Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 46 No. 05
May 2025

Effectiveness of a PLC Programming Learning Module in Industrial Automation Education: A Guided Simulation Approach

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Abstract

Introduction: In the rapidly evolving field of electronics technology education, innovative teaching methods are crucial for preparing students to meet the demands of the industry. This study delves into the effectiveness of a cutting-edge approach to teaching programmable logic controller (PLC) ladder programming with electropneumatics, utilizing a simulated learning module at Tagoloan Community College in Misamis Oriental, Philippines. The integration of simulation-based learning in technical education has gained significant traction in recent years, offering students hands-on experience in a controlled, risk-free environment. As fundamental components in industrial automation, PLCs require a deep understanding of ladder programming and its application in electro-pneumatic systems. However, traditional teaching methods often fall short of providing students with practical, real-world experience due to limitations in equipment availability and safety concerns.

Objectives: This research aims to bridge the gap between theoretical knowledge and practical application by evaluating the impact of a simulated learning module on students' comprehension and skill development in PLC ladder programming with electropneumatics. This study sought to provide a comprehensive analysis of the module's effectiveness by employing a descriptive research design, utilizing means, percentages, and standard deviations, along with inferential statistics.

Methods: This study employed a descriptive research design to evaluate the effectiveness of a simulated learning module for PLC ladder programming with electropneumatics among electronics engineering technology students at Tagoloan Community College. The participants consisted of enrolled electronics engineering technology students who engaged with the newly developed simulation-based module. Data were collected through pre- and post-intervention assessments, including quizzes and laboratory simulation exercises, to measure changes in students' knowledge and skills. Descriptive statistics such as means, percentages, and standard deviations were used to summarize the assessment results. Inferential statistical methods were applied to determine the significance of any observed improvements in student performance. The structured approach allowed for a comprehensive analysis of the module's impact within the classroom setting. Overall, the methodology provided a robust framework for assessing the educational value of simulation-based learning in electronics technology.

Results: The multiple linear regression analysis revealed that most input and process variables did not significantly influence the respondents' overall written post-test scores, except for the overall simulation variable, which had a highly significant positive effect. Similarly, no significant relationship was found between these variables and the respondents' practical post-test performance, supporting the null hypothesis for both outcomes. These findings underscore the limited impact of traditional input and process factors on performance while highlighting simulation as a powerful tool for enhancing written test results. Notably, practical skills improved through the use of a simulated PLC programming learning module, which provided a direct, real-time demonstration of electro-pneumatic component motion sequencing. This hands-on simulation allowed learners to engage virtually with complex motion control processes, bridging the gap between theory and practical application.

Conclusions: This study highlights the critical role of optimized experiential learning and advocates for innovative pedagogical approaches to enhance dynamic learning processes for both instructors and students in industrial automation. The findings suggest that incorporating such methods can significantly improve educational outcomes and preparedness for real-world applications.

Keywords: Electro-pneumatics, Industrial automation, Ladder diagram programming, Programmable Logic Control, Simulation

1. Introduction

In today's globalized and rapidly modernizing world, the organization's success largely relies on creating a sustainable competitive advantage and achieving superior performance [1]. The Survival of industries depends on matching organizational form to the prevailing nature of technology and business management processes [2]. In essence, to thrive in this interconnected, single-market economy, businesses must prioritize innovative strategies that boost both quality and productivity [3]. Innovation is essential for enhancing competitiveness, but its effectiveness depends on a supportive ecosystem that fosters continuous improvement. Innovation ecosystems are socio-economic systems that make innovation happen [4]. These innovation ecosystems are thus generated by networks that have advanced from cooperation to collaboration among agents [5]. This includes a favorable macroeconomic environment, efficient education systems, competitive markets for goods and services, and adaptable labor markets, collectively contributing to a robust economic foundation. This supports political stability by fostering economic growth, reducing social unrest, and promoting overall societal well-being [6]. Together, these factors enable businesses to stay agile and effectively integrate technological advancements, fostering sustained innovation and competitiveness in dynamic economic landscapes [7]. In pursuing enterprise competitiveness, widespread computerization and automation significantly elevate the standards of manufacturing, production, and control systems, driving excellence across these critical areas [8] and increasing the maneuverability of the enterprise’s actions and quick response to the changing market conditions; reducing the costs for external and internal failures [9].

Automation supports innovation by streamlining processes, reducing manual tasks, and reallocating resources toward creative and strategic endeavors. As automation increases significantly, a control system requires programmable, flexible, reliable, robust, and cost-effective [10]. At the industrial automation level, varied programmable logic intelligences to both discrete and analog signal controllers play a significant role in providing control and signal conditioning [11]. A Programmable Logic Controller (PLC) is an industrial computer designed to automate and control machinery and processes [12]. It operates with logic-based software and relay-logic principles, enabling it to process input signals, execute programmed instructions, and manage outputs efficiently. PLCs are the brains of automation systems, controlling machinery, assembly lines, robotic devices, and other industrial equipment through programmed logic. PLCs are integral to process control, enabling high reliability, real-time operation, and adaptability in diverse manufacturing environments. PLCs are named for their focus on implementing logic and switching operations. Input devices like switches and output devices such as motors are interfaced into the PLC, and these inputs and outputs are based on the programmed logic, allowing it to control machinery or processes effectively. This setup enables precise industrial operations by automating tasks based on predefined conditions through a motion sequence diagram [13]. This makes PLCs essential for reliable, adaptable, and precise control in industrial environments. However, there are concerns about the capital intensity of the investment and the cost of systems upgrading, coupled with human resource requirement challenges [14]. Likewise, the industry and the academe are facing challenges attributed to systems integration and skill set inadequacy. This predicament prompted companies to engage in linkages and collaborations with universities and evaluate how the education sector responds to the new demands of the knowledge economy [15].

The industry's competitiveness relies on its capacity to adopt innovations, which depends on academic institutions producing a skilled, multi-craft technical workforce. Without this appropriately trained talent, the industry cannot effectively enhance its innovative capabilities [16], [17]. In essence, the current technological innovations and dynamics of change in work organizations and economies continue to fuel compelling debates on the future of the labor market, and the workers' fate crucially depends on their ability to keep up with the change [18]. The role of talent in the industry is critical to the future viability of the manufacturing sector. Improving competitiveness also requires the creation of a highly educated and motivated workforce [19]. Organizational survival and growth depend heavily on a clear strategy, prompting industries to align human resource development with strategic objectives. This alignment ensures employees understand how their roles contribute to the organization's goals, fostering a shared mindset that links individual skill development to broader strategic success. [20]. Since matching jobs-to-skill requirements has become an issue in human resource development, the industry must define the fundamental skill set that must be developed in professional education for occupational qualification [21]. Skills mismatch can be described as a discrepancy between the portfolio of skills required by an occupation and the portfolio of abilities possessed by a worker [22]. Such imbalance shall be conveyed to the academe for appropriate curriculum review and analysis to avoid a mismatch. Understanding ability development during academic engagement offers a promising lens for examining how individuals relate to outcomes in the knowledge transfer process, especially as academic engagement becomes a key channel for moving academic knowledge into relevant industry needs [23], [24]. Hence, the academe has to keep abreast of current trends in the industry to stay relevant. Although equipment inadequacies pose obvious challenges, industry and academic collaboration come to a place where shared resources offer alternatives translated into mutual interests. The insights are helpful for educators and industry in training the next-generation manufacturing workforce [25].

Given the importance of industrial automation and the scarcity of relevant skill sets of technology students entering the manufacturing industry upon graduation, this research focuses on developing technology-based training relevant to industrial automation, specifically PLC programming skills development, to better prepare students for their future careers. PLCs are central to industrial automation, enabling precise control and monitoring of processes [26]. However, the lack of physical laboratory equipment at Tagoloan Community College (TCC) in Misamis Oriental, Philippines, has posed challenges in PLC programming training. To address this, a learning module utilizing interactive PLC programming simulations has been developed as a cost-effective alternative to expensive physical equipment. By leveraging software like Automation Studio, students can learn ladder programming and industrial automation principles through simulated environments, effectively bridging theoretical knowledge with hands-on experience [27]. This approach ensures students gain practical skills in controlling pneumatic actuator motion sequences, enhancing their readiness for the manufacturing industry despite resource limitations. Hence, virtual laboratories are digital replicas of real-world experiments, simulated on computers to mimic the conditions and processes of actual scientific investigations [28].

2. Objectives

The general objectives of the study are to develop a PLC programming learning module through a simulated platform using the Automation Studio software. The specific objectives are:

1. To develop a PLC programming learning module that incorporates simulation of electro-pneumatic working elements for enhanced practical application and understanding.
2. To establish the respondents' profiles regarding gender and the purpose of enrolling in the academic program.
3. To measure the respondents' pre-test and practical simulation scores in terms of:
   a. Programming single and double-acting cylinders using logic functions.
   b. Programming multiple actuators with sensors guided by the motion sequence diagram.
4. To measure the respondents' post-test written examination scores in terms of:
   a. Programming single and double-acting cylinders using logic functions.
   b. Programming multiple actuators with sensors guided by the motion sequence diagram.
5. To measure the post-test practical examination score of the respondents as evaluated by three experts in terms of:
   a. Programming single and double-acting cylinders using logic functions.
   b. Programming multiple actuators with sensors guided by the motion sequence diagram
6. To measure the extent of input (profile) and process (pre-test, formative simulation score) variables in the respondent's output (written post-test, practical evaluation score) variables.

3. Methods

The learning module development and simulation

This learning module covers the core concepts of programmable logic control, including PLC components, number systems, logic functions, and relay logic. It uses examples to introduce students to fluid power technology and the simulation software's utility. The module focuses on guided lab activities, translating control theories into practical industrial automation skills. These activities use electro-pneumatic components to execute industry-relevant control concepts, progressing from basic to advanced exercises, incorporating timers and counters alongside other working elements. The simulation reflects a pick-and-place PLC-based pedagogical tool as shown in Figure 1.

Figure 2 depicts a manifold of three (3) double-acting cylinders, a vacuum cup, four (4) 5-2 way single solenoid valves, three (3) 5-2 way double solenoid valves, and proximity sensors as simulated using Automation Studio software. The software demonstrates the dynamic movements of the individual working elements as they operate to a specified motion sequence.

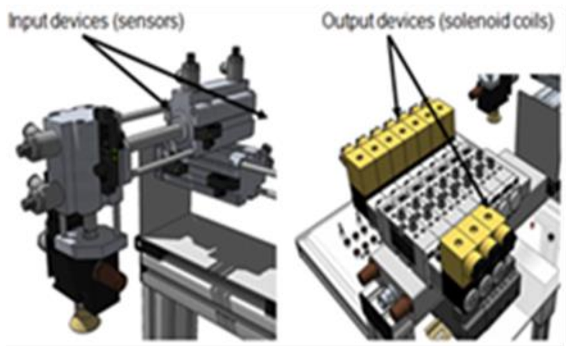

Figure 1: Pick & Place Pneumatic Arm

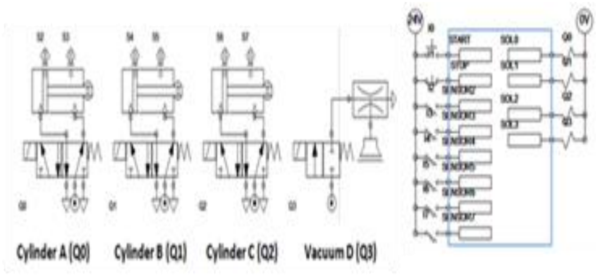

Figure 2: Pick & Place Simulation

The evaluation

The evaluation process of the study intends to assess the effectiveness of the learning module for the PLC programming parameters, utilizing a combination of single-acting and double-acting cylinders. The corresponding skill set is measured through a carefully designed Pre-test and post-test evaluation instrument, where the students' responses might determine the effectiveness of the learning module. The pre-test and post-test scores are tested using acceptable statistical analysis.

4. Results and Discussions

The learning module development and simulation

The application of the PLC programming learning module provides students with a comprehensive foundation in the essential principles of programmable logic controllers, including hardware configuration, logic functions, relay logic instructions, and the use of timers and counters. Through structured lessons and guided examples, students become familiar with the core components and operation of PLCs, such as understanding input/output devices, ladder logic diagrams, and the integration of relay logic for control applications. The module emphasizes hands-on experience by allowing students to design, test, and troubleshoot PLC programs in simulated environments that closely mimic real-world industrial scenarios. This approach not only reinforces theoretical knowledge but also develops practical skills needed to solve control problems and automate fluid power systems, as illustrated in Figure 3. By engaging with realistic programming tasks and event sequencing, students gain confidence and proficiency in applying logic functions and relay logic to control electro-pneumatic devices and other industrial equipment

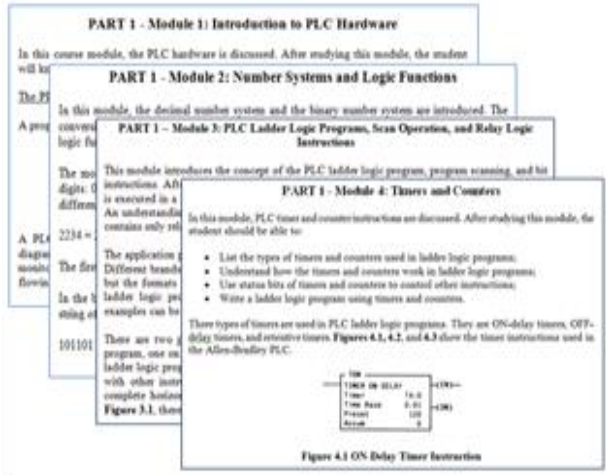

Figure 3: PLC Learning Modules

Electropneumatic control fundamentals and PLC programming concepts applied in real industry scenarios are articulated and demonstrated for application clarity as shown in Figure 4. These examples focus on manipulating fluid power components, control features, electrical circuits, and PLC ladder logic. While these examples form the foundation, additional industry-related applications are introduced during lectures to further enhance instruction delivery. Therefore, the learning module is designed to be supplemented with extra examples as needed throughout the course. The central component of this learning module is a series of laboratory exercises designed to evaluate students' grasp of PLC fundamentals and the application of the concepts presented. Using Automation Studio software, students develop fluid power circuits, practice input-output-PLC interfacing, and create PLC ladder programs within a simulated environment. Successful completion and submission of lab reports for each exercise are mandatory. These diverse examples and exercises aim to cultivate essential competencies in fluid power, electrical controls, and PLC ladder diagram programming, effectively compensating for a lack of physical lab equipment due to funding constraints.

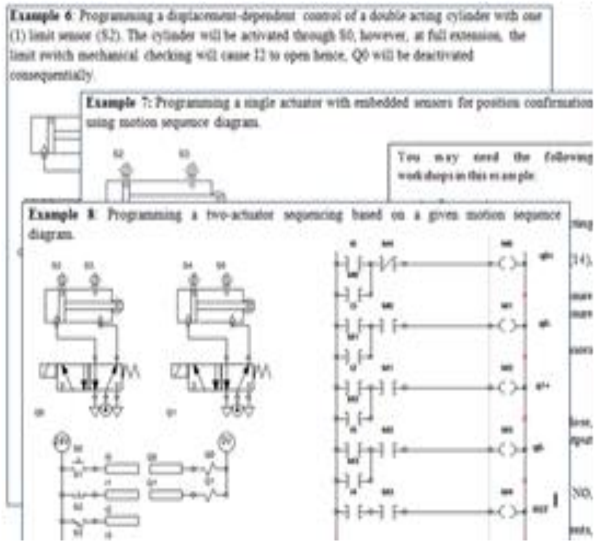

Figure 4: PLC Programming Examples

Figure 5 provides guided laboratory exercises, emphasizing the core learning objectives in fluid power, electrical circuitry for PLC interfacing, and PLC ladder diagram programming. It shows a multi-axis electro-pneumatic system used to demonstrate the applicability of the concept model to real industry applications using pure simulation without compromising its pedagogic impact.

It also captures the dynamics of the inputs, and output devices to PLC interfacing, and ladder diagram programming as depicted in the computer simulation screenshot shown in Figure 6. The development of a simulated multi-axis pneumatic pick and place instructional tool is dynamically demonstrated through the use of Automation Studio software, where the reciprocal actions of the working elements demonstrate a clear representation of actual industrial automation processes using PLC.

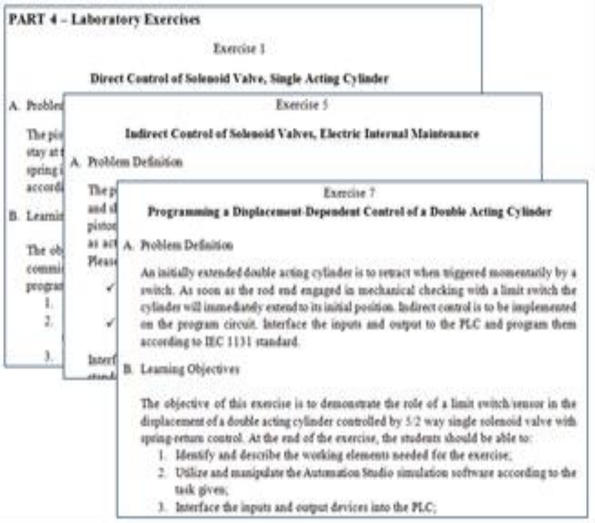

Figure 5: PLC Programming Exercises

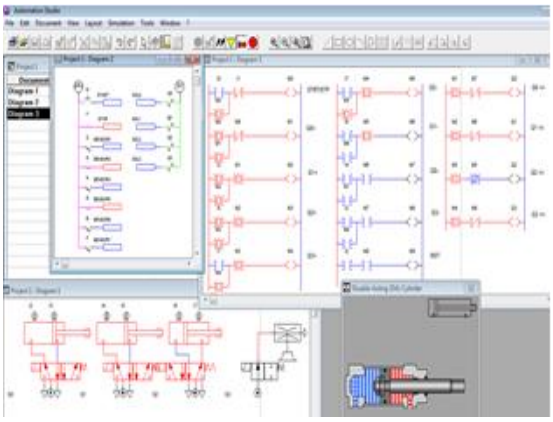

Figure 6: PLC Programming Simulation

The evaluation

In this section, the results of the data analysis are presented. The data were collected and then processed in response to the problems posed as embodied by the specific objectives of the study.

Problem 1. What are the characteristics of the respondents?

a. Gender
b. Purpose of enrolling in a specialization

Table 1 shows that one hundred percent (100%) of the respondents are male. Subsequently, Table 2 shows that the majority, sixty-four percent (64.10%) of the respondents' purpose of taking the specialization is to finish college and intend to land a job. The data indicate that male students residing in Tagoloan, Misamis Oriental, are interested in enrolling in the electronics technology program at TCC, which is believed to offer them promising job opportunities in the industry. It is assumed that women in Tagoloan do not see themselves working in the electronics industry.

Table 1: Characteristics of respondents in terms of gender

Category	Specifications	f	%
Gender	Male	39	100.00%
	Female	0	0.00%

Table 2: Characteristics of respondents in terms of the purpose of taking a specialization

Category	Specifications	f	%
Purpose of taking a specialization	Meet friends	1	2.56
	Finish college	13	33.33
	Land a job	12	30.77
	Work abroad	8	20.51
	Contribute to society	5	12.82

Problem 2. What are the respondents' pre-test and formative simulation scores?

Table 3 reveals that a significant majority of the respondents—69%—performed Very Poorly on the pre-test designed to assess their ability to program single and double-acting cylinders using logic functions. This low performance level indicates that most participants had minimal prior knowledge or skill in applying PLC programming concepts to control electro-pneumatic actuators effectively. The overall mean score of 1.12, which is just above the threshold for the Very Poor category, further underscores the general lack of proficiency among the group at the outset of the study. Additionally, the standard deviation of 1.08 suggests there was considerable variability in the respondents' existing knowledge and skills, meaning that while most struggled, a few may have had slightly better understanding or experience. This wide range could reflect differences in educational background, exposure to industrial automation, or familiarity with digital logic circuits. The poor pre-test results likely stem from insufficient prior instruction specifically focused on the practical application of digital logic circuits in real-world industrial contexts, particularly for critical functions such as safety interlocks and system sequencing. This gap highlights the need for targeted training that bridges theoretical digital logic concepts with hands-on programming skills essential for ensuring the safe and reliable operation of automated equipment in the industry.

Table 3: Pre-test statistics: programming single and double-acting cylinders with basic logic functions

Description	Range	f	% Distribution
Very good	5	0	0.00%
Good	4	1	2.56%
Fair	3	4	10.26%
Poor	2	7	17.95%
Very poor	1	27	69.23%

Mean 1.12
Standard Deviation 1.08

Parameter	% of correct response
1. OR logic function describes this characteristic,	28.21%
2. AND logic function describes this characteristic,	30.77%
3. Latching contact is an example of this logic function.	7.69%
4. The step marker is an example of this logic function.	20.51%
5. This directional valve is appropriate to control a single-acting cylinder.	25.64%

Table 4 reveals that 54% of respondents performed Very Poorly on the pre-test evaluating their ability to program multiple actuators with sensors, guided by a motion sequence diagram. The mean score was 1.38, slightly above the Very Poor level, and the standard deviation of 1.09 signifies substantial variability in existing knowledge among the students. This outcome suggests a lack of prior knowledge and exposure to the technology, leading to Poor performance on the pre-test.

Table 4: Pre-test statistics: programming multiple actuators with sensors guided by motion sequence diagrams

Description	Range	f	% Distribution
Very good	5	0	0.00%
Good	4	1	2.56%
Fair	3	5	12.82%
Poor	2	12	30.77%
Very poor	1	21	53.85%

Mean 1.38
Standard Deviation 1.09
Percentage of correct responses

Parameter	% of correct response
1. The major components of a Programmable Logic Controller are,	28.21%
2. The scan cycle of the PLC is described by,	20.51%
3. The step where the interlocking contact is required,	25.64%
4. In PLC programming simulation, the following are important	33.33%
5. The application programs used in modern PLC are,	30.77%

Table 5 reveals that a majority of the respondents, 54% were rated as having performed poorly on the overall pre-test, with their average score calculated at 6.02. This mean score falls within the "Poor" performance category, indicating that more than half of the participants demonstrated limited understanding or mastery of the material before the intervention. Additionally, the standard deviation of 2.86 highlights a considerable spread in the pre-test scores, suggesting that while many scored poorly, there was notable variation among respondents, with some performing better or worse than the average. This wide range may reflect differences in individual backgrounds, learning styles, or exposure to related concepts. The generally poor performance is likely due to a widespread lack of prior knowledge and hands-on experience with Programmable Logic Controller (PLC) technology, which is a specialized field requiring both theoretical understanding and practical skills. Such a baseline underscores the need for targeted instructional strategies to build foundational competencies in PLC control systems.

Table 5: Overall pre-test score statistics

Description	Range	f	% Distribution
Very good	21-25	0	0.00%
Good	16-20	0	0.00%
Fair	11-15	3	7.69%
Poor	6-10	21	53.85%
Very poor	1-5	15	38.46%

Mean 6.02
Standard Deviation 2.86

Parameter	Mean	SD
1. Programming single and double-acting cylinders using logic functions.	1.12	1.08
2. Programming multiple actuators with sensors guided by the motion sequence diagram.	1.38	1.09

The data presented in Table 6 reveal that a significant majority of the respondents—sixty-nine percent (69%)—received a Very Poor rating on their Overall Formative Simulation Practical Score. This indicates that most participants struggled considerably with the practical simulation exercises designed to develop and assess their hands-on skills in PLC programming and electro-pneumatic control. The overall mean score of 3.02 further confirms this low level of performance, placing the group firmly within the "Very Poor" category. Such a low average suggests that many students were unable to effectively apply the concepts and techniques taught during the formative simulation activities. Additionally, the standard deviation of 2.93 points to a high degree of variability among the respondents' scores, meaning that while the majority performed poorly, there was a wide range in individual performance levels. Some students may have demonstrated better competence, while others struggled significantly more, reflecting differences in prior knowledge, learning pace, or engagement with the simulation tasks. This variability underscores the need for differentiated instructional approaches and additional support to help all learners improve their practical skills in programming and controlling industrial automation systems.

Table 6: Overall formative simulation practical score statistics

Description	Range	f	% Distribution
Very good	21-25	0	0.00%
Good	16-20	0	0.00%
Fair	11-15	0	0.00%
Poor	6-10	12	30.77%
Very poor	1-5	27	69.23%

Mean 3.02
Standard Deviation 2.93

Parameter	Mean	SD
1. Programming single and double-acting cylinders using logic functions.	1.00	1.03
2. Programming multiple actuators with sensors guided by the motion sequence diagram.	0.41	0.50

Problem 3. What are the respondents' post-test written examination scores?

Table 7 reveals that a majority of the respondents—62%—achieved scores ranging from Good to Very Good on the post-test, which assessed their ability to program single and double-acting cylinders using basic logic functions. This indicates a marked improvement in the participants' practical programming skills compared to earlier assessments, demonstrating that most students were able to grasp and apply the fundamental concepts of PLC programming effectively after the intervention. Despite this encouraging trend, the overall mean score was 3.61, which falls within the Fair category, though it is notably close to the Good threshold. This suggests that while many students performed well, there remains room for further development to elevate the entire group's competency to a consistently higher level. The standard deviation of 1.54 points to considerable variability in the post-test scores, indicating that some respondents excelled significantly while others continued to face challenges. This spread may reflect differences in individual learning styles, prior experience, or engagement with the learning module. The observed improvement in performance is largely attributed to the effectiveness of the learning module, which provided structured, guided instruction and practical simulation exercises that helped bridge knowledge gaps and enhance technical skills in programming electro-pneumatic cylinders.

Table 7: Post-test statistics: programming single and double-acting cylinders using logic functions

Description	Range	f	% Distribution
Very good	5	17	43.59%
Good	4	7	17.95%
Fair	3	4	10.26%
Poor	2	6	15.38%
Very poor	1	5	12.82%
Mean 3.61			
Standard Deviation 1.54			

Parameter	% of correct responses
1. OR logic function describes this characteristic,	71.79%
2. AND logic function describes this characteristic,	74.36%
3. Latching contact is an example of this logic function,	64.10%
4. The step marker is an example of this logic function,	61.54%
5. This directional valve is appropriate to control a single-acting cylinder.	89.74%

Table 8 reveals that nearly 72% of the respondents achieved scores within the Good to Very Good range on the post-test, which evaluated their ability to program multiple actuators with sensors according to a motion sequence diagram. This high percentage indicates that a substantial majority of the students successfully demonstrated proficiency in integrating sensor inputs and coordinating multiple electropneumatic components, reflecting a solid understanding of complex automation sequences. The overall mean score of 4.00 places the group's performance squarely in the Good category, signifying a commendable level of competence across the cohort. However, the standard deviation of 1.29 suggests there was some variability in individual scores, meaning that while many students performed well, others showed varying degrees of mastery, possibly due to differences in prior experience, learning pace, or familiarity with the simulation tools. The notable improvement observed in the post-test results is attributed largely to the students' enthusiasm and active engagement with the simulation-based PLC learning module. This interactive approach likely enhanced their motivation and provided hands-on practice, enabling them to better grasp the practical application of programming logic in real-time automation scenarios.

Table 8: Post-test statistics: programming multiple actuators with sensors guided by motion sequence diagrams

Description	Range	f	% Distribution
Very good	5	19	48.72%
Good	4	9	23.08%
Fair	3	7	17.95%
Poor	2	1	2.56%
Very poor	1	3	7.69%
Mean 4.00			
Standard Deviation 1.29			

Parameter	% of correct responses
1. The components of a Programmable Logic Controller are,	97.44%
2. The scan cycle of the PLC is described by,	74.36%
3. The step where the interlocking contact is required,	79.49%
4. In PLC programming simulation, the following are important	61.54%

5. The application programs used in modern PLC are,	87.18%

Table 9 indicates that 56% of the respondents achieved a Very Good rating on the overall post-test, demonstrating that more than half of the students reached a high level of proficiency following the learning intervention. The overall mean score of 19.41 falls within the Good category, reflecting a generally strong performance across the group. However, the standard deviation of 5.28 reveals considerable variation in individual scores, suggesting that while many students excelled, others performed at varying levels of proficiency. This spread in scores may be attributed to differences in prior knowledge, learning styles, or the degree of engagement with the learning module and simulation exercises. The positive outcomes observed in the post-test strongly indicate that the PLC programming learning module, combined with hands-on simulation activities, effectively enhances student understanding and skill development. Regular and consistent engagement with the PLC programming simulations appears to play a crucial role in improving both learning outcomes and knowledge retention, helping students to better internalize complex programming concepts and apply them in practical scenarios. Overall, these results underscore the value of interactive, simulation-based learning tools in preparing students for real-world industrial automation challenges.

Table 9: Overall post-test score statistics

Description	Range	f	% Distribution
Very good	21-25	22	56.41%
Good	16-20	9	23.08%
Fair	11-15	7	17.95%
Poor	6-10	0	0.00%
Very poor	1-5	1	2.56%
Mean 19.41			
Standard Deviation 5.28			

Parameter	Mean	SD
1. Programming single and double-acting cylinders using logic functions.	3.61	1.54
2. Programming multiple actuators with sensors guided by the motion sequence diagram.	4.00	1.29

Problem 4. What is the post-test practical examination score of the respondents as evaluated by three experts?

Table 10 reveals that an overwhelming majority of the respondents—90%—were rated as Very Good by the three expert evaluators on the post-test practical examination, which assessed their ability to program single and double-acting cylinders using logic functions. This high percentage indicates that most participants demonstrated strong proficiency and competence in applying PLC programming concepts to control electro-pneumatic components effectively.

The overall mean rating across all respondents was 4.60, which falls within the Good category but is notably close to the Very Good threshold, reflecting a generally high level of performance. This suggests that while the majority excelled, there remains a small margin for improvement to consistently achieve top-tier mastery. The standard deviation of 1.36 indicates some variability in the expert evaluations, meaning that although most scores clustered around the higher ratings, there were differences in the level of skill demonstrated by individual respondents or variations in evaluator scoring. This variability could be due to differences in programming accuracy, problem-solving approaches, or the ability to handle complex logic sequences. Overall, these results highlight the effectiveness of the learning module in significantly enhancing practical PLC programming skills related to industrial automation tasks.

Table 10: Post-test practical exam: expert evaluation statistics - programming single

and double-acting cylinders using logic functions

Description	Range	f	% Distribution
Very good	5	35	89.74%
Good	4	0	0.00%
Fair	3	0	0.00%
Poor	2	0	0.00%
Very poor	1	4	10.26%
Mean 4.60			
Standard Deviation 1.36			

Parameter	% that respondents that can
1. Demonstrate planning and application of logic functions (AND & OR Logic) in PLC ladder diagram programming.	89.74%
2. Explain the dynamics and relationship of the programming elements of the ladder diagram program relative to the task.	89.74%
3. Perform PLC programming simulation and exemplify the right operation.	89.74%
4. Simulate, test, diagnose, and troubleshoot the ladder diagram program.	89.74%
5. Describe and articulate the fundamental application concerning the logic truth table.	89.74%

Table 11 shows that a substantial majority of the respondents—85%—were rated as Very Good by the three expert evaluators on the post-test practical examination, which focused on programming multiple actuators with sensors according to a motion sequence diagram. This high percentage reflects that most participants successfully demonstrated advanced skills in integrating sensor inputs and coordinating multiple electro-pneumatic components, following complex motion sequences accurately. The overall mean rating was 4.53, placing it within the Good category but very close to the Very Good threshold, indicating that the group’s performance was generally strong with room for slight improvement to consistently reach the highest standard. The standard deviation of 1.37 points to some variability in the expert evaluations, suggesting differences in individual respondent performance or evaluator judgment. This variation could stem from factors such as the precision of programming logic, timing accuracy, or the ability to troubleshoot sensor-actuator interactions effectively.

Table 11: Post-test practical exam: expert evaluation, statistics - programming multiple actuators with sensors guided by motion sequence diagrams

Description	Range	f	% Distribution
Very good	5	33	84.62%
Good	4	2	5.13%
Fair	3	0	0.00%
Poor	2	0	0.00%
Very poor	1	4	10.26%
Mean 4.53			
Standard Deviation 1.37			

Parameter	% of respondents that can
1. Demonstrate setup and configuration of necessary tools to complete the required pneumatic circuit.	88.89%
2. Demonstrate planning and articulate the motion sequence diagram for the task.	89.74%
3. Select, set up, connect, and complete the input-output devices with the PLC and explain its relationship to the task.	88.89%
4. Execute and demonstrate PLC ladder diagram programming for the said tasks.	87.18%
5. Evaluate and exemplify the dynamics of the system’s operation relative to the given motion sequence diagram.	87.18%

Problem 5. To what extent do input (profile) and process (written pre-test, formative practical simulation) variables explain respondents' output variable (post-test written and practical evaluation)?

This question is grounded in the Input-Process-Output (IPO) framework, which models education as a system where resources and learner profiles (inputs) are transformed through instructional methods and activities (processes) into measurable results such as test scores or practical skills (outputs). By analyzing the relationships between these variables, the study aims to determine whether and how strongly the initial conditions and educational interventions impact student achievement and to identify which factors are most influential. This helps stakeholders understand the effectiveness of different educational strategies and resource allocations and informs decisions about curriculum design, teaching methods, and learner support. Ultimately, the problem seeks to clarify the causal pathways that lead to successful educational outcomes, enabling more targeted and evidence-based improvements in teaching and learning.

Table 12: Multiple linear regression analysis: input and process variables vs. Overall post-test score

Independent variable	Regression coefficient	P-Value	T-Value
Purpose of taking specialization	0.20	0.798 132	0.25NS
Over-all pre-test	014	0.641 769	0.46NS
Over-all formative simulation	0.73	0.012 522	2.63**

NS not significant, ** Highly Significant
Constant: 18.68
Adjusted R: 0.09
F- Value: 2.33
P-value: 0.09
Significance Level: Not Significant
Regression model: ŷ= mx + b

- For every unit increase in the respondents' purpose of taking specialization there is a corresponding increase of 0.20 in respondents' overall written post-test score.
- For every unit increase in the respondents' overall pre-test score there is a corresponding increase of 0.14 in respondents' overall written post-test score.
- For every unit increase in the respondents' overall formative simulation score there is a corresponding increase of 0.73 in respondents' overall written post-test score.

Table 12 indicates that the regression model is not statistically significant, leading to the acceptance of the null hypothesis that there is no significant linear relationship between the input and process variables and the overall written post-test score. This suggests that the input and process variables do not significantly influence the post-test scores. However, the overall simulation variable does have a significant effect. The adjusted coefficient of multiple determination (R-squared) is 0.09, meaning that only 9% of the variation in the respondents' overall written post-test scores can be explained by the variation in the purpose of taking the specialization, overall pre-test score, and overall formative simulation score. The remaining 91% of the variance is attributable to other factors not included in the model.

Table 13: Multiple linear regression analysis: input and process variables vs. Overall post-test practical examination score

Independent variable	Regression coefficient	P-Value	T-Value
Purpose of taking specialization	1.77	0.1082	1.64NS
Over-all pre-test	0.02	0.9586	0.05NS
Over-all formative simulation	0.13	0.7139	0.36NS

NS not significant, ** Highly Significant
Constant: 17.19
Adjusted R: 0.01
F- Value: 1.16
P-value: 0.33
Significance Level: Not Significant
Regression model: ŷ= mx + b

- For every unit increase in the respondents' purpose of taking specialization there is a corresponding increase of 1.77 in respondents' Overall Post-test Prac

Table 13 reveals that the regression model used to analyze the relationship between the input and process variables and the respondents' overall post-test practical examination scores is not statistically significant. This means that the data do not provide sufficient evidence to conclude that these variables have a meaningful linear impact on practical exam outcomes. As a result, the null hypothesis is accepted, indicating that there is no significant linear relationship between the selected input factors—such as the respondents' purpose for taking the specialization—and process variables like their overall pre-test scores and formative simulation scores, with their performance on the practical post-test. The adjusted coefficient of multiple determination, or R-squared value, is 0.01, which means that only 1% of the variability in the practical exam scores can be explained by changes in the measured input and process variables. This extremely low explanatory power suggests that the vast majority—99%—of the differences in practical exam performance among respondents are influenced by other factors not included in the model. These unmeasured factors could include variables such as individual learning styles, motivation, prior hands-on experience, quality of instruction, environmental conditions during testing, or other psychological and contextual influences. This finding highlights the complexity of practical skill acquisition and suggests that additional research is needed to identify and measure the key determinants that significantly affect practical PLC programming performance.

References

[1] Ed-Dafali, S., Al-Azad, M. S., Mohiuddin, M., & Reza, M. N. H. (2023). Strategic orientations, organizational ambidexterity, and sustainable competitive advantage: Mediating role of industry 4.0 readiness in emerging markets. Journal of cleaner production, 401, 136765.

[2] Helfat, C. E., & Campo-Rembado, M. A. (2016). Integrative capabilities, vertical integration, and innovation over successive technology lifecycles. Organization science, 27(2), 249-264.

[3] Van Reenen, J. (2020). Innovation policies to boost productivity. The Hamilton Project.

[4] Fransman, M. (2018). Innovation ecosystems: Increasing competitiveness. Cambridge University Press.

[5] Russell, M. G., & Smorodinskaya, N. V. (2018). Leveraging complexity for ecosystemic innovation. Technological Forecasting and Social Change, 136, 114-131.

[6] Hamdaoui, M., Ayouni, S. E., & Maktouf, S. (2022). Capital account liberalization, political stability, and economic growth. *Journal of the Knowledge Economy*, *13*(1), 723-772.

[7] Reche, A.G. and Picazo Tadeo, A.J. (2011), Innovation and Business Competitiveness: Is Our Production Model Resilient?, Mètode, Annual Review

[8] Cuasito Sr, R. J., & Namoco Jr, C. S. (2012). Trends in Industrial Automation and Academic Initiatives in the Philippines: Assessment and Analysis of Mechatronics-Enabling Technologies, Skill Set Demands, and Academic Relevance. Int. J. Autom. Technol., 6(6), 757-764.

[9] Syreyshchikova, N. V., Pimenov, D. Y., Mikolajczyk, T., & Moldovan, L. (2020). Automation of Production Activities of an Industrial Enterprise based on the ERP System. *Procedia manufacturing*, *46*, 525-532.

[10] Russell, M. G., & Smorodinskaya, N. V. (2018). Leveraging complexity for ecosystemic innovation. Technological Forecasting and Social Change, 136, 114-131.

[11] Bolton, W. (2015). Programmable logic controllers. Newnes

[12] Namekar, S. A., & Yadav, R. (2020). Programmable Logic Controller (PLC) and its applications. International Journal of Innovative Research in Technology (IJIRT), 6(11), 372-376.

[13] Alphonsus, E. R., & Abdullah, M. O. (2016). A review of the applications of programmable logic controllers (PLCs). Renewable and Sustainable Energy Reviews, 60, 1185-1205.

[14] Pérez, J. B., & Falótico, A. J. A. (2019). Various perspectives of labor and human resources challenges and changes due to automation and artificial intelligence. Academicus, (20), 106.

[15] Kleibert, J. M. (2015). Industry-academe linkages in the Philippines: Embedding foreign investors, capturing institutions?. *Geoforum*, *59*, 109-118.

[16] Padrigalan, K. E., Cuasito, R. J., & Miparanum Jr, C. L. (2018) Optimization of a Low-Cost Programmable Logic Controller Educational Trainer

[17] Michaelis, T. L., & Markham, S. K. (2017). Innovation Training: Making Innovation a Core Competency A study of large companies shows that, although managers see human capital as central to innovation success, most aren't providing innovation training. Research-Technology Management, 60(2), 36-42.

[18] Goos, M., Arntz, M., Zierahn, U., Gregory, T., Gomez, S. C., Vazquez, I. G., & Jonkers, K. (2019). The impact of technological innovation on the future of work (No. 2019/03). JRC working papers series on Labour, Education, and Technology.

[19] Zen, A., Sukaesih, K., & Malik, A. J. (2022). Analysis of the Effect of the Educational System and Student Motivation in Creating Workforce Competitiveness (A Case Study Facing the Industrial Revolution 4.0). Technium Soc. Sci. J., 31, 662.

[20] Aghapoor Alishahi, M., Rahimi, G., Ramazani, M., & Bohlooli, N. (2021). Presenting a model of alignment of organization strategies with human resource strategies. Journal of Industrial Engineering and Management Studies, 8(2), 233-260.

[21] Kipper, L. M., Iepsen, S., Dal Forno, A. J., Frozza, R., Furstenau, L., Agnes, J., & Cossul, D. (2021). Scientific mapping to identify competencies required by industry 4.0. *Technology in Society*, *64*, 101454.

[22] Guvenen, F., Kuruscu, B., Tanaka, S., & Wiczer, D. (2020). Multidimensional skill mismatch. American Economic Journal: Macroeconomics, 12(1), 210-244.

[23] Dolmans, S. A., Walrave, B., Read, S., & Van Stijn, N. (2022). Knowledge transfer to industry: How academic researchers learn to become boundary spanners during academic engagement. The Journal of Technology Transfer, 1-29.

[24] Zhao, Z., Broström, A., & Cai, J. (2020). Promoting academic engagement: university context and individual characteristics. The Journal of Technology Transfer, 45, 304-337.

[25] Li, G., Yuan, C., Kamarthi, S., Moghaddam, M., & Jin, X. (2021). Data science skills and domain knowledge requirements in the manufacturing industry: A gap analysis. *Journal of Manufacturing Systems*, *60*, 692-706.

[26] Hudedmani, M. G., Umayal, R. M., Kabberalli, S. K., & Hittalamani, R. (2017). Programmable logic controller (PLC) in automation. Advanced Journal of Graduate Research, 2(1), 37-45

[27] Saikumar, T. S. S., & Bandaru, C. R. (2021). Design and simulation of automated pad printing machine using automation studio. Materials Today: Proceedings, 45, 2871-2877.

[28] Morales-Menendez, R., & Ramirez-Mendoza, R. A. (2019). Virtual/remote labs for automation teaching: a cost effective approach. *IFAC-PapersOnLine*, *52*(9), 266-271.