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Development of an IoT-Based 3-Phase Electric Motor Controller Trainer Equipped to Improve Critical Thinking Skills, Creativity, and Learning Outcomes: Supporting SDG 4

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ABSTRACT

Objective: *To develop a learning device for an Internet of Things (IoT)-based Right-Left Rotating Induction Motor Control Trainer equipped with Student Worksheets (LKM) to improve critical thinking skills, creativity, and student learning outcomes.* ***Method:*** *The research method used the ADDIE model development research. The testing or evaluation process is carried out a validity test, a student response test, and an effectiveness test. Data analysis techniques using descriptive statistics, N-Gain test, and Paired Samples Test.* ***Results:*** *The results show that the Internet of Things (IoT)-based Right-Left Rotating Induction Motor Control Trainer equipped with Student Worksheets is highly valid based on expert validation results, highly practical based on student responses, and highly effective in terms of improving critical thinking, creativity, and student learning outcomes. Therefore, the resulting trainer is highly suitable for use in electrical machinery lectures.* ***Novelty:*** *The novelty of this research lies in the integration of an IoT-based Right-Left Rotating Induction Motor Control Trainer with Student Worksheets and learning outcome measurements covering cognitive, affective, and psychomotor domains. This study highlights how technology-based learning innovation supports SDG 4 by promoting quality education, competency development, and improved learning experiences.*

INTRODUCTION

The uncertainty and complexity of the 21st century require a transformation in learning. Learning in this era must prepare students for work, life, and being productive citizens in facing various challenges. Learning needs to equip students with critical and creative thinking skills (S. M. Ritter, et al., 2020) (R. J. Shavelson, et al., 2019). These skills are crucial for dealing with the emergence of new technologies that facilitate the transfer, presentation, manipulation, and re-presentation of information.

Although critical and creative thinking skills are important, many students still lack them. Research shows that the majority of students have moderate or low critical thinking skills (Y. L. O. Siahaan and R. I. Meilani, 2019). Several studies also indicate the need to improve students' critical thinking skills (M. R. Prihatin., et al., (2020). Many university, vocational, and high school students also have low creative thinking skills (H. M. Siregar, 2019).

Research also shows that students' higher-order thinking skills are still low, partly due to the suboptimal use of innovative learning models (H. M. Siregar, 2019) (N. Ika Noviyanti, 2019). Consequently, students often experience difficulty exploring ideas, resulting in difficulty solving problems (S. Paramita Siska Dewi and T. Murwaningsih, 2021). More specifically, this also affects students' creativity in understanding and solving the problems they face. The existence of problems in students' critical and creative thinking skills indicates the need for learning innovations develop critical thinking and creativity (Stéphan Vincent-Lancrin, et al., 2019). One learning approach that follows these principles is the one that integrates Science, Tecnology, Engineering, Art, and Mathematics (STEM).

This approach makes students appreciate various fields of knowledge simultaneously. This stimulates the development of their critical and creative thinking skills in reimagining new and old real-world problems (Arthur I Miller and H. Wilson, B., .2019). The STEAM approach is considered innovative because it is considered cutting-edge in the Industry 4.0 era, which can support critical and creative thinking skills through project-based learning (O. Shatunova, et al., 2019). The STEAM-PjBL approach is based on real-world problems and can teach students how to research, propose, and select solutions, as well as design and build products (A. A. Chistyakov,2023); it provides students with opportunities to create products and helps develop creativity and problem-solving skills (J. Katz-buonincontro, 2018); and it helps develop students' critical and creative thinking skills (Y. A. Alkhabra, 2023; E. Anggraeni, e al., 2022). Critical and creative thinking skills are crucial; these two skills are essential for students to live and contribute productively. However, many students still lack these skills. The STEAM-PjBL approach has the potential to develop critical thinking and creativity skills, as well as learning outcomes. Improving the quality of learning in higher education must prioritize future-oriented skills so that students can compete and face the realities of society and the 21st century (T. Maas, et al., 2018).

The results of the study show an increase in students' abilities, skills, and innovative behavior after being taught a problem-based learning model using the IoT-B-HMI-LM in the form of a Trainer Kit (Joko, 2023). Before and after adopting a project-based learning paradigm that uses MPHMI-B-IoT as a trainer kit, there are noticeable improvements in the students' abilities, individual inventive behavior, and skills. Teachers can consider these results as they work to improve student proficiency in the 4.0 and 5.0 eras (Joko, 2022). The purpose of this research is to produce an IoT-based right-left rotary induction motor control trainer equipped with student worksheets to improve critical thinking, creativity, and student learning outcomes.

In line with Sustainable Development Goal 4 (SDG 4), which emphasizes inclusive and quality education, higher education institutions are required to develop innovative learning approaches that integrate technology and improve students' competencies. The integration of Internet of Things (IoT)-based learning media provides opportunities to create meaningful learning experiences, strengthen students' technical skills, and prepare graduates to face technological developments in Industry 4.0. Therefore, the development of IoT-based trainers equipped with structured learning materials contributes to achieving quality education through technology-supported learning innovation.

The research questions are: 1) What is the validity of the IoT-based right-left rotary induction motor control trainer equipped with student worksheets based on expert validation results? equipped with student worksheets in improving students' thinking, creativity, and learning outcomes?, 2) How practical is the IoT-based right-left rotary induction motor control trainer equipped with student worksheets based on student response results?, and 3) How effective is the IoT-based right-left rotary induction motor control trainer equipped with student worksheets based on improving critical thinking, creativity, and student learning outcomes?

RESEARCH METHOD

The method for achieving these objectives is through research and development of the ADDIE model. The fundamental building blocks of the ADDIE process are an analysis of student background and needs, a collection of specific, efficient, and relevan environmental design, including requirements for individual student learning. resources and settings, learning outcomes, formative tests, and summative tests (Nieeven Nienki, 2013). The stages of the ADDIE model in the learning tool are shown in Figure 1.

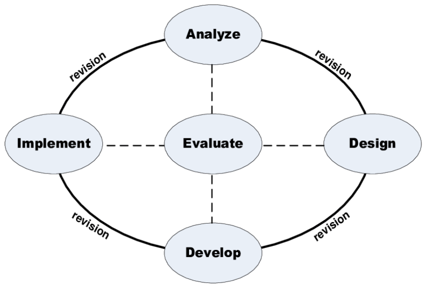

Figure 1. Research stages (R. M. Branch and T. A. Dousay, 2023)

Analyze

Analyze Observing the development needs of an IoT-based Right-Left Rotating Induction Motor Controller Trainer equipped with Student Worksheets for the electrical machines course. Observations were conducted with undergraduate Electrical Engineering students who had already taken the course and interviews with the lecturers. The evaluation results from the analysis activities were used as the basis for designing an IoT-based Right-Left Rotating Induction Motor Controller Trainer equipped with Student Worksheets that meet the learning needs.

Design

This stage involves designing the equipment and material requirements, along with their specifications, as well as the appearance and structure of the IoT-based Right-Left Rotating Induction Motor Controller Trainer equipped with Student Worksheets. Furthermore, the research instruments to be used were designed. Developing At this stage, the conceptual design of the IoT-based Right-Left Rotating Induction Motor Controller Trainer, complete with Student Worksheets, is realized into a product ready for implementation. At this stage, expert validity testing of the research instruments was conducted by language experts, media experts, induction motor controller experts, and IoT experts.

Development

The results of the development stage were analyzed descriptively, and if the results did not meet applicable standards, improvements were made. Implementation At this stage, the IoT-based right-left rotating induction motor controller trainer, complete with the Student Worksheets, was implemented. This stage involved 30 undergraduate electrical engineering education class of 2022 students in the electrical energy conversion laboratory, using the STEAM-PjBL approach in the electrical machines course. A pretest and posttest were conducted to obtain effectiveness data and a questionnaire was administered to students programming the course to obtain practicality data for the IoT-Based Right-Left Rotating Introduction Motor Controller Trainer, complete with student worksheets.

Evaluate

Evaluate This stage will evaluate the results of the validity test, practicality test, and effectiveness test. The validity evaluation and research instrument, based on the expert validation results conducted during the development stage, were analyzed using descriptive statistics, with a minimum validity level of valid. The practicality evaluation was based on data from student responses programming the course, which were then analyzed using descriptive statistics, at least in the practical category (Suharsimi, 2018).The effectiveness evaluation was based on improvements in pretest and posttest results calculated using the N-Gain formula, at least in the effective category, and the average posttest score was greater and significantly different from the pretest, analyzed using the Paired Samples t-test Coletta, V. P., & Steinert, J. J., 2020).

RESULTS AND DISCUSSION

Result

Results Validitas trainer and Student Worksheets The front view of the IoT-based right-left rotating electric motor controller trainer, equipped with student worksheets to improve critical thinking skills, creativity, and learning outcomes, is shown in Figure 2.

Figure 2. Lot-based right-left rotary introduction

Figure 2. Iot-based right-left rotary induction motor controller trainer Validation of the IoT-based right-left rotating induction motor controller trainer, equipped with student worksheets, was conducted by four experts: a linguist, a media Iot-based right-left rotary induction motor controller trainer Validation of the IoT-based right-left rotating induction motor controller trainer, equipped with student worksheets, was conducted by four experts: a linguist, a media expert, an induction motor controller expert, and an IoT expert. The trainer's validation aspects and results (Figure 3), averaged 92.50%, or 0.95, in the very valid category.

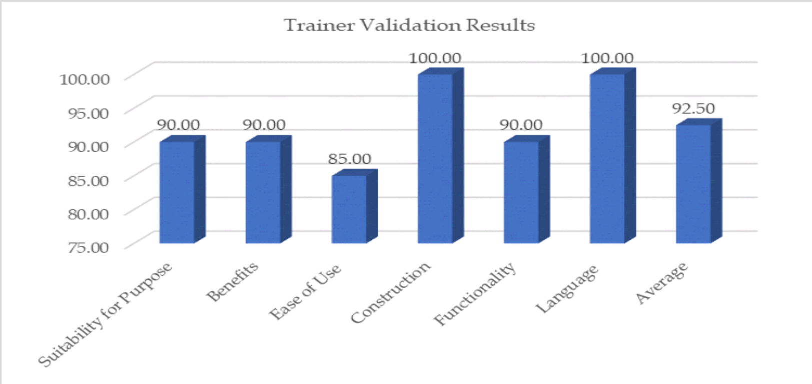

Figure 3. Trainer validation results graph.

The validity of the student worksheet was also validated by linguists, media experts, induction motor controller experts, and IoT experts. The validated aspects were material relevance, conceptual accuracy, presentation (language, clarity, depth), and suitability to learning objectives (suitability to indicators, availability of evaluations or exercises). The validation results of the Student Worksheet are shown in Figure 4, with an average score of 92.14% or 0.9214 in the very valid category.

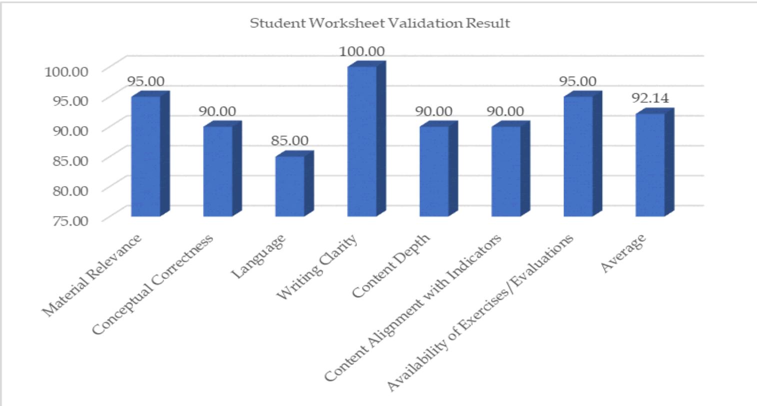

Figure 4. Student worksheet validation results graph

The validation results of the right-left rotary induction motor trainer, complete with student worksheets, were very valid, making them highly valid for use in electrical machines courses (Nieeven Nienki, 2013).

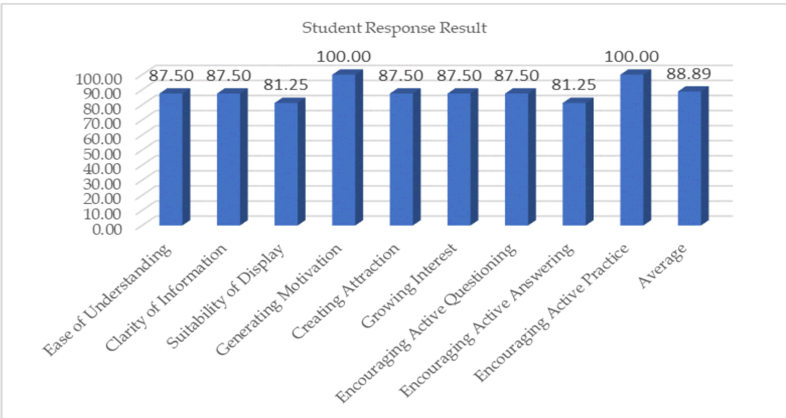

Figure 5. Student response results graph

The results of student responses in Figure 5 show an average score of 88.89, which is in the very high category (Suharsimi, 2018). Because the student response to the developed trainer is high, it is very practical for use in teaching electrical machines courses (Nieeven Nienki, 2013). Instrument reliability was calculated using the Cronbach's Alpha formula, and content validity was based on expert validation results. A summary of the validity and reliability calculations for the research instruments is in Table 1. The reliability values for all instruments are >0.70, indicating reliability (Perry R., et al., 2014) and validity because Aiken's V is >0.3 (L. R. Aiken, 2009), due to its very valid validity and high reliability, the instrument meets the requirements for use in research at the implementation stage (R. W. Thatcher. 2010).

Table 1. Validity and reliability of research instruments

Research Instruments	Validity/Category	Alpha Cronbach/ Category
Learning Outcomes	0.87 / Very Valid	0.78 / High
Critical Thinking	0.88 / Very Valid	0.75 / High
Creativity	0.85 / Very Valid	0.72 / High
Student Responses	0.87 / Very Valid	0.76 / High

Table 2. Summary of descriptive statistics for student learning outcomes

		Statistic	Std. Error
Learning Outcomes - posttest	Mean	81.80	1.57
	Std. Deviation	8.63	
	Minimum	65	
	Maximum	95	
	Range	30	
Learning Outcomes pretest	Mean	34.33	1.47
	Std. Deviation	8.06	
	Minimum	20	
	Maximum	50	
	Range	30	

Student learning outcomes consist of three domains: knowledge, psychomotor, and affective domains. These three are combined into one as student learning outcomes Table. 2, with an average pretest score of 34.50, in the low category, and an average posttest score of 81.80, in the high category (Suharsimi, 2018). The results of the normality test for student learning outcome data are shown in Table 3. The posttest value was 0.063 > 0.05, and the pretest sig. value was 0.052, indicating that the student learning outcome data were normally distributed.

Table 3. Results of the normality test for learning outcome

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Learning outcome - posttest	0.155	30	0.063	0.942	30	0.100
Learning outcome - pretest	0.159	30	0.052	0.949	30	0.158

The results of the homogeneity test for student learning outcomes are shown in Table 4. A significant value of 0.669 indicates that the learning outcomes are homogeneous.

Table 4. Results of the homogeneity test for learning outcomes

		Levene Statistic	df1	df2	Sig.
Learning outcome pretest - postes	Based on Mean	0.185	1	58	0.669
	Based on Median	0.043	1	58	0.836
	Based on Median and with adjusted df	0.043	1	55.600	0.836
	Based on trimmed mean	0.152	1	58	0.698

Because the student learning outcome data is normal and homogeneous, it is continued with a paired sample t-test, the results are shown in table 5. A sig. value of 0.00 means that the student learning outcomes during the posttest are significantly different and greater than the learning outcomes during the pretest.

Table 5. Paired samples t-test results for learning outcomes

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretes - Posttes	-47.46	9.01	1.64	-50.83	-44.10	-28.84	29	0.00

Calculating the magnitude of improvement in student learning outcomes using N-Gain yields the following: The calculation using N-gain yielded a score of 0.72, which is in the high category (Coletta, V. P., and Steinert, J. J., 2020).

$$g = \frac{Posttest\ Score\ -\ Pretest\ Score}{Ideal\ Score - Pretest\ Score} = \frac{81,10 - 34,33}{100 - 34,33} = 0,72$$

Because the students' learning outcomes during the post-test were significantly different and greater than those during the pre-test, and there was an increase in learning outcomes in the high category, the IoT-Based Right-Left Rotating Electric Motor Controller Trainer Equipped with Student Worksheets is effective for use in learning electrical machines. Critical thinking The indicators assessed in critical thinking are the ability to interpret, analyze, conclude, evaluate, explain logically and systematically, identify assumptions, clarify issues, and make reasoned decisions. The average critical thinking 35.10 for the pretest and 83.97 for the posttest Table 6, in the high category (Suharsimi, 2018).

Table 6. Descriptive statistics for critical thinking

		Statistic	Std. Error
Critical thinking - posttest	Mean	83.97	
	Std. Deviation	7.734	1.41
	Minimum	68	

		Statistic	Std. Error
	Maximum	97	
	Range	29	
critical thinking - pretest	Mean	35.10	1.45
	Std. Deviation	7.93	
	Minimum	22	
	Maximum	52	
	Range	30	

The pretest sig. value was 0.101 > 0.05, and the posttest sig. value was 0.071, indicating a normal distribution Table 7. A significant value of 0.854 indicates that the critical thinking data are homogeneous Table 7.

Table 7. Results of the normality test for critical thinking data

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Critical thinking posttest	0.153	30	0.071	0.950	30	0.168
Critical thinking pretest	0.146	30	0.101	0.953	30	0.205

Table 8. Results of the homogeneity test for critical thinking data

		Levene Statistic	df1	df2	Sig.
Critical Thinking pretes-posttes	Based on Mean	0.034	1	58	0.854
	Based on Median	0.161	1	58	0.690
	Based on Median and with adjusted df	0.161	1	56.211	0.690
	Based on trimmed mean	0.044	1	58	0.835

Because the critical thinking data were normal and homogeneous, a paired sample t-test was conducted. The results are shown in Table 9, a significant value of 0.00 indicates that students' critical thinking during the posttest were significantly different and greater than their critical thinking during the pretest.

Table 9. Results of the paired samples t-test for critical thinking

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretest - Posttest	-48.86667	6.21862	1.13536	-51.18874	-46.54459	-43.041	29	0.000

Calculating the increase in critical thinking using N-Gain yields the following

$$g = \frac{Posttest\ Score\ -\ Pretest\ Score}{Ideal\ Score\ -\ Pretest\ Score} = \frac{83{,}97 - 35{,}10}{100 - 35{,}10} = 0{,}75$$

The N-gain calculation of 0.75 is considered high (Coletta, V. P., and Steinert, J. J., 2020). Because the students' critical thinking during the posttest differed significantly and significantly compared to the pretest, and the increase was in the high category, the IoT-based right-left rotating induction motor controller trainer complete with student worksheets, developed is effective for use in teaching electrical machines courses. Student creativity The student creativity indicators used in this study were generating ideas, generating unique ideas, developing, enriching, and elaborating in greater detail. Student creativity data with an average pretest score of 33.60 and a posttest score of 81.00, are in the high category (Suharsimi, 2018).

Table 10. Descriptive statistics of creativity

		Statistic	Std. Error
Creativity - posttes	Mean	81.00	1.56
	Std. Deviation	8.59	
	Minimum	65	
	Maximum	95	
	Range	30	
Creativity - pretes	Mean	33.60	1.49
	Std. Deviation	8.186	
	Minimum	20	
	Maximum	50	
	Range	30	

The pretest sig. value is 0.085 > 0.05 and the posttest sig. value is 0.052, indicating a normal distribution of the data Table 11.

Table 11. Results of the normality test for student creativity

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Creativity - posttest	0.159	30	0.052	0.942	30	0.101
Creativity - pretest	0.150	30	0.085	0.951	30	0.184

The results of the homogeneity test for student creativity data are shown in Table. 12. A significant value of 0.627 indicates that the student creativity data is homogeneous.

Table 12. Results of the homogeneity test for student creativity data.

		Levene Statistic	df1	df2	Sig.
Creativity	Based on Mean	0.239	1	58	0.627
	Based on Median	0.067	1	58	0.796
	Based on Median and with adjusted df	0.067	1	56.648	0.796
	Based on trimmed mean	0.216	1	58	0.644

Because the data is normal and homogeneous, a paired sample t-test can be used. The results of the paired sample t-test for student creativity are shown in Table. 13. A significant value of 0.00 indicates that student creativity during the posttest is significantly different and greater than that during the pretest.

Table 13. Results of the paired samples t-test for student creativity data

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretest - Postestt	-47.40000	6.81074	1.24347	-49.94317	-44.85683	-38.119	29	0.000

$$g = \frac{\textit{Posttest Score} - \textit{Pretest Score}}{\textit{Ideal Score} - \textit{Pretest}} = \frac{81,00 - 33,60}{100 - 33,60} = 0,71$$

The increase in student creativity is calculated using N-Gain, and the results are as follows. The N-gain calculation is 0.71, which is in the high category (Coletta, V. P., & Steinert, J. J., 2020). Because the post-test of student creativity at the time of the post-test was significantly different and greater than at the time of the pre-test, and there was an increase in student creativity in the high category, so that the IoT-based right-left rotary induction motor control trainer equipped with student worksheets that was developed was effective for use in learning electrical machines courses.

Discussion

Validity of the trainer is complemented by student worksheets The result of this research and development (R&D) is an IoT-based Right-Left Rotating Induction Motor Controller Trainer equipped with Student Worksheets. This trainer operates on 220/380V AC at 50 Hz and is technically used to reverse the rotation direction of a 3-phase induction motor as a learning tool for electrical machines. Validation of the IoT-based right-left rotating induction motor controller trainer, equipped with student worksheets, was conducted by four experts: a linguist, a media expert, an induction motor controller expert, and an IoT expert. The trainer's validation aspects suitability for purpose, benefits, ease of use, construction, functionality, and language, averaged 92.50%, or 0.95. The validity of the stu dent worksheet was also validated by linguists, media experts, induction motor controller experts, and IoT experts. The validated aspects were material relevance, conceptual accuracy, presentation (language, clarity, depth), and suitability to learning objectives (suitability to indicators, availability of evaluations or exercises), average score of 92.14% or 0.9214. The validation results for the IoT-based right-left rotating induction motor controller trainer and student worksheets averaged 92.32 points, or 0.92, in the very valid category (Sugiyono, 2021) (Aiken, 2013). These results demonstrate that the IoT-based right-left rotating induction motor controller trainer and student worksheets are highly valid, making them highly suitable for use in learning about electrical machines to enhance critical thinking, creativity, and student learning outcomes. These research findings support a previous development research study entitled development of IoT-based and project-based learning human machine interface learning media to improve ability, innovative behavior, and skill of industrial 4.0 and society 5.0 era students, the average validity score was 86.39% (0.86), categorized as hightly valid (Joko, et al., 2022).

Practicality The practicality of this R&D research is assessed by student responses to the IoT-based right-left rotating induction motor controller trainer equipped with student worksheets (Nieeven Nienki, 2013). Aspects of student responses complete with student worksheets include ease of understanding, clarity of information, appropriateness of display, motivating, creating appeal, fostering interest, encouraging active questioning, encouraging active answering, and encouraging active practice. Rata-rata respon mahasiswa 88.89, pada kategori sangat tinggi atau sangat praktis (Suharsimi, 2018). Because the student response to the developed trainer is very high, it is very practical for use in teaching electrical machines courses increasing critical thinking, creativity, and student learning outcomes (Nieeven Nienki, 2013). These results support research entitled development of IoT-based and project-based learning human machine interface learning media to improve ability, innovative behavior, and skills of students in the Industrial 4.0 and Society 5.0 era student, with a practicality result of 83.38% in the very high category (Joko, et al., 2022). Lerning outcomes student Student learning outcomes consist of three domains: knowledge, psychomotor, and affective domains. These three are combined into one as student learning outcomes, with an average pretest score of 34.50, in the low category, and an average posttest score of 81.80, in the high category (Suharsimi, 2018). The posttest value was 0.063 > 0.05, and the pretest sig. value was 0.052, indicating that the student learning outcome data were normally distributed, and the results of the homogeneity test for student learning outcomes a significant value of 0.669 indicates that the learning outcomes are homogeneous. Because the student learning outcome data is normal and homogeneous, it is continued with a paired sample t-test, the results sig. value of 0.00 means that the student learning outcomes during the posttest. The calculation using N-gain yielded a score of 0.72, which is in the high category (Coletta, V. P., and Steinert, J. J., 2020).

The results of the paired sample t-test showed that student learning outcomes during the posttest were significantly different and greater than those during the pretest; and there was an increase in high category learning outcomes (N-gain test results), indicating that the IoT-based left-right rotary controller trainer equipped with student worksheets was effective in improving critical thinking, creativity, and student learning outcomes in electrical machine learning. These results are supported by a study entitled, which can improve student ability, individual innovative behavior, and skills (Joko et al., 2023); Before and after being taught using the PjBL model employing MPHMIB-IoT in the form of a Trainer Kit of IoT-based and project-based learning human-machine interface learning media to improve student ability, innovative behavior, and skills in the industrial 4.0 and society 5.0 era (Joko et al., 2022); and the application of IoT-based learning media effectively improves learning outcomes (Nurhayati, et al., 2022).

Critical thinking The normality test results for the pretest significance value were 0.101 > 0.05 and for the posttest significance value was 0.071, indicating that the data were distributed. The homogeneity test results showed a significance value of 0.854, indicating that the critical thinking data were homogeneous. Because the critical thinking data were normal and homogeneous, a paired sample t-test was conducted, with a significance value of 0.00. This result indicates that students' critical thinking in the posttest was significantly different and greater than that in the pretest. The N-gain of 0.75 was in the high category (Coletta, V. P., and Steinert, J. J., 2020). Because students' critical thinking in the posttest was significantly different and greater than that in the pretest, and the increase was in the high category, the IoT-based right-left rotary induction motor controller trainer, equipped with student worksheets, was developed effectively to improve critical thinking in teaching electrical machinery courses. Hasil penelitian ini didukung penelitian yang menyimpulkan terdapat perbedaan nyata pada bakat awal siswa, perilaku inventif individu, dan kemampuan membuat proyek kendali motor listrik 3 fasa (Joko, et al., 2022).

Student Creativity Indicators of student creativity in this study included generating ideas, generating unique ideas, developing, enriching, and explaining them in greater detail. The average pretest score for student creativity was 33.60, in the low category, and a posttest score of 81.00, in the high category (Suharsimi, 2018). The pretest significance value was 0.085 > 0.05, and the posttest significance value was 0.052, indicating a normal distribution of student creativity data. The homogeneity test for student creativity showed a significance value of 0.627, indicating a homogeneity of student creativity data. Because the data were normal and homogeneous, a paired-sample t-test was used. The result, with a significance value of 0.00, indicated that student creativity in the posttest was significantly different and greater than in the pretest. The n-gain was 0.71, in the high category (Coletta, V. P., and Steinert, J. J., 2020). The post-test results for student creativity were significantly different and greater than the pre-test results, and there was an increase in student creativity in the high category. These results indicate that the IoT-based right-left rotary induction motor control trainer equipped with the developed student worksheets is effective in increasing student creativity in learning electrical machines courses. The results of this study support the theory that both educators and students must be capable of critical thinking, innovation, creativity, communication, cooperation, collaboration, and confidence (Achuthan et al., 2021).

CONCLUSION

Fundamental Finding : The product of this research and development (R&D) is an IoT-based Right-Left Rotation Induction Motor Controller Trainer equipped with highly valid Student Worksheets. The trainer can be operated from PLN electricity, solar cells, dan accu-bateray. Technically, it can control the rotation direction of a 3-phase introduction motor according to its load requirements and can be used in vocational education as a learning tool in the form of a trainer. The product development of the IoT-based right-left rotary induction motor controller trainer is equipped with student worksheets that can effectively improve students' critical thinking in learning electrical machines courses., was effective in improving learning outcomes in the cognitive, psychomotor, and affective domains. The product development of the IoT-based right-left rotary induction motor controller trainer is equipped with student worksheets that can effectively improve students' critical thinking in learning electrical machines courses. **Implication :** This study contributes to Sustainable Development Goal 4 (SDG 4) by demonstrating the role of IoT-based learning innovation in supporting quality education and competency development in higher education. The developed trainer and Student Worksheets provide technology-enhanced learning experiences that improve students' critical thinking skills, creativity, and learning outcomes. The implementation of IoT-based learning media in engineering education supports institutions in developing inclusive, relevant, and future-oriented learning environments aligned with technological advancement. **Limitation :** The trainer power capacity is limited, maximum for a 1 kW 3-phase induction motor with a source voltage of 220/380V, dan belum berbasis AI. **Future Research :** Further research on trainers with increased capacity, based on IoT and AI.

AUTHOR CONTRIBUTIONS

Joko contributed to the conceptual framework, research design, and validation process; **Ismet Basuki** was involved in methodology development, data analysis, sourcing references, and drafting the manuscript; **Tri Rijanto** handled data management, project coordination, and manuscript drafting; **Aries Dwi Indriyanti** handled data collection, implementation of student trials, statistical analysis; **Alfredo Arianto Permana Putra** heandle visualization of research result, and manuscript revision. All listed authors have reviewed and approved the final version of this submission.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this article.

ETHICAL COMPLIANCE STATEMENT

This manuscript complies with research and publication ethics. The authors affirm that the work is original, conducted with academic integrity, and free from any unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The authors declare that artificial intelligence (AI) tools or digital writing assistants were not used to generate the research findings, analyze the research data, or replace the authors' intellectual contributions. AI-based tools were only used, when necessary, for language improvement, grammar checking, and manuscript formatting assistance. The authors remain fully responsible for the accuracy, originality, and integrity of the content presented in this article.

REFERENCES

A. Chistyakov, M. L. Kunitsyna, and R. I. Yagudina, (2023). Exploring the characteristicsand effectiveness of project-based learning for science and STEAM education," *Eurasia Journal Mathematic Science Technology Education.*, *19(5),* 1–7. https://doi.org/10.29333/ejmste/13128.

Achuthan, K., Raghavan, D., Shankar, B., Francis, S. P., & Kolil, V. K. (2021). Impact ofremote experimentation, interactivity and platform effectiveness on laboratorylearning outcomes. *International Journal of Educational Technology in Higher Education*, *18(1),* 1-24. https://doi.org/10.1186/s41239-021-00272-z.

Arthur I Miller& H. Wilson, B., (2019). *Art and science in a transdisciplinary curriculum.* CIRCE Magazine: STEAM Edition.

Coletta, V. P., & Steinert, J. J. (2020). Why normalized gain should continue to be used in analyzing preinstruction and postinstruction scores on concept inventories. *Physical Review Physics Education Research*, *16(1),* 101-108. https://doi.org/10.1103/PhysRevPhysEducRes.16.010108.

H. M. Siregar, (2019). Analisis kesalahan siswa dalam menyelesaikan soal tes kemampuan berpikir kreatif matematis materi lingkaran, *8(3)*, 497–507. https://doi.org/10.24127/ajpm.v8i3.2379.

Joko, F. Akhmad, and A. A. P. Putra, (2022). Development of IoT-based and project-based learning human machine interface learning media to improve ability, innovative behavior, and skill of industrial 4.0 and society 5.0 students, *Eurasian Journal Education Resistance, 2(2)*, 281–296. https://doi.org/10.14689/ejer.2022.99.017.

Katz-buonincontro, (2018). Creativity for whom ? Art education in the age of creative agency, decreased resources, and unequal art achievement outcomes, *71(6),* 34-37. https://doi.org/10.1080/00043125.2018.1505388.

L. R. Aiken. (2009). *Psychological testing and asessmen*. New York, Pearson Education,

M. R. Prihatin., F. Tentama, and B. Santosa, (2020). The Influence of competence, independence,interest, and discipline on the readiness of working in vocational school students in lombok barat district, *Journal Vocation Education. Stud.*, *3(2)*, 97–110. https://doi.org/10.12928/joves.v3i2.1856.

N. Ika Noviyanti, W. Rosyadah Mukti, I. Dahlia Yuliskurniawati, S. Mahanal, and S. Zubaidah, (2019). Students' scientific argumentation skills based on differences in academic ability. *Journal Physics Confference Series, 12(1),* 1-8. https://doi.org/10.1088/1742-6596/1241/1/012034. Nieeven

Niebki. (2013). *Educational design research*. Netherlands, Netherlands Institute for Curriculum Development (SLO).

Nurhayati, N. Syam H, & Yahya, M. (2022). *Improving learning putcome Embedded System (ES) Using learning media based IoT at Polytechnic*. In 1st world.

O. Shatunova, T. Anisimova, F. Sabirova, and O. Kalimullina, (2019). STEAM as an innovative educational technology. *Journal Social Study Education Resistance, 10*(2), 131–144. https://jsser.org/index.php/jsser/article/view/916

Perry R., I. McMurray, and B. Charlotte. (2014). *SPSS explained*. Second edition. London: Routledge, Taylor & Francis Group.

R. W. Thatcher. (2010). Validity and reliability of quantitative electroencephalography. *Journal Neurother. 14(1),* 122–152. https://doi.org/10.1080/10874201003773500.

R. E. Anggraeni, S. Suratno, and E. Narulita, (2022). The validity and practicality of the SEDC learning model in enhance student's higher order thinking skills in science learning. *Biosfer, 15 (1).* 12–24. Https://doi.org/10.21009/biosferjpb.21616.

R. J. Shavelson, O. Zlatkin-Troitschanskaia, K. Beck, S. Schmidt, and J. P. Marino, (2019). Assessment of university students' critical thinking: Next generation performance assessment. *International Journal Test, 19(4),* 337–362. Https://doi.org/10.1080/15305058.2018.1543309.

R. M. Branch and T. A. Dousay, (2023). *Survey of instructional design models*, Sixth Edition. Bloomington: Association for. Educational Communications & Technolog.

S. M. Ritter, X. Gu, M. Crijns, and P. Biekens, (2020). Fostering students' creative thinking skills by means of a one-year creativity training program, *PLoS One, 15(3)*, 1–18. Https://doi.org/10.1371/journal.pone.0229773.

Sugiyono. (2021). *Metode penelitian kuantitatif, kualitatif, dan R&D*. Bandung, Alphabeta. S.

Stéphan Vincent-Lancrin, Carlos González-Sancho,Mathias Bouckaert, Federico de Luca, Meritxell FernándezBarrerra, Gwénaël Jacotin, Joaquin Urgel and Quentin Vidal (2019). Exsploring differences in perceived innovative thinking skill between first year and upperclassmen engineers. *Educational research and innovation*. https://doi.org/10.1787/62212c37-en.

Suharsimi Arikunto. (2018). *Evaluasi program pendidikan: Pedoman teoretis praktis bagi mahasiswa dan praktisi pendidikan*. Jakarta, Bumi Aksara.

T. Maas, A. Jochim, and B. Gross, (2018). Mind the gap: Will all students benefit from21st Century learning? https://files.eric.ed.gov/fulltext/ED590195.pdf.

Y. A. Alkhabra, U. M. Ibrahem, and S. A. Alkhabra, (2023). Augmented reality technology in enhancing learning retention and critical thinking according to STEAM program. *Humanition Social Science Commun*, *10 (1)*. 1-11. Https://doi.org/10.1057/s41599-023-01650-w. Y. L. O.

Siahaan and R. I. Meilani, (2019). Sistem kompensasi dan kepuasan kerja guru tidak tetap di sebuah SMK swasta di Indonesia. *Jurnal Pendidik Manajemen Perkantoran*, *4 (2).* 141-149. Https://doi.org/10.17509/jpm.v4i2.18008.

Shatunova, O., Anisimova, T., Sabirova, F., & Kalimullina, O. (2019). STEAM as a tool for developing creative thinking skills in students. *International Journal of Emerging Technologies in Learning*, *14*(14), 4–12.

Aiken, L. R. (2009). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement, 45*(1), 131–142.

Branch, R. M., & Dousay, T. A. (2023*). Instructional design: The ADDIE approach*. Springer.

Nieveen, N. (2013). *Educational design research. In T. Plomp & N. Nieveen (Eds.),* Educational Design Research.

Sugiyono. (2021). *Metode penelitian pendidikan: Pendekatan kuantitatif, kualitatif, dan R&D.* Alfabeta.

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