong impression on users. Robot movement and human body expression can provide strong motivation that influences the user's decision-making process. Compared to public reactions to demonstrations of educational robotic kits with demonstrations of educational robotic kits through computer animation and simulation.The results Showed that demonstrations of educational robotic kits resulted in increased public reactions. Thus, robots are expected to be useful as demonstration tools (kits) in various interactive fields, including entertainment, education, security, rescue, and elderly care. In addition, some robots can likely be particularly successful social actors in mixed-reality environments.

Recently, studies in education have investigated various topics related to the application of technology to support and enhance learning motivation in the classroom. Several of these studies have concluded that students who are motivated to learn are more involved, make more effort, and try to complete tasks than students who are not motivated (Chiu et al., 2022; Ismail et al., 2022; Wolters & Brady, 2021). Although learning is a complex process that cannot be understood simply by analyzing human (student) responses to aspects of technology, previous studies have shown that certain technologies can enhance students' learning motivation. Therefore, educational robotic-based learning systems can be considered a step forward in the evolution of educational technology, and many models have been successfully implemented in various educational settings. Previous studies have shown that educational robotics can communicate effectively and enhance students' comfort and engagement in the classroom.

The Japan Robotics Association, the United Nations Economic Commission, and the International Federation of Robotics have indicated that using robots specifically for entertainment and educational purposes has experienced rapid growth in recent years. The Japan Robotics Association, the United Nations Economic Commission, and the International Federation of Robotics anticipate this trend will continue for the next few years. More and more studies have included educational robotics kits as tools to support educational activities, as educational robotics kits offer new benefits in several educational settings (Bano et al., 2024; Ching & Hsu, 2024; Uslu et al., 2023). Novice learners can learn new skills by designing and assembling their robots; activities related to educational robotics kits offer great potential to enhance the teaching and learning process in the classroom.

Educational robotic kits can capture the imagination of new learners and the potential of new learners practically in various needs, including enabling disabled learners to interact with the campus environment. Educational robotic kits encourage new learners to improve their English skills while contributing to new learners' interest in learning English. Teachers concluded that the educational robotics kit created an interactive learning experience and enhanced the learning experience by engaging and maintaining students' interest (Papadakis, 2022; Tang et al., 2023; Yang et al., 2022). Moreover, the learning material facilitated the development of computational and critical thinking skills, which were then elaborated with collaborative skills.

However, educational robotic kits are relatively undeveloped. No empirical evidence supports the importance of using robots in educational settings. Many studies have used educational robotic kits to motivate students to learn. Research on this subject is usually descriptive, and the findings are based only on reports of teachers who have achieved positive results based on personal initiative. In addition, further empirical evidence is needed to confirm the effectiveness of educational robotic kits. Thus, the potential of educational robotic kits requires further research. Specifically related to the world of education, investigating the impact of educational robotic kits on critical thinking, computational thinking, and collaborative skills is very important.

This study conducted an experimental evaluation to stimulate students' critical thinking, computational thinking, and collaborative skills towards a robotics kit-based learning system oriented towards robot contests by targeting one of the state universities in East Java that participated in robot contests at regional and national levels. The participants comprised one teaching staff and 38 students divided into two classes. The course instructor randomly assigned one class as the experimental group (24 students), and the other class was assigned as the control group (14 students). The evaluation results were obtained by collecting and analyzing data from various sources, including pre-test evaluation, post-test evaluation, and questionnaire survey. This study evaluates the learning performance of students who elaborate critical thinking skills, computational thinking skills, and collaborative skills of students with a learning system based on robotics kits (educational robotic-based learning system) and compares it with students who are taught using both classical learning systems and project-based learning. Can the study results show that students taught using educational robotic-based learning systems can significantly outperform classical and project-based learning systems? The following are the specific objectives of this study: to test the influence of computational thinking, critical thinking, and collaborative thinking skills on the learning outcomes of robotics competencies for Electrical Engineering Education students.

RESEARCH METHOD

Population and Sample

The study's population includes all undergraduate students from the Faculty of Engineering at Universitas Negeri Surabaya. A purposive sampling technique was used to select a sample of 150 students actively enrolled in robotics courses. This method targets students directly involved in robotics education, facilitating a focused analysis of their experiences and outcomes.

Data Analysis Techniques

The data in this study were analyzed using the SEM PLS analysis technique with the aid of SmartPLS version 3. The reason for using SEM PLS is that the research model to be estimated is quite complex, involving mediating and moderating variables. Additionally, SEM PLS does not require a minimum or maximum sample size, which is advantageous if the obtained sample is small. However, SEM PLS performs very well with large samples (Hair et al., 2000). Besides these reasons, another reason is that the researcher wants to avoid analysis bias caused by data abnormalities. SEM PLS with SmartPLS is one of the analysis techniques robust against data abnormalities.

Descriptive Statistics

This study involves 150 respondents, all students from the Faculty of Engineering at the State University of Surabaya. Based on the data collected in this study, the following is an overview of respondent characteristics by study program, type of higher education institution, and gender. By study program, the majority of respondents are enrolled in the Bachelor's program in Electrical Engineering (56.0%), while 31.3% are in the Bachelor's program in Electrical Engineering Education, 6.7% are in the Bachelor's program in Mechanical Engineering, 2.0% are in the Bachelor's program in Information Technology Education, 2.0% are in the Diploma 4 program in Electrical Engineering, and 0.7% are in the Bachelor's programs in Information Systems, Mechanical Engineering Education, and Informatics Engineering, respectively. Furthermore, according to higher education institutions, most respondents are from Universitas Negeri Surabaya (61.3%), while the remaining 38.7% are from Politeknik Perkapalan Negeri Surabaya. Most respondents are male (80.0%), with the remaining 20.0% being female.

SEM PLS Analysis

In this study, the influence between variables in the research model will be analyzed using path analysis with the aid of SmartPLS software. The path analysis phase using SmartPLS consists of the goodness of fit testing stage. In the outer model testing stage, the validity and reliability of the constructs are examined, while in the inner model, the research hypotheses are tested.

RESULTS AND DISCUSSION

Results

Convergent Validity

Convergent validity testing is conducted to determine the validity level of each relationship between indicators and their latent constructs. In this test, indicators are considered valid if they have a loading factor value > 0.7 and each construct has an AVE value > 0.5. The results of the outer model test shown in Table 3 indicate that all indicators in the PLS model are valid in measuring their constructs, as they have loading factor values > 0.7. Furthermore, the analysis in Table 1 shows that each construct has an AVE value > 0.5.

Discriminant Validity

Discriminant validity ensures that each concept of the latent variable model is distinct from other variables. In this test, the indicators met the discriminant validity criteria if the HTMT (Heterotrait-Monotrait Ratio) between constructs was below 0.9. The results of the discriminant validity test in Table 2 show that the HTMT values between constructs are below 0.9, indicating that discriminant validity has been achieved for each construct. The results demonstrate that all indicators and constructs have met the criteria for discriminant validity, with HTMT between constructs < 0.9.

Composite Reliability and Cronbach Alpha

Composite reliability measures a variable's actual reliability value, while Cronbach's Alpha measures the lowest (lower bound) reliability value. In the measurement of construct reliability, the required Cronbach's Alpha value is > 0.7; similarly, the required Composite Reliability value is > 0.7. The construct reliability test results in Table 3 show that all constructs have Cronbach's Alpha values > 0.7 and Composite Reliability values > 0.7, indicating that all constructs in this SEM-PLS model are reliable.

Inner Model Testing

Testing the inner model includes evaluating the structural model's goodness of fit, assessing path coefficients, testing the significance of the partial effects of exogenous variables on endogenous variables, and calculating the coefficient of determination. The results from this stage can be used to test research hypotheses.

Table 1. Convergent validity.

Variable	Indicator	Loading factor	Cut Value	AVE	Convergent Validity
COLL	Coll1	0.9	0.7	0.7	valid
	Coll2	0.9	0.7		valid
	Coll3	0.8	0.7		valid
	Coll4	0.7	0.7		valid
	Coll5	0.9	0.7		valid
COMP	Comp1	0.7	0.7	0.7	valid
	Comp2	0.9	0.7		valid
	Comp3	0.8	0.7		valid
	Comp4	0.9	0.7		valid
	Comp5	0.9	0.7		valid
CRTI	Crit1	0.9	0.7	0.8	valid
	Crit2	0.9	0.7		valid
	Crit3	0.9	0.7		valid
	Crit4	0.7	0.7		valid
	Crit5	0.9	0.7		valid
	Crit6	0.9	0.7		valid
ERBL	ERBL1	0.9	0.7	0.7	valid
	ERBL2	0.9	0.7		valid
	ERBL3	0.7	0.7		valid
	ERBL4	0.9	0.7		valid
	ERBL5	0.7	0.7		valid
	ERBL6	0.9	0.7		valid
	ERBL7	0.9	0.7		valid
HB	HB1	0.9	0.7	0.9	valid
	HB2	0.9	0.7		valid

Table 2. Discriminant validity – HTMT.

Construct	COLL	COMP	CRIT	ERBL	HB
COLL					
COMP	0.7				
CRIT	0.7	0.8			
ERBL	0.8	0.7	0.8		
HB	0.7	0.8	0.8	0.8	

Table 3. Composite reliability.

Construct	Cronbach's Alpha	rho_A	Composite Reliability
COLL	0.9	0.9	0.9
COMP	0.9	0.9	0.9
CRIT	0.9	0.9	0.9
ERBL	0.9	0.9	0.9
HB	0.8	0.8	0.9

Goodness of Fit Model PLS

The goodness of fit for the SEM PLS model can be assessed through the model's R Square, Q Square, and SRMR values. The R Square value indicates the model's strength in predicting endogenous variables. This R Square value ranges from 0 to 1 and is categorized into three levels: strong, moderate, and weak. According to Chin (1998), an R Square value greater than 0.6 indicates that the PLS model is in a strong category, an R Square value between 0.3 and 0.6 indicates a moderate model, and an R Square value between 0.1 and 0.3 indicates a weak model. Meanwhile, the Q Square value of the model indicates the model's predictive relevance. The Q Square value is categorized into three levels: small, medium, and large. The Q Square value between 0.02 and 0.1 is considered small, between 0.1 and 0.3 is considered medium, and a Q Square value greater than 0.3 is considered significant.

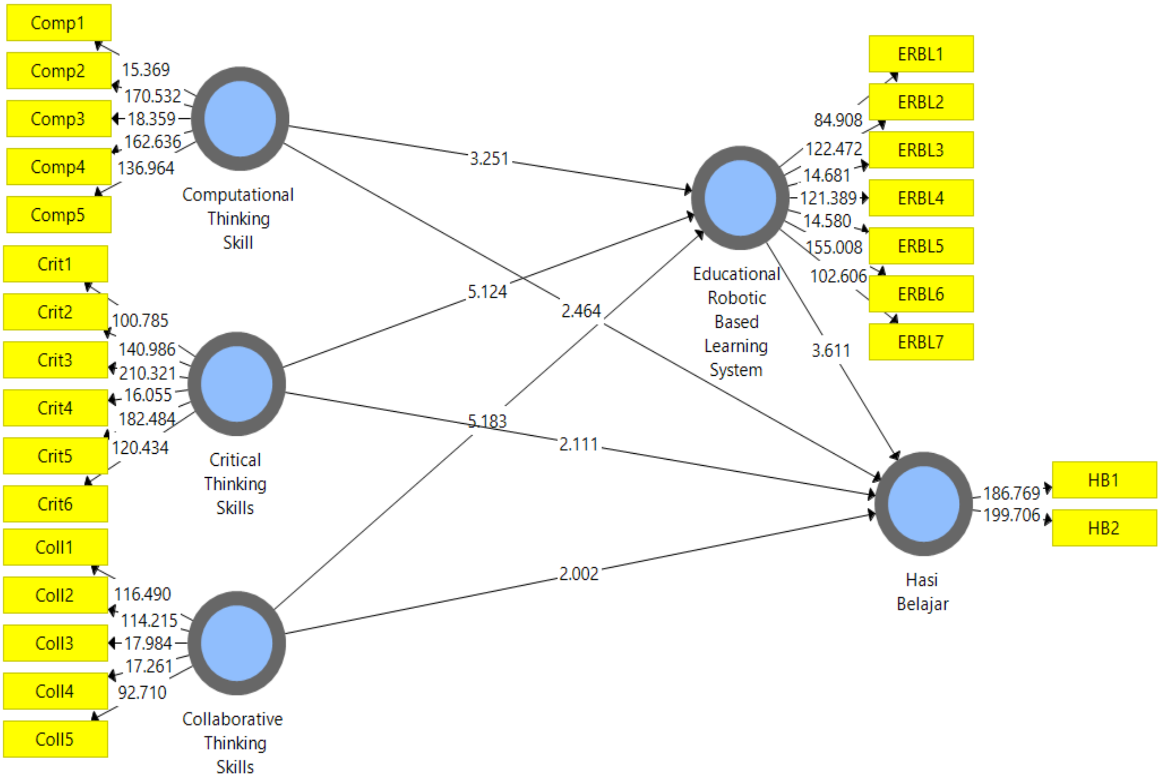

Figure 1. Results of the PLS bootstrapping model with 500 samples.

SRMR model relates to the sample's ability to explain the population. The SRMR value is categorized into three categories: a perfect fit model if SRMR < 0.08, a fit model if SRMR is between 0.08 and 0.10, and a non-fit model if SRMR > 0.10.

Table 4. Goodness of Fit Model

Endogen Construct	R^2	Adjusted R^2	Criteria	Q^2	Predictive Relevance	SRMR
Educational robotic based learning (ERLB)	0.706	0.700	Moderate	0.540	big	0.052 (Fit)
Learning outcomes (LO)	0.701	0.692	Moderate	0.625	big	

The analysis results in Table 4 indicate that the estimated SEM-PLS model fits the analyzed data. It exhibits moderate model strength (sufficiently strong), high predictive relevance, and an SRMR value that meets the fit criteria. Therefore, this model is suitable for testing the research hypotheses.

Direct and Indirect Effects

The direct influence between variables can be observed in SEM PLS analysis from the p-value and T-statistic values. At a 5% significance level, an exogenous variable is considered to have a significant effect on the endogenous variable if the p-value < 0.05 or T-statistic > 1.65 (one-tailed) and T-statistic > 1.96 (two-tailed). The direction of the effect (positive or negative) is assessed from the sign accompanying the path coefficient.

The analysis results in Table 5 indicate that: (1) Collaborative skill has a positive and significant effect on the educational robotics-based learning system, as shown by a significance level of 0.000 < 0.05, a t-statistic of 5.183 > 1.96, and a positive path coefficient of 0.329; (2) Collaborative skill has a positive and significant effect on learning outcomes, as shown by a significance level of 0.046 < 0.05, a t-statistic of 2.002 > 1.96, and a positive path coefficient of 0.178; (3) Computational thinking skill has a positive and significant effect on the educational robotics-based learning system, as shown by a significance level of 0.001 < 0.05, a t-statistic of 3.251 > 1.96, and a positive path coefficient of 0.209; (4) Computational thinking skill has a positive and significant effect on learning outcomes, as shown by a significance level of 0.014 < 0.05, a t-statistic of 2.464 > 1.96, and a positive path coefficient of 0.225; (5) Critical thinking skill has a positive and significant effect on the educational robotics-based learning system, as shown by a significance level of 0.000 < 0.05, a t-statistic of 5.124 > 1.96, and a positive path coefficient of 0.384; (6) Critical thinking skill has a positive and significant effect on learning outcomes, as shown by a significance level of 0.035 < 0.05, a t-statistic of 2.111 > 1.96, and a positive path coefficient of 0.209; (7) The educational robotics-based learning system has a positive and significant effect on learning outcomes, as shown by a significance level of 0.000 < 0.05, a t-statistic of 3.611 > 1.96, and a positive path coefficient of 0.314.

Table 5. Dirrect effect and moderation effect.

	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistics (|O/STDEV|)	P Values
COLL -> ERBL	0.329	0.333	0.063	5.183	0.000
COLL -> HB	0.178	0.174	0.089	2.002	0.046
COMP -> ERBL	0.209	0.213	0.064	3.251	0.001
COMP -> HB	0.225	0.232	0.091	2.464	0.014
CRIT -> ERBL	0.384	0.377	0.075	5.124	0.000
CRIT -> HB	0.209	0.208	0.099	2.111	0.035
ERBL -> HB	0.314	0.314	0.087	3.611	0.000

Table 6. Indirrect Effect

	Original Sample (O)	T Statistics (|O/STDEV|)	P Values
COLL -> ERBL -> HB	0.103	2.794	0.005
COMP -> ERBL -> HB	0.065	2.548	0.011
CRIT -> ERBL -> HB	0.121	2.843	0.005

The analysis results in Table 6 indicate that for the pathway with no effect of collaborative skills on learning outcomes through an educational robotic-based learning system, a p-value of 0.005 was obtained with a t-statistic of 2.794 and a positive indirect path coefficient of 0.103. Since the p-value is < 0.05 and the t-statistic > 1.96, it is concluded that collaborative skills can indirectly affect learning outcomes mediated by the educational robotic-based learning system. In this PLS model, the educational robotic-based learning system is proven to mediate the indirect effect of collaborative skills on learning outcomes.

The analysis also demonstrates that for the indirect pathway of computational thinking skills on learning outcomes through the educational robotic-based learning system, a p-value of 0.011 was obtained with a t-statistic of 2.548 and a positive indirect path coefficient of 0.065. Since the p-value is < 0.05 and the t-statistic > 1.96, it is concluded that computational thinking skills (COMP) can indirectly affect learning outcomes mediated by the educational robotic-based learning system. In this PLS model, the educational robotic-based learning system is proven to mediate the indirect effect of computational thinking skills on learning outcomes.

The analysis further shows that for the direct pathway of critical thinking skills on learning outcomes through the educational robotic-based learning system, a p-value of 0.005 was obtained with a t-statistic of 2.843 and a positive indirect path coefficient of 0.121. Since the p-value is < 0.05 and the t-statistic > 1.96, it is concluded that critical thinking skills can indirectly affect learning outcomes mediated by the educational robotic-based learning system. In this PLS model, the educational robotic-based learning system is proven to mediate the indirect effect of critical thinking skills on learning outcomes.

Table 7. Testing Hypothesis

No	Hypothesis	Regression Coefficient	t	Sig.	Conclusion
1	Critical thinking skill influences the education robotic learning system	0.384	5.124	0.000	Accepted
2	Computational thinking skill influences education in the robotic learning system	0.209	3.251	0.001	Accepted
3	Collaborative skill influences the education robotic learning system	0.329	5.183	0.000	Accepted
4	Critical thinking skill influences learning outcomes	2.209	2.111	0.000	Accepted
5	Computational thinking skill influences learning outcomes	0.225	2.464	0.014	Accepted
6	Collaborative skill influences learning outcomes	0.178	2.002	0.046	Accepted
7	Educational robotic-based learning system influences learning outcomes	0.314	3.611	0.000	Accepted

Discussion

The Influence of Critical Thinking Skills on Education-Based Robotics Learning Systems

Hypothesis 1 in this study is accepted, and it can be concluded that critical thinking skills positively affect a robotics-based learning system. This means that the higher the critical thinking skills, the higher the robotics-based learning system, and conversely, the lower the critical thinking skills, the lower the robotics-based learning system. The results of this study successfully demonstrate that critical thinking positively influences robotics-based learning. For UNESA students enrolled in robotics courses, it is essential for effective and successful learning that students possess critical thinking skills. Critical thinking skills, considered soft skills, are now a common requirement for job applications. Individuals with strong critical thinking abilities can identify information, draw conclusions, and make decisions to solve problems. Learners with high critical thinking skills will be able to engage effectively in learning, especially in environments that involve many visualized activities, including robotics-based learning or education robotics-based learning systems.

The results of this study demonstrate that critical thinking skills are essential in robotics-based learning. The higher the students' ability to think critically, the more successful the robotics-based learning is. Conversely, the lower the student's ability to think critically, the more hindered the success of robotics-based learning becomes.

The Impact of Computational Thinking Skills on Educational Robotics-Based Learning Systems

The results of this study successfully demonstrate that computational thinking skills have a positive impact on robotics-based learning. For students at Universitas Negeri Surabaya who are enrolled in the robotics course, computational thinking skills are essential to ensure that learning proceeds effectively and successfully. Computational thinking is a problem-solving approach that leverages ideas and concepts from computer science. Students with high computational thinking abilities will seek solutions using computer technology. This allows them to solve problems quickly, especially when dealing with calculations, resulting in more accurate outcomes. These students can quickly grasp robotics-based learning because robotics combines students' cognitive processes with the computational outputs of their thinking.

Robotics-based learning is a method designed to help students better understand educational concepts. This is because robotics as a medium allows learning materials to be presented visually and physically, making it easier for students to grasp a concept. Additionally, robotics makes learning more engaging, fostering creativity in problem-solving. However, for robotics-based learning to be practical, high computational thinking skills are essential, as they enable students to tackle complex problem-solving more easily.

The results of this study align with the findings of previous research, demonstrating that the success of robotics-based learning is highly influenced by the computational thinking skills possessed by students (Álvarez-Herrero, 2020; Budiyanto et al., 2022; Ccopa Ybarra & Soares, 2022; Tengler et al., 2021, 2022; Y. Wang, 2023; K. Yang et al., 2020). The higher the students' computational thinking skills, the more successful the robotics-based learning process is supported. Conversely, the lower the students' computational thinking skills, the more hindered the success of robotics-based learning becomes.

The Influence of Collaborative Skills on Education in a Robotics-Based Learning System

The results of this study successfully demonstrate that collaborative skills are essential in supporting robotics-based learning. Collaborative skills involve working together, synergizing, adapting to various roles and responsibilities, and respecting differences (Anasrul & Sirozi, 2024; Jamaluddin et al., 2024). In robotics-based learning, students typically work in groups, making collaboration crucial for the success of this educational approach. Cognitive learning outcomes can be linked to collaborative skills. Through teamwork, social interaction occurs among students within the group, stimulating the elaboration of conceptual knowledge. In group settings, students strive to make themselves understood and to understand other group members, leading to joint knowledge construction.

Robotics-based learning, which is part of STEM education, is an educational approach aimed at equipping students with the ability to communicate across disciplines, collaborate in teams, think creatively, research, produce, and solve problems, emphasizing the integration of knowledge and skills in science, technology, mathematics, and engineering in teaching. Collaborative skills in STEM-based robotics learning but have not linked them to learning outcomes. Their research shows that STEM-based robotics education can develop collaborative skills in participation, perspective-taking, and social regulation. Therefore, this study aims to describe the correlation between collaborative skills and students' cognitive learning outcomes in STEM-based learning.

The findings of this study align with those of previous research, which have demonstrated that collaboration skills are essential in robotics-based learning (Wong & Crowe, 2022).

The Influence of Critical Thinking Skills on Learning Outcomes

This research successfully demonstrates that critical thinking skills impact learning outcomes. Good thinking skills, both critical and creative, are essential for every student to possess in solving or addressing problems that arise in a constantly changing world. Thinking is divided into two levels: lower-order thinking, which only uses abilities for routine and mechanical tasks, and higher-order thinking, where students can interpret, analyze, and manipulate prior information. Education in schools, especially at the high school level, must be able to stimulate and develop students' critical thinking. This can be achieved through various methods. Critical thinking is analyzing, explaining, developing, or selecting ideas, including categorizing, comparing, contrasting, testing arguments and assumptions, solving and evaluating inductive and deductive conclusions, determining priorities, and making choices. To cultivate creativity in children, it is essential to encourage them to think and solve problems regularly. Creativity in children begins with creative thinking, leading to creative actions and products.

The Influence of Computational Thinking Skills on Learning Outcomes

This study successfully demonstrates that computational thinking skills influence learning outcomes. When students solve contextual problems, they connect the problem situations to their experiences. Numerous previous studies have stated that using contextual problems from everyday life can help students understand the material.

Therefore, it is necessary to conduct practice sessions for students before mathematics lessons to train them in problem-solving, especially for contextual problems.

The results of this study align with previous research that proved that students' computational abilities significantly determine their learning outcomes, particularly in subjects that involve calculations, coding, and complex problems (Alam & Zakaria, 2021; Atun & Usta, 2019; Barcelos et al., 2018; Zhang et al., 2021; Ziegler et al., 2020).

The Influence of Collaborative Skills on Learning Outcomes

Collaboration or group work is a series of learning activities by students in specific groups to achieve the predetermined learning objective. Group work involves a small number of students organized for learning purposes. Since not all learning outcomes are derived from individual performance but also from group work, students must possess collaboration skills, especially when participating in learning involving substantial group work.

The results of this study are consistent with previous research findings that have demonstrated the importance of group work skills in supporting student learning outcomes. As a result, many learning methods that employ group work are being developed to enhance student learning outcomes (Akaike et al., 2012; Al-Abbas et al., 2020; Azadi et al., 2021; Bonnano, 2021; Bridges et al., 2011).

The influence of educational robotics-based learning systems on learning outcomes

The results of this study demonstrate that robotics-based learning can enhance learning outcomes. Technology has become a necessity in today's era of globalization, necessitating the development of competent skills to keep pace with rapid technological advancements. To address the 21st-century challenges related to student skills, the School of Indonesia Kuala Lumpur (SIKL) has implemented technology in the educational domain by incorporating robotics as a medium in STEM (Science, Technology, Engineering, Mathematics) based learning. This approach supports the development of technological innovations. It represents a recent trend in educational advancement to enhance the quality and effectiveness of education, particularly in the current era and the 21st century. Robotics has been chosen to support education due to its potential to foster STEM learning. STEM is a learning model integrating four disciplines: science, technology, engineering, and mathematics. Students are expected to master concepts or theories and develop creative, innovative thinking skills and teamwork abilities through robotics media. Existing research on science education indicates that it can build potential or improve student literacy. Students can gain a deeper understanding of science in education to meet the challenges of the 21st century.

The findings of this study align with the results from previous research, which successfully proved that students' computational abilities greatly determine students' learning outcomes in learning materials, especially those involving calculations, coding, and relatively complex problems (Begum et al., 2020; Vogt et al., 2021; L. Wang et al., 2022; X. Yang et al., 2022).

CONCLUSION

Fundamental Findings: This study concludes that (1) Critical thinking skills have a positive effect on educational robotics-based learning systems, (2) Computational thinking skills have a positive effect on educational robotics-based learning systems, (3)

Collaborative skills have a positive effect on educational robotics-based learning systems, (4) Critical thinking skills have a positive effect on learning outcomes, (5) Computational thinking skills have a positive effect on learning outcomes, (6) Collaborative skills have a positive effect on learning outcomes, (7) Educational robotics-based learning systems have a positive effect on learning outcomes. **Implications:** Increasing students' awareness of the importance of robotics-based learning systems that can influence critical thinking and student learning outcomes so that students are serious about implementing robotics learning. **Limitations:** The population in this study is limited to the Electrical Engineering Education Study Program, Faculty of Engineering Education Students, Universitas Negeri Surabaya. **Further Research:** Additional variables, such as learning motivation and employability skills, are needed.

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***Fendi Achmad (Corresponding Author)**
Faculty of Electrical Engineering,
Universitas Negeri Surabaya,
UNESA Kampus 1 Ketintang, Surabaya
Email: fendiachmad@unesa.ac.id

Nur Kholis
Faculty of Electrical Engineering,
Universitas Negeri Surabaya,
UNESA Kampus 1 Ketintang, Surabaya
Email: nurkholis@unesa.ac.id

Agus Wiyono
Faculty of Electrical Engineering,
Universitas Negeri Surabaya,
UNESA Kampus 1 Ketintang, Surabaya
Email: aguswiyono@unesa.ac.id

M. Syariffuddien Z
Faculty of Electrical Engineering,
Universitas Negeri Surabaya,
UNESA Kampus 1 Ketintang, Surabaya
Email: zuhre@unesa.ac.id

Ali Nur F
Faculty of Electrical Engineering,
Universitas Negeri Surabaya,
UNESA Kampus 1 Ketintang, Surabaya
Email: alifathoni@unesa.ac.id

Inaya Retno P
Faculty of Electrical Engineering,
Universitas Negeri Surabaya,
UNESA Kampus 1 Ketintang, Surabaya
Email: Inayaputri@unesa.ac.id

Daeng Rahmatullah
Faculty of Vokasional,
Universitas Negeri Surabaya
UNESA Kampus 1 Ketintang, Surabaya
Email: daengrahmatullah@unesa.ac.id

Yuli Sutoto Nugroho
Electronic Engineering and Computer Science,
Queen Mary University of London,
Westfield College · 1887 – East London College/Queen Mary College
Email: nugroho@qmul.ac.uk