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ENHANCING VOCATIONAL STUDENTS' KNOWLEDGE AND PRACTICAL SKILLS IN INDUSTRIAL CONTROL SYSTEMS THROUGH PROJECT-BASED LEARNING USING AN OBJECT-SORTING CONVEYOR TRAINING KIT

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ABSTRACT

Aim/Purpose	This study aims to examine the effectiveness of the Project-Based Learning (PjBL) model integrated with an object selection conveyor training kit in improving the knowledge and practical skills of vocational education students in the subject of Programmable Logic Controller (PLC)-based industrial control systems.
Background	Industrial control system learning based on PLCs in vocational education still faces major problems: the limitations of context-specific training kits that are not representative of real industrial processes, and the application of PjBL models that tend to be procedural and not yet fully grounded in authentic projects. This situation often leads learning activities to focus on separate exercises (task-oriented), which do not stimulate complex problem-solving and are not optimal for developing the connection between theoretical concepts and the practical skills needed in the industrial world. Therefore, integration between PjBL and

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systematically designed training kits is needed to make learning more meaningful and contextual.

Methodology
This study used a quantitative method with a pretest–posttest nonequivalent control group quasi-experimental design. The research subjects were 64 vocational high school students majoring in Industrial Electronics, divided into an experimental class (n = 33) and a control class (n = 31). The experimental class received PjBL learning integrated with a conveyor-based object-selection training kit, while the control class used conventional PjBL. Data were collected using standardized instruments to measure knowledge (multiple-choice test instrument) and practical skills (observation sheet instrument), then analyzed using paired sample t-tests, independent t-tests, Welch's t-tests, and effect size analysis (Cohen's d).

Contribution
This study makes empirical contributions to the development of vocational education by demonstrating that integrating PjBL with authentic practice media can significantly improve students' knowledge and practical skills.

Findings
Based on the paired-samples t-test, both groups showed significant improvement; however, using the independent t-test and Welch's t-test, the experimental class achieved significantly higher posttest scores in knowledge and practical skills. Effect size analysis showed a large effect on knowledge improvement and a moderate effect on practical skills, confirming the pedagogical significance of the PjBL model in the learning process.

Recommendations for Practitioners
Vocational education teachers and administrators are advised to integrate PjBL with industry-relevant training kits to create authentic learning experiences aligned with the needs of the world of work.

Recommendations for Researchers
Further research should use a more robust experimental design, involve multiple institutions, and examine the long-term impact and development of students' non-technical competencies, including 4C (critical thinking, creativity, collaboration, and communication) and problem-solving skills.

Impact on Society
The implementation of this learning model has the potential to improve the work readiness of vocational school graduates, reduce the competency gap with industry needs, and support human resource development in the Industry 4.0 era.

Future Research
Further studies could explore the application of this model across various skill competencies and the integration of new technologies, such as IoT and digital twins, into vocational learning.

Keywords
project-based learning, training kit, vocational education, industrial control systems, knowledge, practical skills

INTRODUCTION

Industrial development has entered the 4.0 era, where advanced technologies such as robotics, artificial intelligence (AI), the Internet of Things (IoT), and integrated industrial machinery operate automatically. This development has encouraged the development of industrial production systems that are more efficient, flexible, and sustainable, as well as improving quality of life (Najafzadeh et al., 2025; Singh et al., 2025). This development has brought about significant transformations in industrial manufacturing technology, including conveyor control systems that classify goods and distribute them to various destinations. This technology is widely used in industry because it can optimize working time and minimize production operational costs. With technological developments, conveyors used in industry now operate automatically according to instructions programmed through controllers such as Programmable Logic Controllers (PLC). PLCs are widely used in industry because they are efficient, flexible, and easy to repair if a machine is damaged (Lee et al., 2023; Sinico et al., 2025). The industry widely uses PLCs to facilitate the automatic operation of production machines. Along with this development, workers are also required to master PLC-based control systems to overcome machine problems in industry. The ability to operate, program, and create circuits to integrate PLC with sensors and actuators is an essential skill that workers must possess (Aswardi et al., 2023; Sukardi et al., 2023).

Vocational education plays a strategic role in developing a workforce with specific competencies, including in PLC-based industrial control systems (Rahayu et al., 2026). Vocational education graduates are expected not only to master knowledge but also to possess practical skills, including designing, building, operating, and comprehensively analyzing control systems (Billett, 2011; Mori, 2023). One widely adopted approach to achieve this goal is PjBL, which emphasizes learning through authentic, collaborative, and problem-solving-based projects (Calvo et al., 2018; Setyawan, Sukardi, Risfendra, Tri Putra Yanto, & Tze Kiong, 2025). Although PjBL is recognized as an effective learning approach for developing students' knowledge in vocational education, its implementation still faces various conceptual and practical limitations. The PjBL models currently in use remain general because the learning steps outlined are not yet fully adaptable for vocational students. For instance, there is a lack of emphasis on the stages of building foundational knowledge and skills before undertaking a project. This issue causes beginner-level students to struggle to follow the learning process effectively. This issue has the potential to cause cognitive overload due to the high complexity of learning PLC-based control systems (Isa & Azid, 2021; Sinulingga & Moenir, 2022; Tan et al., 2025). Consequently, instead of building meaningful understanding, students experience conceptual confusion and misconceptions when designing projects. This indicates that without systematic scaffolding in the early stages, PjBL vocational learning risks losing its primary function as a means of structured knowledge construction.

This issue is further compounded by the limitations of the learning materials used in vocational education, which generally fail to realistically and contextually represent real-world industrial systems (Lu et al., 2025; Navarro-Durán et al., 2023). Current learning materials (training kit) tend to be basic or simulation-based, thereby limiting students' interaction with physical industrial systems and failing to provide authentic learning experiences (Al-Yaman et al., 2025; Roll & Ifenthaler, 2021; Y. Zhang, 2025). Consequently, learning focuses more on simple procedural exercises than on the exploration of complex, integrated systems. These limitations directly impact students' ability to connect theoretical concepts with practical implementation (Long et al., 2025; Setyawan, Sukardi, Risfendra, Tee, et al., 2025). Consequently, this can hinder the development of students' practical skills, which require direct experience, feedback, and repeated practice. Given these issues, there is a need to develop a training kit that is contextually designed and integrated with the PjBL model. This approach is expected to create an authentic learning environment, improve the quality of practical experience, and bridge the gap between theoretical knowledge and direct implementation.

Previous researchers have developed several media used in the industrial control system learning process, such as creating control system simulators for conducting basic practical work (Abdul Aziz et al., 2025; Aswardi et al., 2023) and their application in the form of filling drying air in industry (Sukardjo et al., 2023; Vargas et al., 2023), but this application was made in the form of simulations in computer applications. However, most previous studies tend to focus on device development or partial learning outcome evaluation, without comprehensively examining the impact of integrating learning models and practical media on improving students' knowledge and practical skills (Abdul Aziz et al., 2025; Aswardi et al., 2023; Sukardjo et al., 2023; Vargas et al., 2023). Thus, empirical studies that directly integrate PLC-based industrial control system learning media with the PjBL model are still very limited, especially in the context of secondary vocational education. Therefore, the gap in this study lies in the lack of systematic studies examining the effectiveness of integrating learning media with Project-Based Learning in improving industrial control system competencies, both in knowledge and practical skills, among vocational students.

The urgency of this research is increasing alongside the industry's need for adaptive, competent, and job-ready vocational workers in automation and industrial control systems. Without learning innovations that can bridge the gap between theory and practice, vocational education risks producing graduates who are less competitive in the job market (Chookaew et al., 2021; Sukardi et al., 2024). Therefore, the development and implementation of Project-Based Learning integrated with an object sorting conveyor training kit as a learning medium for PLC-based industrial control systems is very important as a strategic effort to improve the quality of industrial control system learning. Thus, the purpose of this study is to examine the effectiveness of implementing the PjBL model, integrated with the object-sorting conveyor training kit, in improving the knowledge and practical skills of vocational education students in PLC-based industrial control systems. To achieve the established research objectives, several research questions have been formulated to guide this research process, as follows:

1. Is there a difference in the knowledge of students in the experimental class using the developed approach compared to the control class?
2. Is there a difference in the practical skills of students in the experimental class using the developed approach compared to the control class?
3. How big is the impact of the integrated PjBL model integration with an object-sorting conveyor training kit on improving students' knowledge?
4. How big is the impact of the integrated PjBL model integration with an object-sorting conveyor training kit on improving students' practical skills?

LITERATURE REVIEW

INDUSTRIAL CONTROL SYSTEM LEARNING MEDIA

The development of learning materials for PLC-based industrial control systems has been extensively pursued by previous researchers using various approaches, particularly simulation-based methods implemented in computer applications, as well as the integration of augmented and virtual reality, which are generally classified as virtual laboratories (Abdul Aziz et al., 2025). Although various studies report that the use of virtual laboratories has a positive impact on the learning process, the discussions conducted tend to remain limited to technical aspects and initial validation, such as testing the performance of the media (Al-Yaman et al., 2026), validation by PLC learning experts (Sukardjo et al., 2023), and empirical validation from the user's perspective (Abdul Aziz et al., 2025), thus failing to fully explore their pedagogical effectiveness comprehensively. Research conducted by Vargas et al. (2023) indicates that virtual laboratories can enhance students' knowledge, practical skills, and problem-solving abilities; however, these findings must be interpreted critically given the inherent limitations of virtual environments. Conceptually, virtual simulations tend to simplify industrial system dynamics and are not yet capable of representing the complexity of real-world operating conditions, including sensor–actuator interactions, environmental variations, and non-ideal, non-deterministic system behavior (Guajardo-Cuéllar et al., 2025). Consequently, the resulting learning has the potential to foster procedural and idealistic understanding, yet lacks adaptability when faced with real physical systems. Additionally, limitations in the development of psychomotor skills are a critical issue, as direct interaction with hardware, such as wiring processes, troubleshooting installation errors, and system commissioning, cannot be authentically replicated in a virtual environment (Li & Liang, 2024). Therefore, although virtual laboratories make a significant contribution as a tool for conceptual learning, their exclusive use without integration with real systems has the potential to create a competency gap between academic achievements and the skill demands of the industrial world.

Previous research has developed a training kit for PLC-based industrial control systems in the form of a simulator that represents inputs via buttons and outputs via indicator lights (Aswardi et al., 2023; Rusimamto et al., 2025), with results showing improvements in students' knowledge, practical skills, and creativity. Nevertheless, there are significant methodological limitations: the study by Aswardi et al. (2023) did not include a comparative learning medium, so its effectiveness could not be evaluated, while Rusimamto et al. (2025) used only simulation as a comparison, which remained within a non-authentic learning environment. On the other hand, several studies have developed real-world application-based learning media such as conveyor systems, traffic lights, and object-sorting conveyors integrated with robotic arms (Al-Yaman et al., 2025; Watanakul et al., 2023); however, these studies tend to focus on the technical performance of the hardware, such as system accuracy and reliability, without comprehensively examining their impact on the development of student competencies, particularly in the cognitive and psychomotor domains. This situation indicates a critical research gap, namely the lack of integration between the development of training kits based on real-world industrial applications and empirical evaluation of their pedagogical effectiveness, therefore, further research is needed that not only emphasizes technical validation but is also capable of evaluating the extent to which such media contribute to bridging the gap between simulated learning and the demands of real-world competencies in the industrial sector.

Appropriate learning media play a crucial role in enhancing student learning outcomes, particularly in vocational education contexts such as PLC-based industrial control systems, where the integration of authentic and experiential learning is essential. Grounded in Dale's (1969) Cone of Experience, learning that involves direct engagement through real simulations and hands-on activities fosters deeper understanding and stronger mastery of competencies compared to abstract representations, such as verbal or textual instruction alone. In this context, the development of an object sorting conveyor training kit integrated with PLC systems provides students with concrete, industry-relevant experiences that enhance active participation and support the development of psychomotor skills (Aswardi et al., 2023; Bencheva et al., 2024; Rusimamto et al., 2025).

Beyond experiential learning, this approach is further reinforced by Gagné's (1985) Information Processing Theory, which conceptualizes learning as a sequence of cognitive processes involving attention, encoding, storage, and retrieval. The training kit facilitates these processes by delivering multimodal and tangible stimuli that promote selective attention and meaningful encoding, while simultaneously externalizing abstract PLC logic into observable system behavior, thereby reducing the cognitive gap between symbolic representation and real-world application. This alignment not only minimizes extraneous cognitive load but also supports deeper semantic processing and knowledge integration (Sweller et al., 2019). Furthermore, the interactive and feedback-rich nature of the system enables iterative practice, immediate error correction, and reflective learning, which are critical for strengthening memory retention and enhancing problem-solving abilities. Through structured task execution and real-time system responses, the training kit functions as an integrated cognitive and experiential framework that effectively bridges conceptual understanding and procedural competence, ultimately supporting the development of adaptive expertise required in complex industrial environments (Elvsaas et al., 2025; Mikkonen et al., 2017).

Project-Based Learning Model in Vocational Education

Previous research has shown that PjBL in PLC-based industrial control system instruction is increasingly recognized as an effective approach to improving the quality of vocational education, particularly in bridging the gap between theory and practice. Research conducted by Seke et al. (2018) revealed that PjBL encourages active student engagement in PLC-based projects, thereby enhancing conceptual understanding, creativity, and critical thinking skills. Additionally, Sanfilippo and Austreng (2018) noted that integrating project-based learning through a combination of theoretical lectures, laboratory practice, and group projects creates a more authentic learning experience that is relevant to industry needs. Research conducted by Kaewkham-Ai and Uthaichana (2019) confirms that PjBL in control system laboratories allows students to independently develop PLC-based prototypes, thereby improving problem-solving skills, technical communication, and work readiness. However, its implementation still faces limitations in facilities and resources.

Although these studies reveal a positive impact on student learning outcomes, the implementation of the PjBL model still focuses on project activities as the final product of learning, without a systematic, measurable instructional design to support them. This shortcoming is also highlighted by Dimaculangan et al. (2025) and Işik (2016), who found that the development of training kits can enhance students' practical skills and learning outcomes; however, the approaches used tend not to explicitly integrate the stages of foundational concept formation as a cognitive foundation prior to project implementation. This process risks creating an imbalance between conceptual mastery and practical skills, particularly for beginner-level students. Additionally, limitations in laboratory facilities and learning designs that are insufficiently adaptive to the complexity of real-world industrial systems further hinder the optimal implementation of PjBL (Rehman, 2023). Therefore, there is a need to develop a more comprehensive PjBL model with a structured syntax that is not only project-outcome oriented but also emphasizes the integration of knowledge formation, skill development, and learning reflection to produce competencies that are more adaptive and relevant to the demands of modern industry.

This study introduces five PjBL learning steps for vocational students who are new to the learning process and possess specific skills. These steps begin with formulating learning objectives, learning and training basic concepts, designing projects, creating projects, presenting results, and assessing projects. The development of these PjBL steps is based on a previously measured and tested PjBL framework, which is expanded to include additional basic learning processes to deliver the specific basic skills that students must master (Jalinus et al., 2017; Kilpatrick, 1918). Additionally, this developed model is directly integrated with the learning media of the conveyor sorting training kit used in the PLC-based industrial control system learning process. With a more systematic syntactic structure, this model is expected to enhance students' understanding of PLC-based industrial control systems through project-based learning, while comprehensively strengthening vocational students' learning outcomes across the cognitive domain and practical skills, in line with workplace competency requirements.

Theoretically, this model is based on two main theories in project-based learning. First, this model is strongly supported by Piaget's (1970) constructivist theory, which emphasizes that learners actively construct knowledge through direct interaction with the learning environment. In PLC-based industrial control system learning, students do not just passively receive information; they are actively involved in designing, programming, testing, and problem-solving using a conveyor object selection training kit in PjBL learning (Berselli et al., 2020). This process enables mechanisms of assimilation and accommodation, in which new experiences are integrated into existing cognitive structures or lead to the restructuring of students' conceptual understanding. The PjBL model developed in this study, which begins with a basic phase of concept learning and structured skills training before project implementation, aligns with Piaget's constructivist principle because it provides the necessary cognitive scaffolding for novice vocational students (Hmelo-Silver et al., 2007; Kirschner et al., 2006). This approach helps reduce knowledge fragmentation and supports the formation of more coherent conceptual understanding through direct engagement with real industrial systems.

Second, it is strongly supported by Dewey's (1976) Learning by Doing theory, which emphasizes that learning is more meaningful when students engage in real actions and direct experiences. The integration of the object sorting conveyor training kit within the PjBL framework provides students with the opportunity to directly experience the workflow of an industrial control system, from project planning and technical implementation to evaluation and reflection on the results of their work (Mori, 2023). Through a cycle of action, observation, and reflection, students not only develop technical skills but also critical thinking, problem-solving, and contextual decision-making abilities (Ahmad et al., 2023). This approach bridges the gap between theory and practice while fostering holistic professional competencies, as Dewey emphasized that education must prepare students to face real problems in life and the world of work. Thus, learning by doing-based PjBL in this study plays a strategic role in building the work readiness of vocational students in line with the demands of modern industry.

METHOD

RESEARCH DESIGN

This study used a quantitative, quasi-experimental research design, specifically a pretest-posttest non-equivalent control group design. This design was chosen because the researchers lacked the authority to fully randomize participants (random assignment), as the educational institution had already assigned classes. Nevertheless, this design still allowed the researcher to empirically test the effectiveness of the integrated PjBL model with the object selection conveyor training kit by comparing the changes in learning outcomes between the treatment group (experimental) and the comparison group (control) (Jackson, 2009). Two classes were included in this study: the first as the experimental class and the second as the control class. The experimental class will apply the integrated PjBL model with the object selection conveyor training kit, while the control class will use the conventional PjBL model previously applied in schools. Both classes in this study took a pretest at the beginning of the learning period and a posttest at the end. The research flow is shown in Figure 1, starting with initial testing and treatment implementation, and ending with final testing.

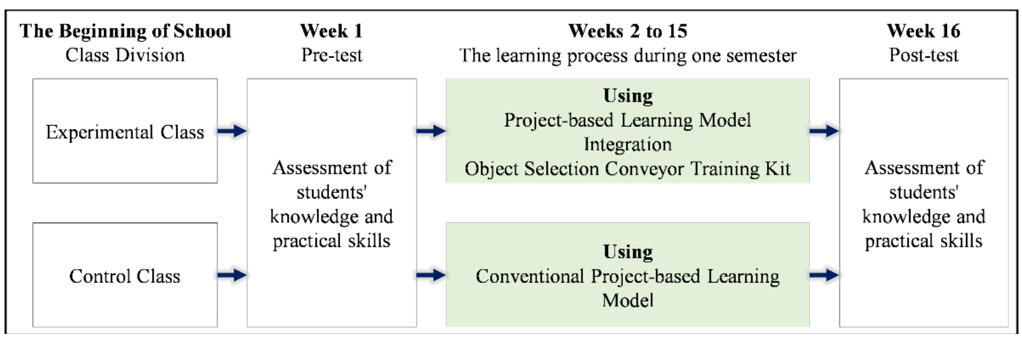

Figure 1. Quasi-experimental research design used

Given that this study uses a quasi-experimental design without full subject randomization, potential research biases need to be identified and systematically controlled to maintain the internal and external validity of the results. First, minimize potential bias due to differences in students' initial abilities by comparing students' initial scores in the PLC-based industrial control system to ensure that students in both classes have equal abilities. Second, minimize bias from teacher effects by implementing a learning process in both classes, conducted by teachers with equivalent backgrounds and teaching experience, and by using comparable learning objectives and time allocations. In addition, to increase external validity, this study was conducted in the context of regular learning in vocational schools without excessive manipulation of the learning environment. This was done to ensure the research results reflect real learning conditions and achieve greater generalizability in the learning process in vocational education.

In particular, the potential for bias stemming from teacher influence is a crucial aspect, as variations in teachers' educational backgrounds, pedagogical and professional competencies, teaching experience, and teaching styles can directly impact student learning outcomes (Bacus et al., 2024; L. Zhang, 2025). Therefore, this potential bias must be properly addressed by ensuring that the learning process for both groups is conducted by teachers with equivalent academic backgrounds, professional qualifications, and teaching experience, so that any differences in learning outcomes better reflect the intervention's effectiveness rather than differences in teacher characteristics. Although this has been addressed, the researchers acknowledge that potential latent biases, such as differences in teachers' interpersonal interactions, levels of enthusiasm, and expectations of students, can lead to indirect effects, such as the expectancy effect, and cannot be entirely avoided (Hu & Qian, 2025). Thus, these approaches represent rational methodological efforts to enhance the internal validity of the research findings.

PARTICIPANTS

This study involved 64 students from two second-year Industrial Electronics Engineering classes at a vocational high school in the province of Sumatera Barat, Indonesia. All students involved in this study were enrolled in a PLC-based industrial control systems course. The two classes consisted of an experimental class with 33 students, comprising 4 females and 29 males. The second was a control class comprising 31 students, 3 females, and 28 males. Thus, two classes with relatively equivalent academic characteristics were selected as the experimental and control classes and met the research criteria for conducting quasi-experimental research. As stated by Fraenkel et al. (2012), in educational research with a pretest-posttest quasi-experimental design, a sample size of around 20-30 participants per group is considered adequate to produce meaningful analysis, as long as the initial differences between groups are well controlled and appropriate statistical analysis techniques are used to test the treatment effect.

LEARNING PROCEDURES IN EXPERIMENTAL CLASS

The learning procedure in the experimental class was carried out using the PjBL model, developed and integrated with the object selection conveyor training kit. Learning lasted for a full 14 weeks, from the second week through the 15th, with one meeting per week lasting 7 hours (315 minutes). Classes are held from 7:30 a.m. to 2:15 p.m. each session. This schedule includes a 30-minute break at 10:00 a.m. and a 60-minute break at 12:00 p.m. The same schedule applies to the control group, with the only difference being the days on which classes are held. The stages of learning are detailed in Table 1. The initial stage of learning focused on formulating learning objectives, during which teachers and students collaboratively discussed the expected learning outcomes, the competencies students must master, and their relevance to the needs and practices of the industrial world. This stage aims to build students' initial understanding of the relevance of the learning materials to the real-world context of industry, while also fostering motivation to learn and an orientation towards the anticipated results of the project.

Table 1. The learning process in the experimental class

Weeks	Learning steps	Learning activities
2	Formulating learning objectives	Teachers and students discuss learning objectives, competencies acquired by students, and related jobs in the industry.
3 to 8	Basic concept learning and training	Basic material learning: 1. Basic concepts of control systems and PLCs in industry 2. PLC construction and input/output components 3. The concept of PLC input, output, and power installation 4. Ladder-based PLC programming 5. Electropneumatic system
9 to 10	Project design	Creating project designs for conveyor systems: 1. Design of electrical control circuits 2. Programming design 3. Pneumatic system design
11 to 14	Creating a project	Creating an object selection conveyor project
15	Presentation of project results and assessment	Presenting the results of completed projects and assessing the achievement of student projects.

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The next stage is learning and training in basic concepts, conducted over several meetings to equip students with the theoretical and practical foundations needed before working on projects. At this stage, students learn the basic concepts of industrial control systems and PLC applications, including the construction and function of PLC input and output components, the concepts of input, output, and PLC power supply installation, ladder diagram-based PLC programming, and the working principles of electropneumatic systems. Learning at this stage is carried out through a combination of conceptual explanations, demonstrations, and guided exercises to ensure students are ready to apply this knowledge in the project stage. This stage is also supported by basic learning media, enabling students to understand the concepts of PLC-based industrial control systems. The learning media used are shown in Figure 2a, and the learning process carried out is shown in Figure 2b.

Once students have acquired sufficient basic understanding, learning continues to the project design stage. At this stage, students begin designing an object selection conveyor system as their main learning project. Design activities include electrical control circuits, PLC programs, and the pneumatic system for the conveyor. This stage emphasizes analytical skills, system planning, and problem-solving, and encourages students to integrate various industrial control system concepts. The next stage is project implementation, where students realize their designs into a functioning object selection conveyor system. At this stage, students assemble the hardware, wire the system, program the PLC, and test and refine it so it operates according to the planned specifications. This activity provides an authentic learning experience that mimics industry work processes, thereby supporting the development of practical skills, accuracy, and teamwork. At this stage, learning uses the developed object selection conveyor training kit. The form of this training kit is shown in Figure 3a, and the learning process is shown in Figure 3b.

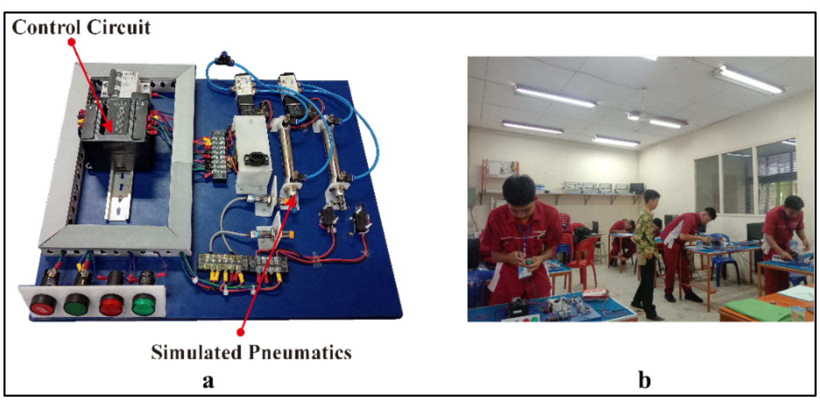
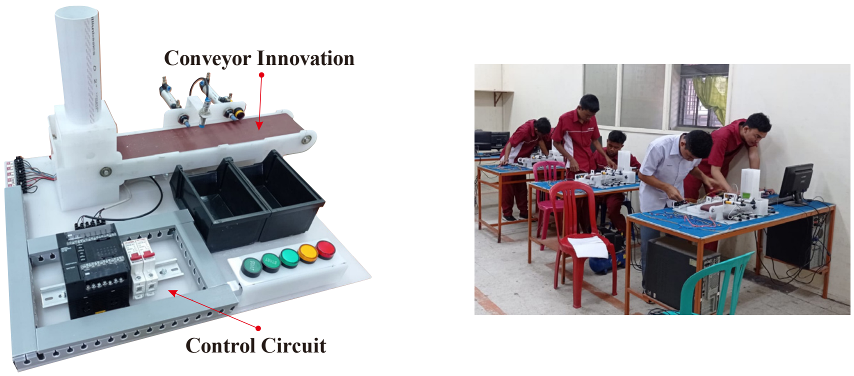


Figure 2. Basic concept learning and training stages: (a) basic PLC training kit, (b) basic learning process



a **b**

Figure 3. Learning stages of creating a project:
(a) training kit for object selection conveyor, (b) project learning process

The final stage of learning is the presentation of project results and assessment. Students present the results of the projects they developed, explain the system's working principles, and demonstrate the functionality of the object selection conveyor. At this stage, teachers assess students' learning outcomes and processes using a performance assessment rubric that covers aspects of planning, implementation, system operation, and problem-solving skills. This stage also serves as a means of learning reflection for students to evaluate the competencies they have acquired. Overall, these learning stages are designed to ensure that the application of the PjBL model is not only focused on the final product but also on a systematic, continuous learning process. The integration of conceptual learning, design, and project implementation is expected to significantly improve students' knowledge and practical skills in PLC-based industrial control systems, while also preparing them for the demands of the automation industry.

Learning Procedures in Control Class

The control group used a conventional PjBL model, following government guidelines consisting of six learning steps: start with the essential question, design a plan for the project, create a schedule, monitor the students and the progress of the project, assess the outcomes, and evaluate the experiences (Kemendikbud, 2020; Prajoko et al., 2023; Suradika et al., 2023). The learning steps carried out are shown in more detail in Figure 4. Broadly speaking, the materials used in the experimental and control classes are the same, but the differences lie in the learning steps and the training kits used. In the control class, there are similarities in the activities carried out at certain steps compared to the experimental class; for example, in the first stage of the control class, starting with the essential question, the objectives, benefits, and projects are explained through essential questions in the field of industrial control systems.

The second step in the control class focuses on project design activities, although this process remains integrated with the basic learning of PLC-based industrial control systems. This integration is necessary because, in the early stages of design, students have not yet fully mastered the fundamental concepts underlying the system being developed, whether in electrical circuits, programming, or component use. Therefore, the project design process is conducted simultaneously with the reinforcement of basic concepts to ensure adequate understanding. In the third step, teachers and students collaboratively discuss and agree on the project implementation schedule for the learning period. Next, in the fourth step, students implement the PLC-based industrial control system project, with the teacher serving as a mentor and facilitator, providing guidance and support throughout the project. In the fifth step, the teacher conducts a comprehensive assessment of the project outcomes, covering the design phase (electrical circuits, programming, and pneumatic systems), the implementation process, and the final product produced. Additionally, the assessment covers the knowledge and practical skills students acquire during the project activities. In the final stage, the teacher and students reflect on the learning process, including the understanding gained, challenges faced, and the relevance of the competencies developed to the needs of the industrial world.

In addition to differences in the learning stages, significant differences also lie in the types of training kits used during the learning process. The control group used only conventionally available training kits, namely basic training kits, as shown in Figure 2a. During the project, students still designed systems based on the real-world conditions they were developing, but their implementation was limited to simulating system operation using these basic training kits. For example, a DC motor is represented by a pilot light indicator. At the same time, the cylinder's movement is modified to reflect the operating principle of the designed system. This approach imposes limitations on the representation of authentic operational conditions. Therefore, the two main aspects distinguishing the experimental class and the control class in this study are the structure of the learning stages implemented and the level of authenticity of the training kits used in PLC-based industrial control system learning, which directly impact the depth of students' learning experiences and the development of their practical skills.

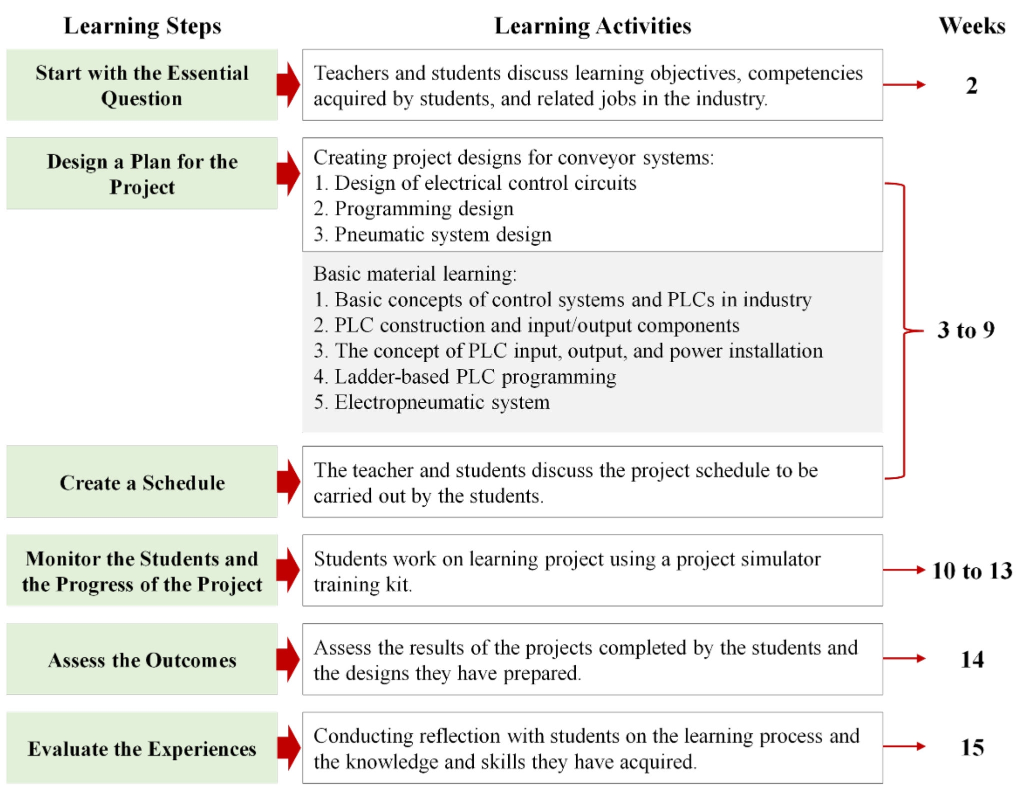


Figure 4. Diagram of the learning process in the control class

RESEARCH INSTRUMENTS

Two data collection instruments are used in this study: the first to measure knowledge, and the second to measure students' practical skills in PLC-based industrial control systems. The first instrument for measuring knowledge was developed as a multiple-choice test, scored dichotomously (1 = correct, 0 = incorrect). The questions developed consisted of 35 items referring to the knowledge of PLC-based control systems that students must master. In addition, the questions developed to measure students' knowledge refer to the levels of knowledge according to Bloom's Taxonomy, starting from understanding (C2), applying (C3), analyzing (C4), and evaluating (C5) (Salas et al., 2024). The questions developed are shown in Table 2. More specifically, the form of the instrument used is as shown in Appendix A. Before this instrument was used in the research process, it was tested in a class studying PLC-based industrial control systems to assess the validity and reliability of the test questions. The test was administered to 28 students, using the Pearson product-moment correlation to assess validity and the Kuder–Richardson (KR-20) to assess test reliability. The validity analysis results obtained r-values ranging from 0.423 to 0.748, which are greater than the r-table value of 0.388 (df=26). Thus, from these results, it is known that all test items developed are valid. Furthermore, the reliability analysis yielded a value of 0.927, which is greater than 0.70, indicating that all test items are reliable (Kelley et al., 2011). Thus, based on these results, the test instruments developed accurately measure students' knowledge of PLC-based industrial control systems and exhibit high measurement consistency.

The second instrument measures students' practical skills in PLC-based industrial control systems. This instrument is designed in the form of a practical skills observation sheet using four main assessment elements in this learning process, namely (1) PLC Control System Design (CSD), (2) PLC Control System Installation (CSI), (3) PLC Programming (Prg), and (4) System Commissioning and Testing (SCT). The assessment framework also adopts assessments developed by previous researchers to enhance assessment quality (Aswardi et al., 2023; Noviyanto & Sudira, 2020). Each assessment item is scored on a Likert scale from 1 (lowest) to 5 (highest). The students' scores are converted to a 0-100 range to standardize the format of their knowledge and practical skills scores. The design of the practical skills assessment in this study is based on the principles of performance-based and authentic assessment in vocational education, which require direct observation of students' work processes, as PLC-based industrial control system competencies cover conceptual, procedural, occupational safety, and problem-solving aspects (Aswardi et al., 2023; Chiou, 2021). More specifically, the types of instruments used to measure students' practical skills, as shown in Appendix B.

Table 2. The multiple-choice test instrument grid measures student knowledge

Main topics	Subtopics	Number questions			
		C2	C3	C4	C5
PLC-Based Control System Concept (CSS)		2	1		
PLC construction and input/output components (IOC)	PLC Construction	2			
	PLC input concepts and components		1	2	1
	PLC output concepts and components		1	2	
PLC-based control system installation series (CSI)	PLC power circuit concept	2			
	PLC input circuit concept		1	1	1
	PLC output circuit concept		2	1	1
PLC programming (Prg)	Basic PLC instructions: coil, NO, NC, Timer, Counter	1	1	2	
	Advanced instructions for increment, decrement, comparison, addition, and move.	1		2	
Electropneumatic System (ES)	The concept of an electropneumatic system	1	1		
	Electropneumatic system components and circuits	1	1	2	1

To ensure reliability and minimize observation bias in the assessment of practical skills, the researcher first pilot-tested the instrument in a third-year class that had already completed the course. The results indicated that the developed instrument validly and consistently assessed students' practical skills, with product-moment correlation coefficients ranging from 0.522 to 0.944, greater than the critical r-value of 0.388 (df=26) and a Cronbach's alpha of 0.969, exceeding the 0.70 (threshold) (Emerson, 2019). Second, the study enhanced the objectivity and consistency of the assessment process by involving two expert teachers simultaneously evaluating students at a teacher-to-student ratio of 1:6; this allowed for a more in-depth observation of work processes, procedural accuracy, and practical skills during the practical session. This approach strengthens inter-rater reliability and reduces teacher subjectivity in assessment (Peppler et al., 2023). The three potential biases arising from differences in perception among raters are minimized through a rater calibration process conducted prior to the observation activity, during which teachers systematically discuss criteria, indicators, and performance standards to achieve a shared interpretation of the instruments used (OECD, 2023; Yusop et al., 2022). This approach is crucial for enhancing consistency and inter-rater reliability, although it is acknowledged that variations in subjectivity cannot be fully eliminated; thus, assessment results must still be interpreted while considering the possibility of residual contextual bias.

DATA ANALYSIS TECHNIQUE

The research data obtained in this study were analyzed using SPSS software. First, descriptive analysis was performed using mean values, standard deviations, standard errors, and 95% confidence intervals for each data set. Before further analysis, the data obtained underwent preliminary analysis (assumptions) to assess normality using the Kolmogorov–Smirnov test and homogeneity using Levene's test. The test results showed that the research data did not fully meet these assumptions. Thus, to determine and draw conclusions from the results of the first study in this research, a paired-samples t-test was used to compare the pretest and posttest scores of both the experimental and control classes. Second, an independent t-test was conducted to compare the scores of the experimental class with those of the control class, both in the pretest to assess students' initial learning outcomes and in the posttest to assess their final learning outcomes. Third, Welch's t-test was used because the students' practical skills posttest data did not meet the homogeneity-of-variance assumption. This analysis is a modification of the independent-samples t-test, which does not assume equal variances and uses adjusted degrees of freedom (the Welch–Satterthwaite correction), making it more robust to differences in variance and unbalanced sample sizes (Jan & Shieh, 2020). Fourth, an effect-size analysis using Cohen's d was conducted to assess the intervention's impact on student learning outcomes. The results were interpreted according to three criteria: 0.2 (small), 0.5 (medium), and 0.8 (large) (Cohen, 1988). These four analyses enabled a comprehensive evaluation of the stability of the impact of the PjBL model developed to improve the knowledge and practical skills of vocational students.

Table 3. Descriptive analysis of pretest and posttest data

Assessment	Class	Value	N	Mean	SD	SE	CI = 95%
Knowledge	Control	Pretest	31	72.258	8.041	1.444	[69.419 – 75.000]
		Posttest	31	78.806	7.232	1.299	[76.291 – 81.323]
	Experiment	Pretest	33	71.580	8.992	1.615	[68.549 – 74.773]
		Posttest	33	85.065	6.475	1.163	[82.775 – 87.193]
Practical Skills	Control	Pretest	31	63.935	15.729	2.825	[58.709 – 69.484]
		Posttest	31	77.097	12.639	2.270	[72.812 – 81.419]
	Experiment	Pretest	33	62.419	14.546	2.613	[57.454 – 67.774]
		Posttest	33	83.903	8.942	1.606	[80.614 – 87.031]

Note: Number of students (N), standard deviation (SD), standard error (SE), and confidence interval (CI)

RESULTS

DESCRIPTIVE ANALYSIS OF RESEARCH DATA

Based on the descriptive data presented in Table 3, the initial performance of students in the control and experimental groups was relatively equivalent. In terms of knowledge, the pretest results showed comparable mean scores between the control group (M = 72.258, SD = 8.041, SE = 1.444, CI 95% [69.419–75.000]) and the experimental group (M = 71.580, SD = 8.992, SE = 1.615, CI 95% [68.549–74.773]), indicating no significant difference in initial cognitive ability (knowledge). This equality was also reflected in practical skills, where the control group obtained a pretest average score of 63.935 (SD = 15.728, SE = 2.825, CI 95% [58.709–69.484]) and the experimental group scored 62.419 (SD = 14.546, SE = 2.613, CI 95% [57.454–67.774]). The overlap of the 95% confidence intervals for both aspects of the assessment indicates that the initial abilities of students in the control and experimental groups were relatively similar, so the difference in results at the posttest stage can be more convincingly attributed to the learning treatment.

In addition, posttest data show that the experimental class achieved a higher average score (M = 85.065, SD = 6.475, 95% CI [82.775–87.193]) compared to the control class (M = 78.806, SD = 7.232, 95% CI [76.291–81.323]). This difference in means indicates that students in the experimental class achieved greater mastery of the material after the treatment was administered. In addition, the 95% confidence intervals for both groups show a clear difference, as the lower and upper bounds of the mean values do not overlap. This indicates that the experimental class's learning outcomes are superior to those of the control class. Similar findings were also seen in the Practical Skills aspect of students, with the average score of the experimental class (M = 83.903, SD = 8.942, 95% CI [80.614–87.031]) being higher than that of the control class (M = 77.097, SD = 12.639, 95% CI [72.812–81.419]). These findings indicate that the average practical skills of students in the experimental class were consistently higher than those in the control class; however, the lower and upper bounds of the 95% confidence interval overlap, suggesting that a more rigorous statistical analysis is needed to determine whether there is a significant difference in practical skills between the experimental and control classes. Although the experimental class had higher average scores than the control class, to ensure that this difference was not solely due to differences in initial abilities, a paired t-test, an independent t-test, and a Welch's t-test were conducted. These tests were conducted to obtain accurate estimates of group differences (see Tables 5 and 6).

Assumption Analysis

The results of the test for the normality assumption of the research data are shown in Table 4. Based on the results of this knowledge assumption test, the pretest and posttest data in both the control and experimental classes showed normal distributions. This is indicated by the p-value in the Kolmogorov–Smirnov test, which is above the significance limit of 0.05 (control pretest p = 0.200, experimental pretest p = 0.115, control posttest p = 0.200, experimental posttest p = 0.069). In addition, the results of the Levene test for homogeneity of variances indicate that the variances between groups are homogeneous, both in the pretest (p = 0.627) and in the posttest (p = 0.492). These results are shown in Table 6. Thus, statistically, the knowledge data met the assumptions of normality and homogeneity of variance, making it suitable for analysis using a parametric approach. Therefore, to analyze differences between groups in knowledge, a paired-samples t-test and an independent-samples t-test were used, as the data met the assumptions of normality and homogeneity of variance.

In terms of practical skills, the Kolmogorov–Smirnov test results also show that the Pretest and Posttest data in both groups are normally distributed, with all p-values above 0.05 (all p = 0.200). For the homogeneity of variance test, the Pretest results show homogeneous variance (p = 0.705). However, in the Posttest data, the Levene test value was very close to the significance limit (p = 0.051) or could be considered equal to the specified significance limit, indicating marginal or borderline homogeneity. These results are presented in Table 9. Nevertheless, because the p-value is still slightly above 0.05, the assumption of homogeneity remains technically acceptable; however, further analysis should be conducted carefully or supported by a more robust analytical approach to ensure the stability of the inferential results.

Thus, in this study, the paired sample t-test was still used to analyze the paired data. Meanwhile, to analyze differences between independent groups in the control and experimental classes, two t-tests were used: the independent t-test and Welch's t-test (equal variances not assumed). The selection of these two tests was based on the finding that the data did not show strong variance homogeneity but were in a marginal condition, warranting caution in selecting the analysis method. Therefore, a more robust test, such as Welch's t-test, was applied as a verification step to ensure that the conclusions were more stable and statistically valid.

Table 4. Results of the data normality test (Kolmogorov-Smirnov)

Description		Knowledge				Practical skills			
		Control		Experiment		Control		Experiment	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post
N		31	31	33	33	31	31	33	33
Normal parameters	Mean	72.258	78.806	71.580	85.065	63.935	77.097	62.419	83.903
	Std. deviation	8.041	7.232	8.992	6.475	15.729	12.639	14.546	8.942
Most extreme differences	Absolute	0.109	0.120	0,138	0,147	0.083	0.093	0.091	0.081
	Positive	0.072	0.120	0,138	0,126	0.083	0.093	0.091	0.064
	Negative	-0.109	-0,111	-0,074	-0.147	-0.064	-0.062	-0.069	-0.081
Test statistic		0.109	0.120	0.138	0.147	0.083	0.093	0.091	0.081
Asymp. Sig. (2-tailed)		0.200	0.200	0.115	0.069	0.200	0.200	0.200	0.200

ANALYSIS OF STUDENT KNOWLEDGE

Based on the analysis in Table 5, both the control and experimental classes showed a statistically significant increase in knowledge after learning, as indicated by the paired-samples t-test. In the control class, a t-value of 3.900 ($p = < 0.001$) and an effect size of 0.692 (CI = 0.298-1.076) were obtained, indicating a moderate increase. Meanwhile, the experimental class showed a much stronger increase, with a t-value of 8.099 ($p = < 0.001$) and an effect size of 1.436 (CI = 0.975-1.960), which falls into the very large effect category. The effect size values obtained are shown in Table 7. These findings indicate that although conventional learning can increase students' knowledge, the intervention applied in the experimental class had a substantially stronger impact.

Furthermore, a comparison of posttest results between the control and experimental classes using an independent t-test showed a statistically significant difference ($t = 3.538$, $p = < 0.001$). These results are presented in Table 6 under the "equal variances assumed" column because the posttest data on student knowledge met the assumption of homogeneity. The effect size was 0.885 (CI =0.367-1.396), indicating a large effect, confirming that learning outcomes were superior in the experimental class compared to the control class after the intervention.

Overall, the combination of intra- and inter-group test results provides strong empirical evidence that the learning method applied in the experimental class is not only effective in improving students' knowledge internally, but also significantly superior to conventional learning when compared between groups. More detailed information on students' knowledge of each learning topic is shown in Figure 4.

Table 5. Results of the paired-sample t-test on students' knowledge

Group	Paired differences					T	DF	SIG.
	M	SD	SEM	CI = 95%				
				Lower	Upper			
Control	6.548	9.348	1.679	3.119	9.977	3.900	30	< 0.001
Experiment	13.788	9.249	1.610	10.508	17.067	8.563	32	< 0.001

Note: mean (M), std. deviation (SD), std. error mean (SEM)

Table 6. Results of the independent t-test (posttest) on students' knowledge

Type	Levene's test		T-test for equality of means						
	F	Sig.	T	DF	Sig.	MD	SED	CI = 95 % Lower	CI = 95 % Upper
EVS	0.479	0.492	3.538	62	< 0.001	6.042	1.708	2.628	9.456
EVNS	-	-	3.524	60.048	< 0.001	6.042	1.714	2.613	9.471

Note: Equal variances assumed (EVS), equal variances not assumed (EVNS), mean difference (MD), std. error difference (SED), confidence interval (CI).

Table 7. Results of the analysis of Cohen's d effect size for students' knowledge

Group	Paired samples			Independent samples		
	d	CI = 95% Lower	CI = 95% Upper	d	CI = 95% Lower	CI = 95% Upper
Control	0.692	0.298	1.076	0.885	0.367	1.396
Experiment	1.473	0.975	1.960			

Based on the radar diagram in Figure 5a, the experimental class showed higher and more consistent knowledge achievement in all learning topics compared to the control class. In the CSC topic, the experimental class achieved an average of 84.42, while the control class ranged from 80.18. A similar pattern was observed for IOC (85.71 vs. 79.26), CSI (85.71 vs. 82.49), Prg (84.42 vs. 75.12), and ES (83.55 vs. 76.96). The larger polygon area of the experimental class reflects a more comprehensive and even mastery of concepts across various dimensions of knowledge. In contrast, the control class shows lower achievements and greater variation between indicators. These findings are reinforced by the histogram of the Posttest score distribution in Figure 6b, which shows a shift in the distribution of the experimental class scores to a higher value interval.

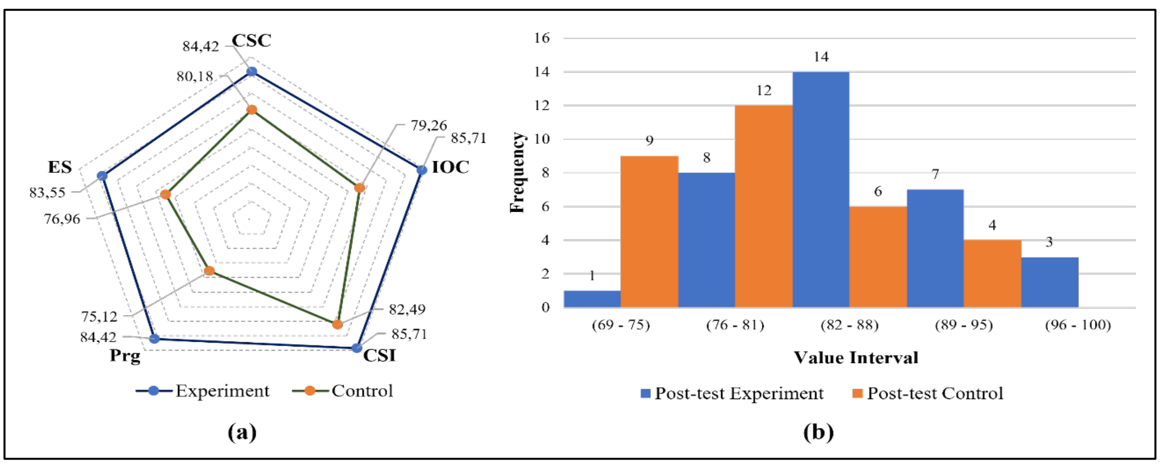


Figure 5. (a) Radar chart, (b) Histogram of student knowledge scores

In the experimental class, the highest frequency was in the 82–88 interval, with 14 students, followed by the 89–95 interval, with 7 students, and the 96–100 interval, with 3 students, while only 1 student was in the 69–75 interval. In contrast, the control class had the highest concentration of scores in the

76–81 interval (12 students), the 82–88 interval (6 students), and still showed a relatively larger number in the low-score interval of 69–75 (9 students). This distribution shows that learning in the experimental class not only increased the average score but also shifted most students to the medium-high and high achievement categories, thus descriptively confirming the effectiveness of the learning intervention compared to conventional learning.

ANALYSIS OF STUDENTS PRACTICAL SKILLS

The results of the analysis of students' practical skills in PLC-based industrial control systems are presented in Table 8. Based on the paired-samples t-test results, both the control and experimental groups showed statistically significant improvements from pretest to posttest. In the control group, the analysis yielded a t value of 14.538 (p = < 0.001) and an effect size of 2.578 (CI = 1.837-3.309), indicating a very large effect. Similarly, the experimental group demonstrated a significant improvement, with a t value of 11.508 (p = < 0.001) and an effect size of 1.979 (CI = 1.385-2.563), both of which fall within the very large effect category. The effect size values obtained are shown in Table 10. These findings suggest that both instructional approaches were effective in significantly enhancing students' practical skills, although the magnitude of improvement differed between the two groups.

Table 8. Results of the paired-sample t-test on students' practical skills

Group	Paired differences					T	Df	Sig.
	M	SD	SEM	CI = 95 %				
				Lower	Upper			
Control	13.161	5.040	0.905	11.312	15.010	14.538	30	< 0.001
Experiment	21.091	10.528	1.833	17.358	24.824	11.508	32	< 0.001

Note: Mean (M), std. deviation (SD), std. error mean (SEM).

Table 9. Results of the independent t-test (posttest) of students' practical skills

Type	Levene's test		T-test for equality of means						
			T	DF	Sig.	MD	SED	CI = 95 %	
	F	Sig.						Lower	Upper
EVS	3.965	0.051	2.537	62	0.014	6.964	2.745	1.476	12.451
EVNS	-	-	2.512	54.420	0.015	6.964	2.773	1.406	12.522

Note: Equal variances assumed (EVS), equal variances not assumed (EVNS), mean difference (MD), std. error difference (SED), confidence interval (CI).

Table 10. Results of the analysis of Cohen's d effect size for students' practical skills

Group	Paired samples			Independent samples		
	d	CI = 95%		d	CI = 95%	
		Lower	Upper		Lower	Upper
Control	2.578	1.837	3.309	0.627	0.128	1.121
Experiment	1.979	1.385	2.563			

Furthermore, posttest scores between groups were compared using two different testing approaches to ensure the stability and robustness of the inferential results. In an independent samples t-test (equal variances assumed), a t value of 2.537 with p = 0.014 was obtained, indicating a statistically significant difference between the control and experimental groups. This finding was corroborated by Welch's t-test (equal variances not assumed), which yielded a comparable level of significance ($t = 2.512$, $p = 0.015$), despite not assuming homogeneity of variances between groups. In addition, the observed effect size of 0.627 (CI = 0.128-1.121) indicates a moderate effect, suggesting that students' practical skill achievement in the experimental group was substantially higher than that of the control group following the instructional intervention. The consistency of results across both analyses strengthens the validity of the conclusion that the implemented instructional intervention had a positive, meaningful impact on students' practical skills. Overall, these findings confirm that the intervention in the experimental group was not only effective in improving students' practical skills internally but also produced significantly superior outcomes compared to conventional instruction.

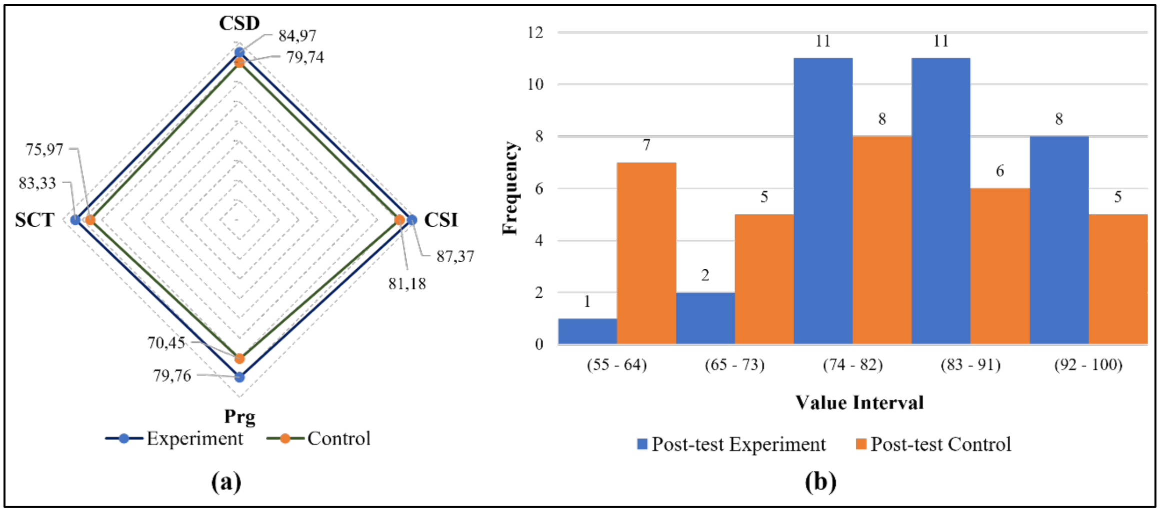


Figure 6. (a) Spider chart, (b) Histogram of students' practical skill scores

Based on the data analysis presented in Figures 6a and 6b, the results indicate that the experimental group consistently outperformed the control group in both multidimensional mean achievement and score frequency distribution. The radar chart in Figure 5a confirms the superior performance of the experimental group across all indicators, with particularly pronounced differences in the Prg (79.76 vs. 70.45) and SCT (83.33 vs. 75.97) dimensions, suggesting that the implemented intervention exerted a strong reinforcing effect on procedural and technical aspects. In line with these findings, the frequency distribution shown in Figure 6b reveals a rightward shift of the curve for the experimental group, with a higher concentration of student scores within the upper score intervals (74–91) and a greater number of respondents achieving the highest score range (92–100) compared to the control group. These results demonstrate that the PjBL model, integrated with the object-sorting conveyor training kit, not only significantly enhances overall collective performance but also effectively reduces the proportion of low-achieving participants, thereby strengthening the case for the intervention's efficacy in promoting more homogeneous, high-quality learning outcomes.

DISCUSSION

The findings of this study indicate that the PjBL model integrated with an object-sorting training kit, as implemented in the experimental group, significantly enhanced students' knowledge and practical skills in PLC-based industrial control systems compared to conventional instruction. This finding is consistent with the core characteristics of vocational education, which emphasize the integration of conceptual knowledge and applicable practical skills (Y. Zhang, 2025). In the context of technical and vocational education and training (TVET), effective learning is not solely about theoretical mastery but also about the ability to apply concepts in authentic workplace settings (Isa & Azid, 2021). The higher and more evenly distributed learning gains across all instructional topics observed in the experimental group suggest that the applied intervention effectively facilitated a learning-by-doing process, as emphasized in experiential learning theory and competency-based education, which constitute the foundational principles of vocational education (Ibrahim, 2025).

The superiority of the experimental group in the knowledge dimension indicates that the applied instructional approach did not compromise the depth of theoretical understanding; instead, it strengthened concept construction through contextualized activities. According to constructivist learning theory, knowledge becomes more meaningful when learners actively construct their own understanding through engagement with the learning environment (Kirschner et al., 2006; Tan et al., 2025). This finding is reflected in more consistent knowledge achievement across various PLC-related topics, suggesting that students did not merely memorize isolated concepts but were able to integrate control system principles, installation procedures, and programming concepts into a coherent, functional whole. This outcome is highly relevant to the demands of vocational education, which emphasize systemic and integrative understanding (Díaz-Lauzurica & Moreno-Salinas, 2025).

In terms of practical skills, the findings indicate that the PjBL model, when integrated with a training kit, has a moderate impact on students' practical skills. Although the impact falls into the moderate category, these results still show that the experimental class's practical skills are better than those of the control class. This result aligns with the principles of vocational pedagogy, which position practice as the primary means for developing occupational competence (Bencheva et al., 2024; Berselli et al., 2020). Learning activities involving training kits and industrial system simulations enabled students to practice in contexts that closely resemble real workplace environments, thereby supporting the transfer of learning from the classroom to industry settings. Consequently, the more substantial improvement in practical skills observed in the experimental group can be understood as a result of the alignment between the instructional design and the inherently applied nature of vocational competencies.

Based on these two findings, although the experimental class demonstrated a strong effect size in the knowledge domain, the effect size was relatively moderate in the practical skills domain. These results reflect fundamental differences in cognitive and psychomotor learning. The acquisition of knowledge is largely conceptual in nature and can be enhanced through real-world experiences, direct interaction, and contextualized problem-solving activities, as facilitated by the PjBL approach (Dale's, 1969; Dewey, 1976; Gagné, 1985; Piaget, 1970). Meanwhile, practical skills are acquired through a cycle of repeated actions, feedback, and refinement that requires integrating cognitive and psychomotor components. In vocational learning, this process involves not only procedural understanding but also the development of fluency, accuracy, and adaptability in performing real-world operations. In PLC-based control system learning, these variables must be embedded in the skills of circuit design and PLC programming. These competencies emerge through continuous practice under various conditions, where students gradually progress from the imitation stage to the natural stage within the psychomotor domain (practical skills) (Ericsson, 2008; Zhong et al., 2026). Thus, the development of practical skills is highly dependent on immediate feedback, error correction, and direct engagement with physical systems, all of which require sufficient time and exposure to stabilize student performance. In this study, although the PjBL approach provided authentic and contextual learning experiences, the intervention's duration was still relatively short, and the structured nature of the practical tasks may have limited the depth of students' procedural internalization.

Conceptually, the findings of this study reinforce the view that vocational learning becomes more meaningful when it is designed around authentic activities, the integration of theory and practice, and contextual problem-solving. The implemented instructional intervention not only enhanced learning outcomes quantitatively but also reflected learning processes aligned with the fundamental principles of vocational education, namely relevance to industry needs, strengthening of practical competencies, and development of applicable conceptual understanding (Navarro-Durán et al., 2023; Roll & Ifenthaler, 2021). Therefore, these findings provide strong empirical support for the development and implementation of contextual learning models in vocational education, particularly in PLC-based industrial control systems.

Vocational high schools in Indonesia are part of the national formal education system. They are explicitly designed to produce graduates who are ready for the workforce and aligned with industry demands through competency-based education. Thus, vocational high schools aim to develop students' technical expertise, professional attitudes, and adaptive skills to meet existing industry job standards. These competency standards have also been established through the Indonesian National Occupational Competency Standards, which serve as a reference for the design of vocational high school curricula. Under these standards, vocational high schools are classified at levels 2–3, where students must be able to perform operational tasks, apply standard procedures, and solve routine technical problems in specific fields of work, such as PLC-based industrial control systems (Billett, 2011; Mori, 2023). Thus, learning in vocational high schools not only enhances conceptual understanding but also strengthens procedural and applied competencies, ensuring that students meet national competency standards. This approach produces graduates who are job-ready and capable of adapting to an ever-evolving industrial environment.

IMPLICATIONS OF PROJECT-BASED LEARNING MODELS INTEGRATED WITH OBJECT SORTING CONVEYOR TRAINING KIT

This study makes a significant theoretical contribution to the development of learning models in vocational education, particularly in the context of PLC-based industrial control systems. These findings reinforce the theoretical link between PjBL and experiential learning by empirically demonstrating that PjBL becomes much more effective when systematically integrated with authentic learning media that represent industry, because the depth and consistency of conceptual understanding are greatly influenced by the level of contextual authenticity embedded in the learning environment. Furthermore, the proposed learning model expands the existing PjBL framework by emphasizing the important role of a structured foundation phase prior to project implementation; unlike conventional PjBL approaches that assume learners' readiness for open-ended projects, this model explicitly incorporates basic concept teaching and guided skills training, which contributes to more coherent knowledge construction and reduces conceptual fragmentation, particularly among novice vocational learners. These findings refine PjBL design principles by highlighting the need for a balanced integration of guided teaching and learner autonomy rather than a discovery-oriented approach alone. Furthermore, the integration of the object sorting conveyor training device within the PjBL framework reinforces the theoretical perspective that vocational competencies are essentially multidimensional, encompassing cognitive, procedural, and systems integration domains, thereby empirically supporting competency-based education theory that meaningful learning arises from simultaneous engagement with conceptual understanding and applied performance in competencies.

From a practical perspective, the findings of this study have significant implications for vocational educators, curriculum designers, and institutions. For teachers, the study's results show that integrating PjBL with industry-relevant training tools can substantially improve students' conceptual understanding and practical performance. Rather than implementing PjBL as a general teaching strategy, educators are encouraged to align learning projects with authentic industrial systems, such as object sorting conveyors, so that learning activities closely resemble real-world workplace tasks and enable students to experience the complete industrial control workflow, including system design, PLC programming, installation, testing, and troubleshooting. For curriculum developers, this study provides empirical support for embedding a structured preparation phase in PjBL-based curricula, where systematic instruction of basic concepts and guided skills training precede project implementation, thereby enhancing learning effectiveness without diminishing the student-centered nature of PjBL, especially in contexts characterized by heterogeneous prior knowledge. At the institutional level, the findings underscore the importance of investing in contextual learning media that reflect the latest industrial technologies. This object-sorting conveyor training device serves not only as a teaching aid but also as a core pedagogical component that enables authentic learning experiences, offering vocational schools and training centers a cost-effective strategy to bridge the gap between school-based learning and industry requirements and to strengthen graduate work-readiness in the era of Industry 4.0.

RESEARCH LIMITATIONS AND FUTURE RESEARCH

Although this study provides strong empirical evidence for the effectiveness of PjBL, integrated with an object-sorting conveyor training kit, in enhancing knowledge and practical skills in PLC-based industrial control systems, several limitations should be acknowledged. First, the use of a quasi-experimental design without full randomization limits the strength of causal inference. However, baseline equivalence between groups was confirmed through pretest analysis and statistical assumption testing. Second, the study's scope, which involved only a single vocational education institution and a single competency area in PLC-based industrial control systems, limits the generalizability of the findings to broader vocational education contexts characterized by diverse student profiles, facilities, and learning cultures. Third, the relatively short duration of the intervention did not allow for the evaluation of long-term effects, particularly with respect to knowledge retention, the sustainability of practical skills, and graduates' work-readiness. Consequently, the results of this study primarily represent the short-term effectiveness of the implemented intervention.

Given these limitations, future studies are recommended to employ more rigorous and comprehensive research designs, such as randomized controlled trials or longitudinal studies, to enhance internal validity and evaluate the sustainability of learning impacts over the long term. In addition, implementing the proposed PjBL model across multiple vocational education institutions, within similar or different areas of expertise, is necessary to examine the consistency and generalizability of the effectiveness of the developed PjBL instructional steps. Future research is also encouraged to broaden the scope of evaluation by integrating measures of affective domains, soft skills, and industry work readiness, thereby enabling a more comprehensive understanding of the model's contribution to the holistic competency development of vocational education students. This is particularly important given that soft skills, such as critical thinking, creativity, collaboration, communication, and problem-solving, are increasingly essential for vocational students to adapt to the dynamic pace of technological advancement (Bell, 2010; Roll & Ifenthaler, 2021).

CONCLUSIONS

This study concludes that the PjBL-based instructional intervention, integrated with a training kit, significantly and consistently enhances vocational students' learning outcomes in both knowledge and practical skill domains in PLC-based industrial control system learning. Descriptive and inferential analyses indicate that the initial competencies of students in the control and experimental groups were relatively comparable, allowing the observed posttest improvements to be attributed with greater confidence to the instructional intervention. In the knowledge domain, the experimental group exhibited greater gains, with a large effect size, and more evenly distributed achievement across instructional topics, thereby confirming the effectiveness of PjBL in strengthening conceptual understanding through contextualized, authentic, problem-oriented learning.

Furthermore, in the practical skills domain, although both groups demonstrated significant improvement, the experimental group consistently achieved higher performance and a more favorable score distribution than the control group. The significant and consistent findings obtained from both the independent-samples t-test and Welch's t-test strengthen the robustness of the inferential validity, particularly under conditions of marginal variance. These results confirm that integrating PjBL with authentic practical media not only enhances students' technical performance but also contributes to a more equitable mastery of procedural skills essential to vocational education. Overall, this study provides strong empirical evidence that implementing project-based learning supported by an object-sorting conveyor training kit is an effective and meaningful pedagogical approach for bridging the gap between school-based learning and the competency demands of the workplace in vocational education.

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APPENDICES

APPENDIX A. STUDENT KNOWLEDGE ASSESSMENT INSTRUMENT

Topic: PLC Based Control System Concept

1. The main advantage of PLCs over relay-based control systems is ... **(C2)**
   A. PLCs are cheaper.
   B. PLCs do not require a power source.
   C. PLCs are easy to program and modify if changes are needed.
   D. PLCs can only be used for simple systems.

2. The input module on a PLC functions to ... **(C2)**
   A. Receiving signals from sensors or switches
   B. Storing PLC programs
   C. Directly moving actuators
   D. Processing data from the process

3. A light turns on when the Start button is pressed and turns off when the Stop button is pressed. The component that is included in the PLC input in this system is ... **(C3)**
   A. Pilot Lamp
   B. Relay
   C. Start and Stop Buttons
   D. Power supply

Topic: PLC Construction and Input/Output Components

4. The part of the PLC that functions as the data processing center and program logic is ... **(C2)**
   A. Power supply
   B. Input module
   C. CPU (Central Processing Unit)
   D. Output module

5. The input module in PLC construction functions to ... **(C2)**
   A. Receiving signals from external devices
   B. Storing user programs
   C. Processing data from the process
   D. Providing operating voltage for the PLC

6. Proximity sensors are used to detect the presence of objects on conveyors. In PLC systems, these sensors function as ... **(C3)**
   A. Digital output
   B. Digital input
   C. Analog output
   D. Processor

7. A PLC receives a signal from a 24 VDC push button, but the input status indicator on the PLC does not change (on). The most likely cause of this condition is ... **(C4)**
   A. The PLC output is damaged.
   B. The PLC program has not been downloaded.
   C. The input voltage does not match the input module specifications.
   D. The PLC CPU is working too fast.

8. In a system, an NPN proximity sensor is connected to a PNP type PLC input module. Based on the input characteristic analysis, the condition that occurs is ... **(C4)**
   A. The system is working normally
   B. The PLC input is always active
   C. The PLC input voltage has become more stable
   D. The PLC input cannot detect the sensor signal

9. In designing a PLC input system, the main evaluation that must be considered before selecting a sensor is ... **(C5)**
   A. Signal type and system requirements
   B. Sensor color
   C. Cable length
   D. PLC brand

10. A 24 VDC solenoid valve will be controlled by a PLC. To ensure the solenoid operates safely, the PLC output should be connected via … **(C3)**
   A. Relay
   B. PLC CPU
   C. Contactor
   D. Analog input module

11. The PLC output module was damaged after being used to control a large load. The indication of the cause of this damage is ... **(C4)**
   A. The PLC input voltage is too high
   B. The PLC program is too complex
   C. The output sensor is incompatible
   D. The load current exceeds the PLC output capacity

12. A PLC panel is used to control several types of loads with different voltages. The safest output circuit design analysis is ... **(C4)**
   A. Using one type of output for all loads
   B. Connecting all loads directly to the PLC
   C. Separating output circuits based on load type and voltage
   D. Reducing the number of PLC outputs

Topic: PLC Based Control System Installation Series

13. The main function of the power supply in a PLC system is ... **(C2)**
    A. Processing input signals
    B. Storing program data
    C. Connecting the PLC to a computer
    D. Changing and supplying voltage according to system requirements

14. PLC output devices such as motors or lights are not directly connected to the PLC because ... **(C2)**
    A. The load voltage and current exceed the PLC's output capacity.
    B. The PLC does not have a program.
    C. The PLC does not require output.
    D. The PLC output is only for sensors.

15. A limit switch is used as a PLC input to detect mechanical position. The function of the limit switch in the PLC input circuit is ... **(C3)**
    A. Processing logic signals
    B. Providing digital signals to the PLC
    C. Controlling loads
    D. Storing process data

16. The PLC input indicator light is on, but the logic in the program is not running. Proper analysis shows that ... **(C4)**
    A. The sensor is not working
    B. There is a problem with the power circuit
    C. There is an error in the PLC program logic
    D. The input module is completely damaged

17. A system requires stable and secure signal reading from a 24 VDC sensor. The most appropriate PLC input design evaluation is ... **(C5)**
    A. Input with optoisolator isolation
    B. Input without isolation
    C. Input directly to the CPU
    D. Passive analog input

18. If the PLC output is a relay type, then its main characteristic is ... **(C3)**
    A. Can only be used for DC
    B. Does not require a voltage source
    C. Does not require a safety circuit
    D. Can be used for both AC and DC

19. A PLC is used to turn on an AC motor via a contactor. The component that must be connected directly to the PLC output is ... **(C3)**
    A. AC motor
    B. Contactor
    C. Power supply
    D. Current sensor

20. The PLC output is active, but the load is not working. After checking, it turns out that the load is using a different voltage. The analysis of the problem is ... **(C4)**
    A. Incorrect sensor selection
    B. Output circuit voltage mismatch
    C. PLC programming error
    D. PLC CPU damage

21. For systems with high switching frequencies and DC loads, the most appropriate type of PLC output to evaluate is … **(C5)**
    A. Relay output
    B. Analog output
    C. Communication output
    D. Transistor output

Topic: PLC Programming

22. A Normally Closed (NC) contact will conduct current or connect the program when ... **(C2)**
    A. Input value is ON
    B. Output is active
    C. Input value is OFF
    D. Timer is complete

23. If a motor must turn on 5 seconds after the button is pressed, then the PLC instruction used is ... **(C3)**
    A. Timer
    B. Counter
    C. Coil
    D. NC

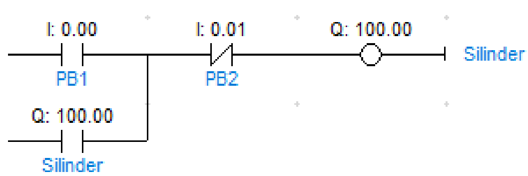
24. A machine may only be turned on if the Start button is pressed and the Emergency button is inactive. In the ladder diagram, the most appropriate combination of contacts to use is ... **(C4)**
    A. Start (NC) series Emergency (NO)
    B. Start (NO) series Emergency (NC)
    C. Start (NO) parallel Emergency (NC)
    D. Start (NC) parallel Emergency (NO)

25. In a PLC program, the output is only active when two sensors are active simultaneously. The most appropriate ladder diagram logic analysis is ... **(C4)**
    A. Two NO contacts arranged in parallel
    B. Two NC contacts arranged in parallel
    C. One NO contact and one NC contact
    D. Two NO contacts arranged in series

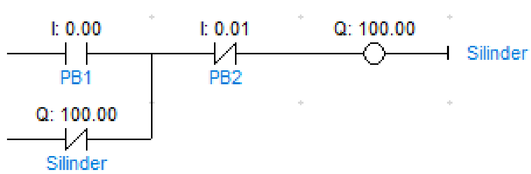
26. The Increment (INC) instruction on a PLC functions to ... **(C2)**
    A. Decrease the value of one unit of data
    B. Increase the value of one unit of data
    C. Move data to another address
    D. Compare two pieces of data

27. If a system has one cylinder and two push buttons named PB1 and PB2 with the following operating principles:
    - In the initial state, the cylinder is retracted.
    - If PB1 is pressed, the cylinder will advance.
    - If PB2 is pressed, the cylinder will retract again.

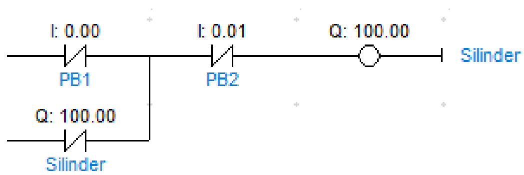
    Based on the working principle above, which PLC program is suitable for use ... **(C4)**



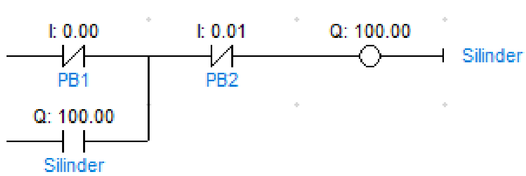
A.



B.



C.



D.

28. A PLC-based control system has a button (S1) connected to address 0.00 and a light (L) connected to address 100.01. If S1 is pressed, the light will turn off, and when S1 is not pressed, the light will turn on. The correct program to enter into the PLC is ... **(C4)**

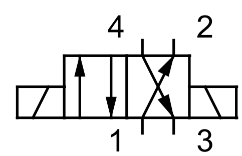
A.
B.
C.
D.

Topic: Electropneumatic Systems

29. An electropneumatic system is a system that ... **(C2)**
    A. Combining electrical and pneumatic systems to control actuators
    B. Using electrical energy only
    C. Using compressed air energy only
    D. Using a purely mechanical system

30. In an automatic electropneumatic system, the electrical signal to activate the solenoid valve usually comes from ... **(C3)**
    A. Compressor
    B. Flow control
    C. PLC or control circuit
    D. Pneumatic cylinder

31. Look at the picture on the right! The symbol represents a component of .... **(C2)**



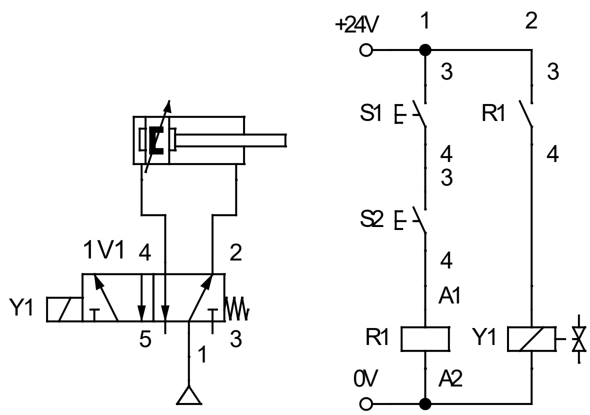
    A. 5/2 valve, single solenoid with spring
    B. 5/2 valve, single solenoid with push button
    C. 5/2 valve, double solenoid
    D. 4/2 valve, double solenoid

32. The pneumatic component used to generate compressed air is .... **(C3)**
    A. Solenoid
    B. Compressor
    C. Cylinder
    D. Air Service Uni

33. Look closely at the picture on the right! The statement that matches the solenoid name plate in the picture above is .... **(C4)**

    A. The solenoid operates at a voltage of 12 VDC with a power of 3.0 W and a voltage range of 10.8 V to 13.2 V
    B. The solenoid operates at a voltage of 24 VDC with a power of 3.0 W and a voltage range of 10.8 V to 13.2 V
    C. The solenoid operates at a voltage of 12 VDC with a power of 3.0 W
    D. The solenoid operates at a voltage range of 10.8 V to 13.2 V

34. Look closely at the picture on the right! How can you make the cylinder move forward as far as possible ... **(C4)**
    A. If neither button is pressed
    B. If button S2 is pressed
    C. If buttons S1 and S2 are pressed simultaneously for a moment
    D. If buttons S1 and S2 are pressed and held simultaneously



35. In an automatic electropneumatic circuit, the cylinder moves too quickly, endangering the operator. The most appropriate action from a safety and system design perspective is to evaluate ... **(C5)**
    A. Reduce the solenoid's electrical voltage
    B. Add an emergency stop only
    C. Adjust the flow control valve and air pressure
    D. Replace the PLC with a relay

Table A1. Results of instrument validity and reliability testing

Topic material	Question item	Correct	Mean	Standard deviation	Validity		Reliability (KR-20)
					R-value	R-table	
PLC-based control system concept	1	25	0.893	0.315	0.541	0.388	0.927
	2	25	0.893	0.315	0.541		
	3	18	0.643	0.488	0.665		
PLC construction and input/output components	4	25	0.893	0.315	0.451		
	5	25	0.893	0.315	0.451		
	6	21	0.750	0.441	0.748		
	7	21	0.750	0.441	0.683		
	8	13	0.464	0.508	0.510		
	9	9	0.321	0.476	0.541		
	10	17	0.607	0.497	0.478		
	11	13	0.464	0.508	0.482		
	12	23	0.821	0.390	0.501		
PLC-based control system installation series	13	25	0.893	0.315	0.541		
	14	25	0.893	0.315	0.451		
	15	21	0.750	0.441	0.629		
	16	13	0.464	0.508	0.697		
	17	5	0.179	0.390	0.423		
	18	23	0.821	0.390	0.501		
	19	16	0.571	0.504	0.449		
	20	23	0.821	0.390	0.574		
	21	10	0.357	0.488	0.589		
PLC programming	22	25	0.893	0.315	0.541		
	23	19	0.679	0.476	0.477		

	24	11	0.393	0.497	0.533		
	25	10	0.357	0.488	0.443		
	26	23	0.821	0.390	0.465		
	27	22	0.786	0.418	0.577		
	28	23	0.821	0.390	0.696		
Electropneumatic System	29	24	0.857	0.356	0.527		
	30	22	0.786	0.418	0.441		
	31	25	0.893	0.315	0.466		
	32	23	0.821	0.390	0.428		
	33	18	0.643	0.488	0.451		
	34	11	0.393	0.497	0.486		
	35	10	0.357	0.488	0.560		

Appendix B. Student Practical Skills Assessment Instrument

Table B1. Assessment instrument

Competency elements	Indicator	
Planning the Control System	MC1	Students make electrical working drawings of industrial control systems according to the instructions given.
	MC2	Students make working drawings of electropneumatic industrial control systems according to the instructions given.
	MC3	Students identify the electrical components of industrial control systems.
	MC4	Students identify the electropneumatic components of industrial control systems.
	MC5	Students prepare the work equipment needed to make industrial control systems.
Installing Control System	MI1	Students read electrical circuit drawings of industrial control systems.
	MI2	Students read the electropneumatic circuit drawing of industrial control system.
	MI3	Students install electrical components of industrial control systems.
	MI4	Students install electropneumatic components of industrial control systems.
	MI5	Students create basic PLC programming according to the instructions given.
	MI6	Students create PLC timer and counter programming according to the instructions given.
Control System Commissioning	CS1	Students prepare commissioning implementation documents properly and correctly.
	CS2	Students ensure that the components are properly and correctly positioned.
	CS3	Students adjust the parameters of electrical and pneumatic systems.
	CS4	Students identify problems that arise in the system properly and correctly.
	CS5	Students fix problems that arise in the system properly and correctly.
	MP1	Students operate the system according to the predetermined work steps.

Operating a Control System	MP2	Students monitor the system and ensure that the system is running according to its working principle.
	MP3	Students adjust system parameters to optimize performance based on operational conditions
	MP4	Students make a test result report properly and correctly.

Table B2. Results of instrument validity and reliability testing

Competency elements	Indicator	Mean	SD	Validity		Reliability (CA)
				R-v	R-t	
Planning the Control System	MC1	2.857	1.145	0.888	0.388	0,969
	MC2	3.071	1.514	0.904		
	MC3	3.143	0.525	0.552		
	MC4	3.214	1.031	0.883		
	MC5	3.393	0.567	0.856		
Installing Control System	MI1	2.714	1.213	0.910		
	MI2	3.107	1.370	0.893		
	MI3	2.821	1.156	0.944		
	MI4	3.679	0.612	0.905		
	MI5	3.393	1.227	0.910		
	MI6	2.643	1.193	0.896		
Control System Commissioning	CS1	3.250	0.701	0.830		
	CS2	2.500	0.745	0.862		
	CS3	2.786	0.917	0.874		
	CS4	3.143	0.356	0.661		
	CS5	3.143	0.651	0.751		
Operating a Control System	MP1	3.357	1.162	0.907		
	MP2	3.607	0.497	0.822		
	MP3	3.143	0.525	0.552		
	MP4	3.071	0.663	0.522		

Note: df=26, SD= standard deviation, R-v=R-value, R-t=R-table, CA = Chronbach's Alpha.

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