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Effectiveness of Automation Studio Software in Enhancing Electrical Engineering Students' Skills in Designing PLC Ladder Diagrams

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Abstract

The growing complexity of industrial automation requires Electrical Engineering students to develop higher skills in the area of Programmable Logic Controller (PLC) programming, more specifically on ladder diagram design. The conventional methods often lack sufficient interaction, practice, and actual industry exposure for the students. In this regard, this study aims to determine whether or not Automation Studio Software is effective in developing students' abilities in designing PLC ladder diagrams. A quasi-experimental study was conducted with 30 students for each experimental and control class. The experimental class was taught using Automation Studio, whereas the control class used conventional method of teaching. The instruments included a validated performance test and a student perception survey questionnaire. Results show a significantly improved post-test score for the experimental class by 40.96%, with an *N*-Gain of 74.96% which falls under moderate category and a very large effect size. Students' perceptions were overwhelmingly positive, 87% reporting enhanced understanding and 92% recommending the integration of the software in the curriculum. This implies that Automation Studio Software presents an industry-based learning environment that is capable of bridging the gap between theory and practice, improving student PLC programming competencies.

1. Introduction

The growing sophistication of industrial automation requires greater skills in Programmable Logic Controller (PLC) programming, especially in ladder diagram design, since it is the major method that industries use (Kaid et al., 2020; Zhao, 2021). Although this course makes a significant contribution to knowledge, many Electrical Engineering students find it difficult to learn ladder diagrams, which require logical reasoning and problem-solving abilities (Arowolo et al., 2020; Kholikhmatov et al., 2023). The challenge gets doubled up due to conventional teaching methodologies that are not interactive and do not connect to the real-life situation, thus inhibiting students' ability to translate theoretical knowledge into practice (Ali, 2023; Siwy, 2024; Suseno et al., 2022). Hence, most graduates fall short of the competency standard that industrial sectors require from them under a similar condition, particularly when Industry 4.0 is being implemented (Aswardi et al., 2021; Santika & Mukhaiyar, 2020).

To overcome these limitations, educational tools with simulation-based presentations can be used as an alternative, such as Automation Studio Software (Cahyono & Irwanto, 2023; Cahyono & Sumbodo, 2020). This software enables the user to do interactive and real-time simulations that are very close to field conditions, so it will help fill the gap between theory and practice (Kohpeisansukwattana, 2024; Liljaniemi & Paavilainen, 2020). Previous studies have already highlighted how the software can improve student engagement, skill acquisition, and readiness for work (de Oliveira & Souza, 2021; Ruan Lyngdorf, 2024). However, a dearth of empirical evidence exists about their particular influence on ladder diagram design competence in higher education settings (Cahyono & Sumbodo, 2020; Sezer, 2024).

The main problem being tackled here is the persistent gap between theoretical PLC knowledge and practical ladder diagram design skills among Electrical Engineering students; this leads to inadequate preparedness for industry demands on them. Conventional teaching methods have not offered an interactive and real-time simulation experience, which consequently results in the low rates of skill acquisition and limited problem-solving skills. Therefore, this study aims to determine the effect of Automation Studio Software on the Electrical Engineering students' ladder diagram design skills by means of simulation-based learning. In line with this general objective, the study seeks to answer the following research questions:

1. Is there a significant difference in post-test scores between students who received the Automation Studio Software training (experimental group) and those who received conventional instruction (control group)?
2. What are the students' perceptions of the use of Automation Studio Software for learning concepts related to PLC?
3. How much has learning improved when measured by effect size and N-Gain?

2. Research Methods

2.1 Research Design

The study used a quasi-experimental design with pre-tests and post-tests. Sixty students majoring in Electrical Engineering at one of the Indonesian public universities were randomly assigned into two groups: one experimental class and one control class with 30 students each. The experimental class was taught using Automation Studio software, whereas the control class used a conventional teaching method. Both classes belonged to the same academic year for drawing comparison.

2.2 Research Instruments

The main instruments used in this study were a performance test and a student perception questionnaire.

The performance test consisted of ten items covering four items on logic accuracy, three items on design efficiency, two items on how well the complexity of the diagram is handled, and one item on simulation function. Each item carried a maximum of 10 points, making a total of 100 points with rubrics standardized by industry for ladder diagrams (for example, correct rung sequencing and input-output mapping). High reliability was determined for the instrument (Cronbach's α = 0.89 pre-test, 0.92 post-test). The content validity was adjudged to have been attained through Aiken's V index of 0.85, calculated based on ratings provided by three experts of Electrical Engineering. Exploratory factor analysis provided evidence of construct validity, showing that 78% of the variance could be explained by one factor.

The perception questionnaire consisted of fifteen items on a Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree). The questionnaire comprised five items for the usability of the software, five items for key features, and five items concerning learning impact. It showed a very high reliability (Cronbach's α = 0.91) and validity (face validity by pilot testing with 20 students, correlation with performance scores r = 0.72).

2.3 Research Procedures

The study was conducted in 8 weeks in the Electrical Engineering Department's PLC Programming course. Week 1: Pre-test administration (45 minutes) for both classes to establish baseline equivalence (no significant difference, p = 0.92). Weeks 2-6: Treatment phase (detailed below). Week 7: Post-test (identical format to pre-test). Week 8: Perception questionnaire (20 minutes). All sessions were held in equipped labs, with data anonymized and ethical approval obtained from Universitas Negeri Surabaya.

Treatment Details

Experimental Class: Received Automation Studio Software-based instruction (5 sessions with 3 hours each). The teaching and learning activities and materials involved (1) lectures on ladder logic fundamentals (20%), (2) hands-on software tutorials for building electropneumatic circuits (40%), (3) real-time simulations and debugging of student-designed diagrams (30%), and (4) peer reviews and instructor feedback via software's diagnostic tools (10%). Students designed five progressively complex ladder diagrams (e.g., sequential motor control, fault-tolerant systems) with virtual PLC hardware emulation.

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Control Class: Received conventional instruction (identical duration/content coverage), covering (1) lectures with slides (40%), (2) paper-based diagram drawing and manual logic verification (40%), and (3) Group discussions without simulation (20%). There was no software access; the students focused on theoretical explanations and whiteboard exercises.

2.4 Data Analysis

Descriptive and inferential statistics were used to determine the effect of the pedagogical treatment. The means (*M*) and standard deviations (*SD*) were analyzed from the pre-test and post-test scores. A paired sample *t*-test was undertaken to find within-group differences, whereas between-group differences were calculated through an independent sample *t*-test, with a significance level of $p < 0.05$. *N*-Gain provided one way of expressing improvement in learning, supported by effect size, so that some appreciations of practical significance could be offered where 0.5 or greater approximated a moderate-to-large effect. Visual data representations were utilized for clarity support and interpretability enhancement.

3. Result

3.1 Improvement in Ladder Diagram Designing Skills

A great improvement in the post-test performance of students in the experimental class over and above that of the control class was recorded. The mean post-test scores for the experimental class rose by 40.96%, whereas the mean post-test scores for the control class were only 18.65%. Therefore, any improvement in students' abilities was examined using a quantitative Difference-in-Differences approach, comparing pre-test and post-test scores between the experimental and control groups. Table 1 depicts a summary of statistical results.

Table 1 *Paired sample statistics*

Group	Test	*M*	*N*	*SD*
Experiment	Pre-test	45.29	30	2.71
	Post-test	86.25	30	4.041
Control	Pre-test	45.18	30	3.78
	Post-test	63.83	30	5.467

To further test the improvement, a paired sample *t*-test was conducted for both classes. This test helped to find out if the difference between pre-test and post-test scores for each group was significant or not. Table 2 shows that there were significant gains by both classes since the corresponding *p*-values were less than 0.001 in each case, therefore showing that the intervention had an effect.

3.2 Statistical Significance and Correlation

Paired sample t-tests were undertaken to analyze within-group differences for student performance statistically significant differences were observed in both the experimental and control groups, as shown in Table 2 ($p < 0.001$), indicating that the learning interventions had a measurable effect on learning outcomes.

Table 2 *Paired samples test*

Pair	Mean Difference	SD	t	df	Sig. (2-tailed)
Pre-Post Experimental Class	-40.96	3.73	-60.22	29	0.000
Pre-Post Control Class	-18.65	3.45	-29.57	29	0.000

Next, a correlation analysis was conducted to examine the relationship between pre-test and post-test scores within each class. As shown in Table 3, the experimental class demonstrated a very strong positive correlation ($r = 0.780$, $p < 0.001$), indicating consistent individual learning gains. In contrast, the control class showed only a moderate correlation ($r = 0.447$, $p = 0.013$), suggesting greater variability in students' performance over time.

Table 3 *Paired samples correlations*

Group	Test	N	Correlation	Sig.
Experiment	Pre-test - Post-test	30	.780	.000
Control	Pre-test - Post-test	30	.447	.013

The above statistical findings proved that the introduction of Automation Studio Software in the experimental class had a greater effect on their improvement and consistency in learning outcomes.

3.3 Student Perception Analysis

The survey resulted in very positive students' perceptions regarding the use of Automation Studio Software. 87% agreed that the software helped them to better understand basic principles relating to Programmable Logic Controllers (PLC) by a great margin, while 78% said that its interactive simulation function made them more involved and facilitated navigation through complicated design processes. 92% of them strongly recommended its inclusion in electrical engineering studies because this software was conceived relevant for practical learning and matches current industrial practice. This puts forward the psychological pedagogical value of this software from the students' point of view (see Figure 1).

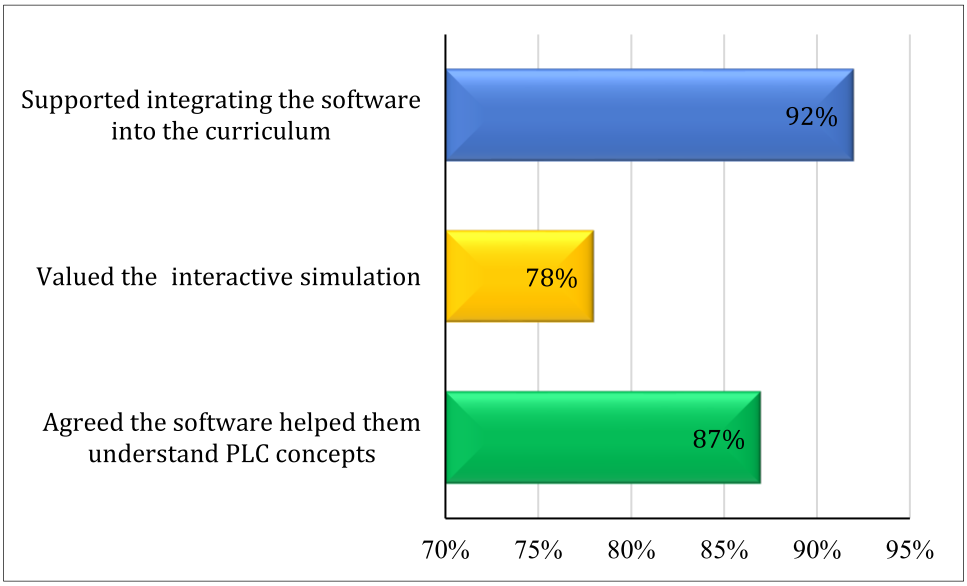

Fig. 1 *Student perceptions of automation studio software*

As shown in Figure 1, most of the students had a positive perception regarding Automation Studio Software, which will be discussed in detail in the discussion section to better understand the reason behind this perception.

3.4 Effect Size Analysis

An analysis of effect size was undertaken using Cohen's *d* to quantify the learning gain observed. Cohen's *d* was interpreted as the magnitude of difference between pre-test and post-test scores for both groups. Findings revealed a large effect size for both groups with Cohen's d = 11.91 for the experimental class and 3.97 for the control class. This finding indicated that though very high learning gains were obtained from both classes, the use of Automation Studio Software yielded an even more prominent effect.

The probability distributions shown in Figure 2 further clarify these differences. As illustrated, the experimental class exhibits a wider spread and a sharper distribution curve between the pre-test and post-test scores compared with the other class, indicating more pronounced score changes. The visual distance between the means stands as testament to those large effect sizes reported above and, once again, speaks to the promise of simulation-based learning in raising performance in challenging technical subject areas.

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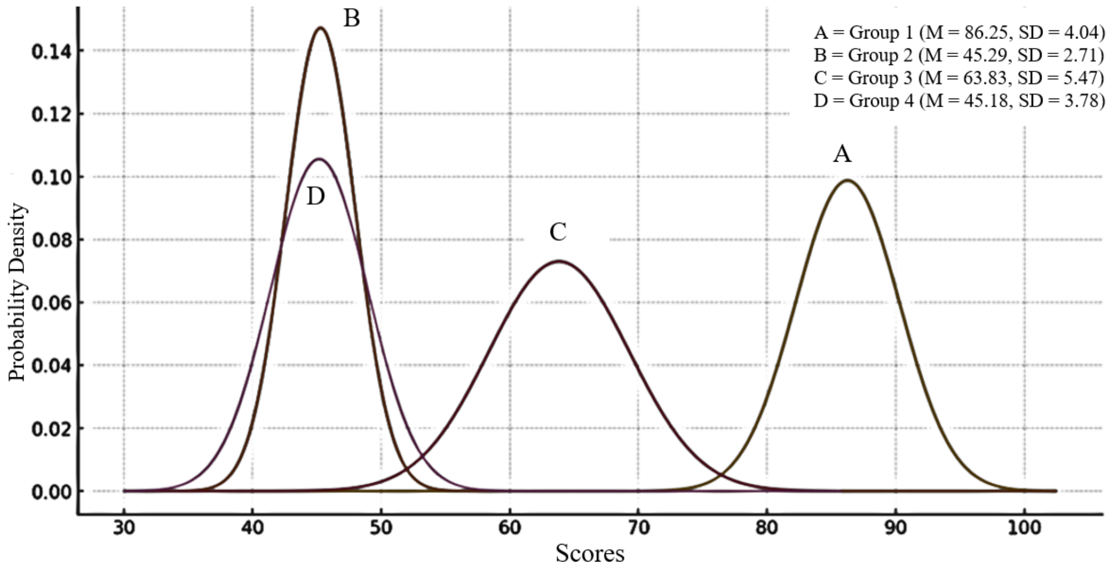

Fig. 2 *Probability distribution of experimental and control group results*

3.5 *N*-Gain Analysis

To evaluate learning effectiveness, students' performance was analyzed using the Normalized Gain (*N*-Gain) metric. *N*-Gain is a widely used measure in educational research for assessing learning gains based on pre-test and post-test scores. It is particularly suited to pretest–posttest research designs for evaluating changes attributable to experimental interventions. In this study, *N*-Gain was calculated at the individual level using a standard formula.

$$N\text{-Gain}=\frac{(\text{Post-test Score} - \text{Pre-test Score})}{(\text{Maximum-Score} - \text{Pre-test Score})} \quad (1)$$

After calculating the individual scores, the average *N*-Gain for each class was computed. The meaning of *N*-Gain scores were summed up in Table 4.

Table 4 *Interpretation of N-Gain scores*

Score	Interpretation
N-Gain ≥ 0.70(or 70%)	High
0.30 ≤ *N*-Gain < 0.70 (or 30% ≤ *N*-Gain < 70%)	Medium
N-Gain < 0.30 (or < 30%)	Low

Results showed a mean *N*-Gain score of 74.97% for the experimental class, indicating a moderate effectiveness. For the control class, the mean *N*-Gain was 34.24%, indicating a low effectiveness. This finding indicated that though there had been some degree of improvement for both classes, substantially greater and more effective learning gains were facilitated by Automation Studio Software in the experimental class.

Table 5 presents in detail the *N*-Gain scores for every student of both classes so that an overview of individual progress can be made, as well as some variability within the class. Summary statistics for each class, comprising minimum, maximum, and mean values, are disclosed in Table 6. Apart from indicating a statistically significant gain by the experimental class, these results show that there was a real and practically meaningful improvement in learning outcomes due to the use of Automation Studio Software. These findings are consistent with prior research emphasizing the importance of calculating learning gains from pre- and post-test data to accurately evaluate improvement.

Table 5 *Results of N-Gain score calculation*

Student in Experiment Class	*N*-Gain %	Student in Control Class	*N*-Gain %
SE1	74.86	SC1	39.92
SE2	79.84	SC2	37.43
SE3	68.62	SC3	29.36
SE4	64.59	SC4	38.82
SE5	86.49	SC5	42.77
SE6	73.19	SC6	37.43
SE7	81.1	SC7	53.23
SE8	72.1	SC8	41.1
SE9	64.59	SC9	44.37
SE10	82.21	SC10	43.67
SE11	76.34	SC11	35.23
SE12	68.62	SC12	33.28
SE13	81.1	SC13	33.27
SE14	68.62	SC14	29.36
SE15	74.86	SC15	31.19
SE16	70.46	SC16	29.36
SE17	64.59	SC17	22.19
SE18	87.34	SC18	39.92
SE19	81.1	SC19	37.43
SE20	77.65	SC20	29.36
SE21	70.46	SC21	27.73
SE22	76.34	SC22	31.19
SE23	68.62	SC23	29.36
SE24	64.59	SC24	23.49
SE25	82.21	SC25	33.27
SE26	76.34	SC26	31.19
SE27	68.62	SC27	29.36
SE28	76.34	SC28	22.19
SE29	87.34	SC29	33.27
SE30	79.84	SC30	37.43

Note: SE1–SE30 = Students in Experimental Class; SC1–SC30 = Students in Control Class.

Table 5 shows the detailed *N*-Gain scores for each student in both classes, providing an overview of individual progress. Summary statistics, including minimum, maximum, and mean values for each class, are presented in Table 6. These findings demonstrated not only a statistically significant gain in the experimental class but also a meaningful improvement in learning outcomes attributable to the use of Automation Studio Software.

Table 6 *Summary statistics N-Gain*

	Experimental	Control
Mean (%)	74.97	34.24
Minimum (%)	64.59	22.19
Maximum (%)	87.34	53.23

Figure 3 illustrates the distribution of *N*-Gain scores for the experimental and control classes. The experimental class showed greater consistency and higher levels of improvement, as indicated by a tighter distribution shifted upward. In contrast, the control class exhibited a wider spread with generally lower gains. This distribution corroborates the earlier statistical analyses, demonstrating that the simulation-based instruction produced more uniform learning gains across different ability levels than conventional teaching.

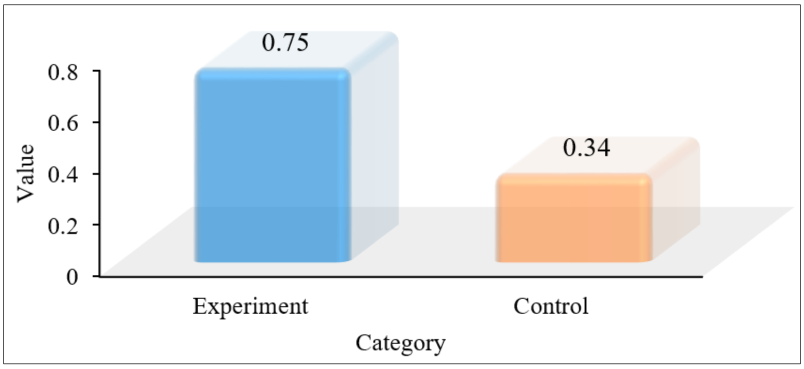

Fig. 3 *Distribution of N-Gain between experimental and control classes*

According to Figure 3, the distribution is much more discrete and significant in the experimental class than it is in the control class. This finding is consistent with the earlier results. Overall, the findings indicate that the use of the Automation Studio Software effectively improved students' skills in designing PLC ladder diagrams. The following discussion section elaborates on how these results address key challenges in Electrical Engineering education and outlines their theoretical and practical implications.

3.6 Results Summary and Interpretation

The results indicate that students in the experimental class demonstrated significantly greater improvement (M = 40.96%, SD = 3.73) than those in the control group (M = 18.65%, SD = 3.45). N-Gain analysis further showed that the experimental class achieved a moderate level of improvement (M = 74.96%), whereas the control class exhibited a low level of improvement (M = 34.23%). A paired-samples t-test confirmed that the difference between the two classes was statistically significant ($p < 0.05$), with a substantially larger effect size observed for the experimental class (Cohen's d = 11.91). In addition, questionnaire results revealed that 65% of students perceived Automation Studio Software as an effective tool for enhancing their understanding of PLC concepts, and 72% recommended its integration into the curriculum to promote more equitable and effective learning outcomes.

4. Discussion

The results of this study demonstrated a highly significant improvement in the experimental class, with an average gain of 40.96%, compared to 18.65% in the control class ($p < 0.001$, Cohen's d = 11.91). This finding strongly supports the claim that students in the experimental class outperformed those receiving traditional instruction. The conclusion is further substantiated by the mean N-Gain of 74.97% (moderate effectiveness) and the strong pre–post correlation observed in the experimental class (r = 0.780), indicating consistent learning gains across students. In contrast, the control class exhibited greater outcome variability, reflected in a weaker pre–post correlation (r = 0.447). The rapid and effective acquisition of programming logic observed in the experimental class can be attributed to the use of interactive simulations and real-time visualizations provided by Automation Studio Software, which facilitate problem-solving, testing, and debugging within a virtual environment. The relatively limited improvement in the control class suggests that conventional instructional methods, while providing a theoretical foundation, are less effective in supporting the practical application of knowledge. These findings are consistent with prior studies highlighting the effectiveness of project-based learning and interactive technologies in strengthening engineering competencies.

In Electrical Engineering education, particularly in PLC programming and industrial automation, theoretical instruction often diverges from practical application. Conventional teaching methods, such as oral instruction combined with paper-based assignments, fail to adequately replicate the dynamics of real industrial environments. As a result, students may understand theoretical concepts but lack the practical experience required to solve authentic engineering problems, creating a persistent gap between knowledge and application. The present study demonstrates that software tools such as *Automation Studio* help bridge this gap by providing realistic simulations of industrial control systems. Through virtual PLC environments, sensor–actuator modeling, and fault diagnostics, students can visualize, test, and refine their designs in a safe digital setting. This simulation-based learning approach enhances both student confidence and competence, better aligning academic preparation with industry requirements.

Experiential and constructivist learning theories emphasize active learner engagement, inquiry-driven learning, and the contextual construction of knowledge. The findings of this study support these theoretical perspectives by demonstrating that meaningful and real-world tasks enhance students' conceptual understanding, as proposed in constructivist learning models. The hands-on activities implemented in this study closely resemble authentic industrial scenarios, enabling experiential learning in which students actively translate theoretical concepts into practice. Such high levels of cognitive engagement foster advanced thinking skills, including analysis, synthesis, and problem-solving, which are essential for addressing complex automation systems. Consequently, this pedagogical approach aligns strongly with engineering education practices designed to meet the demands of Industry 4.0.

The findings of the present study align with experiential and constructivist learning principles, which emphasize active student participation in knowledge discovery and contextual meaning-making. Consistent with the constructivist paradigm, learning is most effective when students engage in authentic tasks that mirror real-world problems. The interactive software used in this study supports experience-based learning by enabling practice-oriented classroom activities that reflect industrial contexts, allowing theoretical concepts to be applied and refined. This approach promotes deep cognitive engagement through higher-order thinking processes, including analysis, synthesis, and problem solving, which are essential for working with complex automated systems. Consequently, it situates engineering education within the pedagogical and skill requirements of Industry 4.0.

Automation Studio Software provides students with real-time simulations of industrial automation systems, enabling them to examine complex control processes within a safe virtual environment. This capability strongly supports experiential learning by allowing students to integrate theoretical understanding with industry-relevant practical skills. Moreover, the software contributes to students' employability by aligning learning outcomes with key Industry 4.0 competencies, such as digital fluency and systems thinking. High levels of student satisfaction (e.g., 87% rating the software as effective and 92% as supportive) further indicate its strong pedagogical value. Effective implementation, however, requires targeted professional development for instructors, focusing not only on technical proficiency with the software but also on the pedagogical design of simulation-based curriculum modules. Overall, the integration of Automation Studio software offers a modern, industry-aligned, and pedagogically robust framework for Electrical Engineering education.

Future research should involve larger and more diverse samples across multiple institutions to enhance the generalizability of the findings. Longitudinal studies are also recommended to examine the durability of the effects of Automation Studio Software on students' skill retention and professional readiness over time. In addition, the application of this software could be extended to related domains such as industrial robotics, smart manufacturing, and intelligent control systems, where simulation-based learning is increasingly important. Future studies may also explore the integration of Automation Studio Software with emerging technologies, including digital twins, augmented reality, and virtual reality, to create more immersive and adaptive learning environments. Furthermore, the development of standardized instruments to assess higher-order thinking, problem-solving, and job-relevant competencies in automation contexts is needed. Collectively, these directions will strengthen the evidence base for curriculum design and educational technology integration in engineering education aligned with Industry 4.0.

5. Conclusion

The results of this study adequately prove that Automation Studio Software will effectively enhance the skills of Electrical Engineering students in designing PLC ladder diagrams. The experimental class has shown statistically significant and educationally meaningful improvement to prove the effectiveness of this particular software as an instructional medium. The software simulates authentic industrial conditions, enabling students to develop conceptual understanding and practical skills that effectively bridge the gap between theory and application in engineering education. Its interactive and visual features interest students, helping with problem-solving and logical reasoning closely related to competencies highlighted by Industry 4.0. Student perceptions also showed a high satisfaction, indicating that the software is effective in supporting students' learning experiences. Besides, students perceived that the tool would support learning outcomes besides enhancing motivation and readiness for real applications. This study supports the sustained use and institutional adoption of Automation Studio Software as a key instructional medium for implementing a modern and competency-based engineering curriculum. This study also recommends that future research examine its integration across multiple technical disciplines and larger student cohorts.

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Conflict of Interest

The authors declare no conflict of interest regarding this publication.

Author Contribution

The authors confirm contribution to the paper as follows: ***Study conception and design:*** *Endryansyah and Bambang Suprianto;* ***Data collection:*** *Endryansyah;* ***Analysis and interpretation of results:*** *Endryansyah, Puput Wanarti Rusimamto;* ***Draft manuscript preparation:*** *Endryansyah, Puput Wanarti Rusimamto. All authors have seen and approved the final version of the manuscript.*

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