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The Effect of the PLC Training Kit on Critical Thinking Ability in PLC Programming for Electrical Engineering

Puput Wanarti Rusimamto [1], Endryansyah Endryansyah [1], Rina Harimurti [1], Nurkholis Nurkholis [1]

[1] *Universitas Negeri Surabaya, Surabaya, Indonesia*

***Abstract* – Strong critical thinking abilities must be developed as part of an electrical engineering curriculum that prepares students for life in the industrial environment. The aim of this research is to assess how using a PLC (programmable logic controller) training kit affects electrical engineering students' critical thinking abilities when it comes to PLC programming. In this study, a control group of 31 students and an experimental group of 36 students each participated in a pre-test, post-test control group design. While the control group employed simulation, the experimental group used a PLC training kit to learn. The data analysis results indicate that the experimental group significantly outperformed the control group in critical thinking abilities related to PLC programming. According to this study, using the PLC Training Kit improves electrical engineering students' critical thinking abilities when it comes to PLC programming. PLC training kits help students learn by helping them analyze and solve problems, apply theory to real-world situations, and gain a deeper grasp of PLC system. These results suggest that including the PLC Training Kit into the Electrical Engineering Education curriculum can be a smart move to help students become more adept at using critical thinking when programming PLCs.**

These results also offer fresh perspectives on instructional strategies that can help students get ready for the increasingly complicated demands of the workplace.

***Keywords* – PLC training kit, critical thinking skills, PLC programming, Electrical Engineering Education Students.**

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Corresponding author: Puput Wanarti Rusimamto,
Universitas Negeri Surabaya, Surabaya, Indonesia
Email: puputwanarti@unesa.ac.id

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1. Introduction

An essential component of any educational system is its teachers. Developing a more professional outlook on educational and learning design is necessary for becoming a great teacher, and this can be done in a number of ways. According to [1] it was found that in order to be classified as a professional teacher, a teacher must have their certification, receive professional allowances, be in the classroom for a certain number of hours, and be in good attendance.

Teachers in the 21st century must be competent and professional since students' learning styles differ from those of earlier generations. The 21st century student possesses the attribute of being a free learner, meaning that they acquire knowledge independently of assignments, directives, and expectations from educators or educational institutions. Free students will pick up knowledge on the basis of their own drive and support. Resources for student learning are not just found in textbooks and instructors; they can also be found online in the form of written or multimedia content. In response, educators need to be able to adapt to these changes by being lifelong learners [1].

In light of the demands of the 21st-century on educators, who must equip students with the four competencies of critical thinking, communication, collaboration, and creativity [2], the PTE (Electrical Engineering Education) study program needs to provide prospective teachers with the knowledge, skills, and resources they need to stay ahead of the curve and become successful 21st-century educators. PLC programming is one of the knowledge and abilities that PTE study program prospective vocational school teachers need to possess.

Developing critical thinking abilities in PLC programming is essential for instructors of the 21st-century [3].

According to [4], [5], there is a consistent correlation between student accomplishment and critical thinking skills, however the degree of students' critical thinking is more strongly associated with long-term than short-term outcomes. Conversely, critical thinking abilities can only be improved by those who possess the aptitude, drive, and opportunity, according to [6], [7]. Students must be required to be creative in the current learning process, which includes learning. Teachers in the 21st century teach pupils how to study rather than just imparting knowledge, since most of it is already available to them. Depending on the teacher's capacity to plan the learning process in the classroom, the process can be completed with the aid of technology or traditional means.

A smart way to start acquiring the four-C skills is by honing the critical thinking abilities in PLC programming. PLC training kit with modules is one of the needed learning resources. With the aid of [8] study, they developed a PLC-based industrial control process prototype with the goal of assisting students in gaining real-world experience in this field. Students will be able to watch the control actions being performed on the prototype in this way, and it will also be feasible to reduce the amount of errors that could happen throughout the learning and control process. In order to complete the means of development in these subjects—especially for engineering students—prototypes are regarded as an integral part of the educational system. According to [9] research, learning is made simpler and safer by PLC and module experimental setups.

Students' comprehension of PLC practice and material is crucial since they will mentor their peers in PLC education. Proficiency with PLC programming is crucial in the industrial realm. Therefore, it is necessary for students to grasp the material and be able to impart it to other students in an effective and efficient manner. This suggests that PLC has been effectively used in all industrial sectors, including power plants, steel mills, paper mills, industries that produce food, and chemical factories [10].

PLCs carry out a broad range of regulatory functions, from complex manufacturing and process settings to recurring on/off settings of basic machinery. Automation of the control systems in use is typically referred to as industrial process control systems [11]. Automated control systems have mostly taken the place of control systems in industries where humans still play a major role.

Research has been done to examine the impact of PLC training kits on students' critical thinking abilities in PLC programming for Electrical Engineering Education, based on the description given above. The purpose of this study was to;

1) Ascertain whether there were any appreciable differences between the critical thinking abilities of students in PLC programming before and after they used the training kit.

2) Determine whether there are any appreciable differences between the critical thinking abilities of students in PLC programming before and after they participate in simulation-based learning.

3) Determine whether there are any appreciable differences between the critical thinking abilities of students in PLC programming before and after using training kits and simulations.

4) Determine whether there are any appreciable differences between the critical thinking abilities of students in PLC programming after using a training kit and a simulation.

This research has four hypotheses, namely:

1) Hypothesis 1 is that students' critical thinking skills in PLC programming before and after taking part in learning using the training kit are significantly different, H0: $\mu_1$pre = $\mu_1$post, H1: $\mu_1$pre ≠ $\mu_1$post.

2) Students' critical thinking abilities in PLC programming before and after participating in learning using simulation are significantly different, H0: $\mu_2$pre = $\mu_2$post, H1: $\mu_2$pre ≠ $\mu_2$post.

3) Students' critical thinking abilities in PLC programming before taking part in learning using training kits and learning using simulations are significantly different, H0: $\mu_1$pre = $\mu_2$pre, H1: $\mu_1$pre ≠ $\mu_2$pre.

4) Students' critical thinking abilities in PLC programming after participating in learning using training kits and learning using simulations are significantly different, H0: $\mu_1$post = $\mu_2$post, H1: $\mu_1$post ≠ $\mu_2$post.

2. Methodology

This study uses a quantitative approach with a quasi-experimental design. This design was chosen because not all variables can be fully controlled, but researchers can observe the effect of using the PLC Training Kit on students' critical thinking skills in PLC programming. The design used is nonequivalent control group design, which involves two groups, as shown in Figure 1 [12], [13]. Two groups were employed: the experimental group, which consisted of 36 students, whose learning process used a PLC training kit, and the control group, which consisted of 31 students, whose learning process used simulation. A pretest was administered prior to the research to determine whether the two classes' starting skills differed, and a posttest was administered following therapy to determine whether the two classes' final abilities differed.

Group	Pre-test	Treatment	Post-test
E	O_1	X_1	O_2
K	O_3	X_2	O_4

Figure 1. Nonequivalent pretest-posttest control group design

It is evident from Figure 1 that X_1 is learning using a PLC training kit, and X_2 is learning through simulation. E is the experimental group, K is the control group, and 0_1 is the pre-test, 0_2 is the post-test, 0_3 is the pre-test, and 0_4 is the post-test in the control group [14].

Both groups took the initial test as part of the investigation. After that, both groups received care. therapy in the control group combined with simulation-based learning. With CX-Programmer, practical activities run simulations. Instruction in the experimental class utilizing a PLC training kit as a learning medium. A posttest was subsequently administered to both groups to wrap up the study. Pre-test and post-test research instruments are multiple-choice tests with questions about PLC programming analysis and solutions ranging from simple instructions to ladder diagram program creation [15].

3. Result

The training kit can be utilized for the learning process because it has been deemed valid after being validated by three validators [16], [17]. The initial scores in PLC programming ability and critical thinking ability served as baseline data for both the control and experimental groups in this study [18]. These scores were collected prior to the implementation of the instructional intervention and were used to assess the participants' starting competencies in the respective domains.

By comparing the pre-intervention scores between the two groups, it was possible to ensure the equivalence of the groups at the outset and to control for potential confounding variables [18]. Moreover, these baseline scores provided a critical reference point for evaluating the extent of improvement following the treatment, thereby enabling a more accurate measurement of the instructional impact of the training intervention [19].

As presented in Tables 1 and 2 below, tests for normality and homogeneity were conducted as preliminary steps prior to performing hypothesis testing [20], [21]. The normality test was utilized to examine whether the distribution of the data conformed to the assumptions of a normal distribution, which is a fundamental requirement for many parametric statistical analyses [22], [23].

Similarly, the homogeneity test was employed to assess the equality of variances between groups, ensuring that the data met the assumption of homoscedasticity [24], [25]. These preliminary statistical procedures are essential for validating the appropriateness of subsequent inferential analyses and for ensuring the reliability and validity of the results derived from hypothesis testing [26].

The normality test is conducted to determine whether the population is normally distributed. A normally distributed population means that the population is evenly distributed, with low, medium, and high values, or no low or high values.

In this study, the normality test calculation uses the Shapiro-Wilk test because the sample size is less than 50. In this normality test, H0 will be tested against H1, where H0 indicates a normally distributed population, while H1 is the counter-hypothesis, indicating a non-normal distribution of the population [27]. The results of the normality test calculation are shown in Table 1 below.

Table 1. Test of normality

	Instructional Media	Kolmogorov-Smirnov [a]			Shapiro-Wilk		
		Statistics	df	Sig.	Statistics	df	Sig.
Initial Critical Thinking Skills	Simulation	,171	31	,022	,968	31	,462
	Training Kit	,084	36	,200 *	,985	36	,907
Final Critical Thinking Skills	Simulation	.134	31	,163	,951	31	,167
	Training Kit	,140	36	,074	,970	36	,420

From the results in Table 1 above, it can be concluded that the pretest score data is normally distributed. This is evidenced by the significance values of the Shapiro-Wilk pretest and posttest results, which are 0.402, 0.907, 0.167, and 0.420, all greater than 0.05. Therefore, H0, which states that the population is normally distributed, is accepted and H1 is rejected.

A homogeneity test was conducted to determine whether the two samples have the same variance. In this study, the homogeneity test was calculated using the Levene statistic. The results of the homogeneity test are shown in Table 2 below.

Table 2. Test of homogenity of variance

		Levene Statistics	df1	df2	Sig.
Initial Critical Thinking Skills	Based on Mean	,363	1	65	,549
	Based on Median	,571	1	65	,453
	Based on Median and with adjusted df	,571	1	64,337	,453
	Based on trimmed mean	,356	1	65	,553
Final Critical Thinking Skills	Based on Mean	1,553	1	65	,217
	Based on Median	1,333	1	65	,252
	Based on Median and with adjusted df	1,333	1	62,362	,253
	Based on trimmed mean	1,558	1	65	,216

In Table 2, it appears that each data in the two groups is homogeneous as indicated by a significance value of more than 0.005.

Next, data analysis was carried out using the Paired Samples Test to test hypotheses 1 and 2, with the results shown in Table 3 and Table 4 below.

Table 3. Paired samples statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pre test Control	47.71	31	6,664	1,197
	Post Test Control	58.29	31	10,746	1,930
Pair 2	Pre Test Exp	51.44	36	5,578	,930
	Post Test Exp	74.97	36	8,557	1,426

Students in the control class appear to have learning outcomes with an average initial ability value of 47.71 and an average final ability value of 58.29, according to Table 3.

In the meantime, the experimental group's average ability value was 51.44 at the beginning and 74.97 at the end.

Table 4. Paired samples test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Pre Control Test - Post Control Test	-10,581	9,110	1,636	-13,922	-7,239	-6,467	30	,000
Pair 2	Pre Test Exp - Post Test Exp	-23,528	8,368	1,395	-26,359	-20,696	-16,869	35	,000

H0 is rejected since the control class analysis's p-value of 0.000 is revealed. It follows that there is a substantial difference in the students' critical thinking skills in PLC programming before and after they used simulation media to learn. According to the data analysis, students' average score before using simulation to learn was 47.71; after using simulation, that score rose to 58.29. There was a 10.6% increase as a result.

H0 is discarded in the meantime because the experimental class analysis indicates that the p-value is 0.000. Therefore, it can be said that there is a considerable difference in the students' critical thinking skills in PLC programming before and after they used the training kit to learn. According to the data analysis, students who did not use simulation to learn previously had an average score of 51.44; however, after utilizing the training kit, that score rose to 74.97. There was a 23.5% increase as a result.

Next, an independent samples test was carried out to test hypotheses 3 and 4, with the results shown in Table 5 below.

The analysis produced two p-values: 0.015 and 0.017. Given that the p-value is less than 0.05, H0 is disproved. Therefore, it can be said that there was a substantial difference in the control and experimental groups' pre-treatment critical thinking abilities related to PLC programming.

The analysis's p-value was found to be 0.000. Given that the p-value is less than 0.05, H0 is disproved. Therefore, it can be said that following treatment, there was a substantial difference between the control and experimental groups' critical thinking abilities in PLC programming.

Table 5. Independent samples test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Initial Critical Thinking Skills	**Equal variances assumed**	1,366	,247	-2,497	65	,015	-3,735	1,495	-6,721	-.748
	Equal variances not assumed			-2,464	58,777	.017	-3,735	1,516	-6,768	-.702
Final Critical Thinking Skills	**Equal variances assumed**	1,553	,217	-7,070	65	,000	-16.68190	2.35946	-21.39406	-11.96974
	Equal variances not assumed			-6,951	57.112	,000	-16.68190	2.39984	-21.48730	-11.87650

The effectiveness of training kits as instructional tools in the learning process cannot yet be conclusively determined. While improvements in students' learning outcomes may be observed, these enhancements do not necessarily reflect the inherent effectiveness of the training kits themselves. One potential confounding factor is the variation in students' initial abilities, which can significantly influence the degree of learning gains. Learners often enter the educational process with differing levels of prior knowledge, skills, and preparedness, all of which may affect their performance independently of the instructional intervention.

Therefore, to obtain a more accurate and objective measure of the impact of the training kits, it is essential to control for these initial differences. In this context, the normalized gain (N-Gain) or gain value analysis is commonly employed. This analytical approach quantifies the relative improvement in students' performance by accounting for their starting point, thereby offering a more valid assessment of the actual learning gains achieved as a result of the instructional tool or method under investigation [28].

To more precisely measure the effectiveness of an instructional intervention, especially in quasi-experimental studies involving pretest and posttest designs, the normalized gain is a widely accepted metric. The N-Gain is calculated to assess the relative improvement of students' performance and to control for variation in students' initial abilities. The formula for normalized gain is shown in Equation 1 below.

$$N\text{-}Gain = \frac{\text{Scor Posttest} - \text{Scor Pretest}}{\text{Scor Maks Ideal} - \text{Scor Pretes}} \quad (1)$$

Next, the N-Gain results were tested to see whether there really was a significant difference between the two groups. The results of the paired sample t-test are shown in Table 6 and Table 7 below.

Table 6. Group statistics

	Instructional Media	N	Mean	Std. Deviation	Std. Error Mean
Score Improvement	**Simulation**	31	.2026	.17127	.03076
	Training Kits	36	.4844	.17341	.02890

Table 7. Paired samples t-test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Score Improvement	Equal variances assumed	,395	,532	-6,672	65	,000	-.28186	.04225	-.36624	-.19749
	Equal variances not assumed			-6,678	63,758	,000	-.28186	.04221	-.36619	-.19754

As [29] introduced the normalized gain to evaluate the effectiveness of interactive engagement methods in physics education, categorizing gain values as high ($g > 0.7$), medium ($0.3 < g \leq 0.7$), and low ($g \leq 0.3$). In this study, the N-Gain analysis revealed a considerable improvement in the experimental group (mean N-Gain = 0.4844) compared to the control group (mean N-Gain = 0.2026), with a statistically significant difference ($p < 0.05$), as presented in Tables 6 and 7. This indicates that students exposed to the PLC Training Kit experienced a higher relative increase in their critical thinking performance compared to those who learned through simulation.

The application of N-Gain is especially relevant in educational research where pretest and posttest designs are employed. It helps reduce bias arising from unequal initial ability levels among groups. As demonstrated in [30], guided inquiry-based approaches assessed using N-Gain showed effectiveness in improving conceptual understanding in technical education. In another study, the integration of HMI-based control training kits led to notable improvements in automation control skills, as indicated by high N-Gain values [20].

Thus, the significant N-Gain difference between groups in this study validates the effectiveness of the PLC Training Kit. The findings support that active and practical-based instructional tools enhance critical thinking more effectively than simulation-based instruction alone, contributing to the ongoing effort of aligning engineering education with 21st-century skill demands.

4. Discussion

The results of this study demonstrate that the use of a PLC Training Kit significantly enhances students' critical thinking abilities in PLC programming compared to simulation-based learning. This finding is supported by the statistical outcomes of both paired and independent samples t-tests, and further validated by the normalized gain analysis.

The experimental group, which engaged with a real-world PLC Training Kit, showed a substantial improvement in their post-test scores, with a mean score increase from 51.44 to 74.97, equating to an N-Gain value of 0.4844 (medium category) [31], [24]. In contrast, the control group, which relied on simulation tools, improved from a mean of 47.71 to 58.29, resulting in an N-Gain of only 0.2026 (low category) [31]. The statistically significant difference in N-Gain scores between the two groups ($p = 0.000$) indicates that hands-on, tangible learning media such as the PLC Training Kit have a stronger pedagogical impact on developing critical thinking skills than purely virtual or simulation-based instruction.

This finding aligns with Hake's framework [29], which posits that interactive engagement methods—such as using physical training kits—tend to yield higher learning gains than traditional or passive instructional techniques. Furthermore, it resonates with previous studies in engineering and vocational education that highlight the effectiveness of practical, experiential learning in enhancing students'higher-order thinking skills [25], [26], [23]. For instance, [20] confirmed that HMI-based training kits significantly improved automation control competencies.

The superior performance of the experimental group may be attributed to the nature of the training kit, which offers direct interaction with physical hardware and facilitates contextualized problem-solving experiences. This hands-on engagement allows students to explore the practical implications of PLC logic, immediately observe the consequences of programming errors, and iteratively refine their understanding—an instructional approach that simulation environments, though valuable, may not fully replicate. This tactile and visual feedback loop likely stimulates the cognitive processes underlying critical thinking, such as analysis, synthesis, and evaluation.

Moreover, the results reflect the demands of 21st-century learning paradigms, where education must transcend rote memorization and foster the skills of critical thinking, creativity, communication, and collaboration [2].

In technical education, particularly within the context of Industry 4.0, integrating real-device programming into the curriculum is crucial for bridging theoretical knowledge with industrial applications. The PLC Training Kit functions as a crucial medium for this integration, promoting the development of problem-solving strategies and the application of logical reasoning in realistic contexts.

Nevertheless, it is important to acknowledge that the initial abilities of students in the experimental group were slightly higher than those in the control group, as evidenced by pre-test differences. While this disparity was controlled through N-Gain normalization, future studies may consider matched-pair groupings or covariance analyses to further isolate treatment effects.

In conclusion, this study provides robust empirical evidence that supports the integration of PLC Training Kits into electrical engineering education. These tools significantly contribute to the development of students' critical thinking skills, making them more capable of addressing complex challenges in automation and control systems. By offering authentic, problem-centered learning experiences, the PLC Training Kit enhances not only academic achievement but also the readiness of graduates to meet industrial demands.

5. Conclusion

The discussion outcomes, problem formulation, and hypothesis were taken into consideration for formulating the following research conclusions:

1) There is a noticeable difference between the students' critical thinking skills in PLC programming before and after using the training kit.

2) There is a notable difference between the critical thinking skills of students in PLC programming before and after they participate in simulation-based learning.

3) Before engaging in training kits and simulations, students' critical thinking abilities in PLC programming were noticeably different.

4) Following their involvement in training kits and simulations, students' critical thinking skills in PLC programming change dramatically.

Overall, the use of PLC Training Kit significantly affects the improvement of students' critical thinking skills in the PLC Programming course. Students who study with the support of this practice-based learning media show better improvements in analyzing problems, compiling program logic, and evaluating and modifying control circuits systematically.

Real-tool-based learning such as PLC Training Kit not only facilitates conceptual understanding, but also encourages students to actively explore, solve problems, and make decisions based on logic.

This is very relevant to the demands of 21st century competencies, especially in electrical engineering education which emphasizes the integration of theory and practice.

Therefore, PLC Training Kit is recommended as an effective innovative learning media to improve students' critical thinking skills and readiness to face challenges in the automation-based industrial world.

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