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Problem-Based Learning Module for Programmable Logic Controller Learning Processes: An Effectiveness Study

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ABSTRACT
This study aims to analyze the effectiveness of the Problem-Based Learning Module (PBL-M) for the learning process of programmable logic controllers (PLC) in vocational high schools (VHS). The study used a pre-experimental design with a one-group pre-test-post-test design, involving a group of students from a VHS in Pariaman, West Sumatra, Indonesia. multiple choice tests were used as research instruments. The effectiveness was determined by analyzing the difference between pre-test and post-test scores using the paired sample t-test. Additionally, Cohen's D effect size analysis was conducted to measure the magnitude of the effect. The results showed a significant difference between the post-test scores and the pre-test scores, with the post-test scores being higher. Moreover, the effect size analysis indicated a large effect of using the PBL-M. These findings suggest that the PBL-M is effective in improving the PLC learning process in VHS.

Keywords: *Effectiveness, PBL-M, Programmable Logic Controller Learning Processes, Vocational High School.*

1. INTRODUCTION

Vocational education is a type of education that emphasizes the development of practical and technical skills among students, with the aim of preparing them for employment in various industries and business sectors. In Indonesia, vocational education is primarily provided by Vocational High Schools (VHS) for secondary education and Vocational Higher Education (VHE) for higher education.

VHS is a level of secondary education that aims to prepare students for working in specific fields, such as engineering, healthcare, and tourism. VHS offers various vocational programs or majors, such as mechanical engineering, electrical engineering, computer science, accounting, and others [1]–[3]. The curriculum at VHS consists of both theoretical and practical subjects, allowing students to not only learn theory but also apply their skills in laboratories or workshops[4], [5]. VHS Pariaman, located in Sumatera Barat, Indonesia, shares similar goals with other VHS and is continuously striving to improve the quality of services and implementation of learning in schools.

In improving the quality of vocational education, a particular problem that requires special attention is the implementation of learning. This is because the success of achieving learning objectives is not solely determined by curriculum factors, but also by learning implementation factors, which determine the success or failure of learning activities [6], [7]. One of the factors that influence the quality of learning implementation is the availability of quality and adequate teaching materials that are in line with the characteristics of the learning materials. Teaching materials that are well-prepared, developed, and of good quality will affect the quality of learning implementation, which in turn will ultimately affect student learning outcomes [1], [2], [7]. Furthermore, the implementation of learning in vocational education needs to be adaptive to the developments that occur in the world of work or the industry. This is due to the objective of vocational education to produce graduates who are ready to work and have competency skills relevant to the industry's needs [3], [7].

The initial observations on the implementation of PLC learning at VHS of Pariaman revealed that the learning process was suboptimal, as evidenced by several problems encountered during the learning process, including (1) the absence of books or learning modules for students to use as references, resulting in learning being teacher-centered and the teacher's role being dominant while students appeared passive; (2) low student interest in participating in the learning process; and (3) the lack of learning modules that incorporate certain relevant industry-specific learning models.

The problems in implementing learning must be resolved promptly to achieve the objectives of vocational education optimally. The most prominent issue is the unavailability of learning modules that can enhance problem-solving and critical-thinking skills, which are essential for students when they enter the workforce. Currently, these skills are highly valued in the world of work or industry. Vocational education aims to produce graduates who have competencies relevant to the industry's needs and must promptly implement the learning that can improve students' critical thinking and problem-solving skills[1], [3], [8]. Previous studies have demonstrated that problem-based learning is an effective approach to enhancing students' critical thinking and problem-solving skills [9], [10]. Problem-based learning at each stage can trigger students' ability to solve problems and think critically [11], [12]. However, the successful implementation of problem-based learning depends on the availability of relevant learning modules and support for the learning application. The innovation proposed to address these issues is to compile and develop PBL-M.

This PBL-M is utilized in the PLC learning process as an effort to optimize the implementation of learning and attain the learning objectives. One of the assessments conducted in the analysis of effectiveness testing [7], [13]. The analysis of effectiveness testing is conducted to evaluate the extent to which the module has succeeded in achieving the set learning objectives and can aid in improving the quality of learning [7], [14]. The analysis of the effectiveness of learning modules aims to determine whether the modules can assist students in comprehending certain concepts or skills being taught, acquiring new abilities or skills, and enhancing their existing knowledge [10], [15].

This study aims to analyze the effectiveness of using PBL-M in the PLC learning process at VHS. The general objective is to determine the effectiveness of PBL-M in the PLC learning process at VHS, while the specific objectives are: (1) to assess students' understanding of PLC material before and after using the PBL-M; (2) to evaluate the impact of using PBL-M on students' problem-solving skills in PLC material; and (3) to determine the magnitude of the effect of using PBL-M on VHS students in the PLC learning process.

The results of this study have several contributions and benefits. Firstly, it can help to improve the quality of learning in vocational education by introducing innovative and effective learning models. Secondly, by introducing more effective learning methods, students are expected to develop better skills and understanding in learning and applying PLC technology. Thirdly, this study has produced PBL-M that can be effectively used in the PLC learning process in vocational schools, making them relevant to industry needs. Lastly, this research can contribute to the development of science, especially in the field of vocational education and PLC technology.

2. LITERATURE REVIEW

2.1. Problem-Based Learning Module

PBL-M is designed to facilitate learning through the solution of problems or the completion of specific tasks that simulate real-world situations[10], [15]. These modules emphasize the application of knowledge and skills in situations relevant to everyday life or actual work settings. PBL-M are frequently employed in vocational education, particularly in fields such as technology and engineering, as they help prepare students with problem-solving skills essential for real-world situations [4], [16]. Furthermore, PBL-M helps students to develop critical thinking skills, work collaboratively in groups, and make effective and appropriate decisions.

When developing PBL-M, module developers must ensure that the problems provided are relevant to the learning context, are appropriate for the level of student ability, and can facilitate active and participatory learning [4], [15]. This way, the PBL-M can help students achieve the learning objectives that have been set. The advantages of PBL-M are: (1) increased learning motivation, (2) improved problem-solving ability, (3) strengthened connections with the real world, and (4) encouraged cooperation and collaboration [12], [17]. In addition to these advantages, the project-based learning module used in the learning process also has disadvantages, namely: (1) requires more time to implement, (2) requires many resources in its application, and (3) requires good classroom management skills. Therefore, when developing a PBL-M, it is necessary to consider these shortcomings so that they can be minimized [17], [18].

2.2. PLC Learning Processes

The PLC is an electronic system utilized for process control in industrial and manufacturing environments. The PLC learning process is a mandatory component of the curriculum for VHS students studying Electrical Power Installation Engineering. The PLC learning process generally requires an understanding of the fundamental concepts of electronics, logic, and PLC programming [19], [20]. PLC is a complex technology and is often used in real-world industrial and manufacturing environments. Through the use of PBL-

M, students can gain a better understanding of how PLC work and develop the ability to solve problems related to PLC applications [20], [21].

The PLC learning process with PBL-M starts with providing problems or assignments that require students to identify, analyze, and solve problems using PLC. Once students understand the problem, they will be asked to identify the components involved in the problem and choose the appropriate management and control methods to solve the problem. By utilizing PBL-M, students can engage in more active and participatory learning, which can enhance their understanding of PLC. Moreover, the learning process with PBL-M can offer a safe and controlled environment for students to learn and practice, allowing them to experience real-world situations without the risk of causing damage or errors. Therefore, PBL-M can improve the effectiveness and efficiency of the PLC learning process.

3. METHOD

This study is an experimental research utilizing a Pre-experimental Design [22]. Pre-experimental design is a type of study that does not have a control group, and the sample is not randomly selected [16], [22]. The research design used in this study is the One-Group Pre-test-Post-test as shown in Figure 1 [7]. The pre-test is a test conducted before the implementation of the action research aimed to measure students' initial abilities before being given research actions (O1). The research action being tested in this study is the PLC learning process that applies a PBL-M for VHS (X) students. Post-test, on the other hand, is a test conducted after the research activities are carried out, aimed to measure students' final abilities after participating in the PLC learning process that applies PBL-M[7], [10], [23].

$$\boxed{O_1 \, X \, O_2}$$

Figure 1 Initial Path Model

The research instrument used in this study was a multiple-choice test used for the pre-test and post-test. The multiple-choice test was developed based on the dimensions and indicators presented in Table 1. The validity and reliability of the research instrument were tested. The validity of the instrument was tested using Pearson Product Moment Correlation analysis [24], [25], while reliability was analyzed using Cronbach's Alpha reliability analysis. The validity analysis showed that the value of the r count for all indicators was greater than the r table (> 0.361), indicating that all indicators in the research instrument are valid [24], [25]. The reliability analysis using Cronbach's alpha obtained a Cronbach's alpha value of 0.815. As Cronbach's alpha value is greater than 0.60 (0.815 > 0.600), the research instrument in the form of a multiple-choice test is considered reliable [7], [24], [25].

Table 1. Indicators of Research Instrument

No.	Basic Competencies	Competency Achievement Indicators	Item Numbers
1	1. Analyze the operating conditions of the PLC hardware system and components based on the operation manual	1.1 Explain the components of the PLC device based on the operation manual book 1.2 Determine the operating conditions of the system and components of the PLC device based on the operation manual 1.3 Characterizing the operating conditions of the PLC system and components	1,2,3,4,5
2	2. Analyzing Digital I/O PLC Relationships with external components	2.1 Describes the relationship between Digital I/O PLC and external components 2.2 Analyzing Digital I/O PLC Relationships with external components	6,7,8,9,10
3	3. Implement PLC configuration and set-up	3.1 Describe the configuration and setup of the PLC 3.2 Implement PLC configuration and set up	11,12,13,14,15
4	4. Define PLC Memory Map and I/O address	4.1 Explain PLC Memory Map and I/O addressing 4.2 Determine PLC Memory Map and I/O Addressing	16,17,18,19,20

A valid and reliable research instrument will be used to measure the level of students' cognitive understanding. The research instrument consists of multiple-choice test questions that were administered to students both before and after they were given research actions in the form of PLC learning using PBL-M. The data collected in this study pertains to student learning outcomes obtained from test results using the research instruments. The collected student learning outcomes are categorized as student learning outcomes in the cognitive domain. The research data is divided into two categories, pre-test data, and post-test data. Prior to conducting an effectiveness analysis, a normality test was carried out using the Kolmogorov-Smirnov Z normality analysis to ensure data normality [7], [25].

The effectiveness of PBL-M in the PLC learning process was assessed using two analytical techniques, namely paired sample t-test analysis, and Cohen's d Effect Size analysis. The paired sample t-test was used to determine whether there was a significant difference between the pre-test and post-test data [7], [25]. On the other hand, Cohen's d Effect Size analysis was used to determine the magnitude of its effectiveness [7], [25]. All data analyses were conducted using the SPSS computer-based data analysis application.

The effect size value obtained from Cohen's d Effect Size analysis is interpreted using the effect size criteria table to determine the effect category of the given research action, i.e., the PLC learning process using PBL-M. Based on the interpretation results, the effectiveness of the PBL-M used as a learning medium can be determined. The criteria for effect size based on Cohen's d value are presented in Table 2 [7], [25].

Table 2. Effect Size Criteria

No.	d Value Range	Categories
1	$0,8 \leq d \leq 2,0$	Big
2	$0,5 \leq d < 0,8$	Medium
3	$0,2 \leq d < 0,5$	Small

The research subjects of this study were one class of students from the electrical power installation engineering study program, comprising 36 students from VHS of Pariaman, Sumatera Barat, Indonesia. All 36 students participated in the study as one experimental group and followed the research procedures according to the research design, which involved the pre-test, intervention, and post-test.

4. RESULT AND DISCUSSION

4.1. Result

4.1.1. Problem-Based Learning Modules

The PBL-M is a learning approach that employs problems as a starting point for developing students' comprehension of a particular topic. Within the context of PLC learning in vocational education, PBL-M may be utilized to assist students in comprehending and mastering fundamental concepts related to PLC programming. In the PBL-M for PLC learning, students are introduced to problems or scenarios connected to the utilization of PLC in the industrial or manufacturing sector. They are then required to analyze the problem, find a solution, and apply PLC programming to address the problem. For instance, students may be presented with a problem on how to automate a conveyor system in a factory. They must comprehend the function of a PLC and subsequently devise an appropriate program to meet the conveyor system's requirements. In this case, the PBL-M can help students refine their problem-solving abilities and PLC programming skills in a practical and meaningful way. This research provides a detailed account of the PBL-M applied in the PLC learning process, including the following main points.

4.1.1.2. Cover Page

The cover page of the module includes several elements, including the title of the subject, class, the name of the compiler, the year of compilation, and pictures related to the subject.

4.1.1.2 Preface

The preface of the problem-based PLC Basic Operations learning module includes expressions of gratitude from the author to several parties who have contributed to the completion of the learning module preparation process.

4.1.1.3. Table of Content

The table of contents contains the framework of the learning module which is equipped with page numbers.

4.1.1.4. Chapter 1: Introduction

Chapter I of this module, there is an introduction section that includes a module description, requirements, instructions for module usage, final objectives, and basic competencies.

4.1.1.5. Bab II Learning Processes

In Chapter II, the PBL-M discusses the learning activities. The learning module consists of three activities which include Basic Competence (BC), Competency Achievement Indicators (CAI), learning objectives, and learning instructions. The learning instructions include the PBL syntax (observing, asking questions, gathering information, associating, and communicating), material description, summary, and formative tests.

4.1.1.6. Bab III Learning Evaluations

In Chapter III of the PBL-M, there is a learning evaluation conducted to assess the student's mastery of the material covered during the one-semester learning process. The evaluation comprises 30 multiple-choice questions designed to measure the extent to which students have understood the activities undertaken.

4.1.1.7. Bibliography

In the bibliography, all the reference sources used to create the teaching materials included in the problem-based PLC basic operation learning module are listed.

4.1.2. Research Data

The data obtained in this study are derived from the results of the multiple-choice test instrument, which is filled out by the student as the research subject. In accordance with the planned research design, data collection was conducted twice, namely prior to the research action (Pre-test) and after being given the research action (Post-test). The research activity conducted was the PLC learning process using a PBL-M as a learning media.

4.1.2.1 Pre-test Data

The pre-test is an initial test administered to students to assess their baseline abilities before receiving research treatment in the form of a PLC learning process using the PBL-M. Pre-test data were obtained through test results using research instruments that were given to all research subjects. The pre-test data are needed to conduct data analysis to determine the effectiveness of implementing PBL-M in the learning process.

The pre-test data analysis showed that the minimum score for student learning outcomes before using the PBL-M was 40 and the maximum score was 80, with an average score of 65 for 36 students and a standard deviation of 8.769. The normality test for pre-test data was conducted before analyzing the effectiveness using the effect size, and the results using the Kolmogorov-Smirnov Z formula are presented in Table 3.

The results of the normality test on the pre-test data presented in Table 3 indicate a significance value of 0.627, which is higher than the standard alpha value of 0.05. Therefore, it can be concluded that the pre-test data follows a normal distribution ($\alpha = 0.627 > 0.05$) [7], [25]. Thus, the pre-test data can be further analyzed to evaluate the effectiveness of the PBL-M in the PLC learning process.

4.1.2.2 Post-test Data

The post-test is the final assessment of student learning outcomes after completing the research activities, which is in the form of a PLC learning process that utilizes learning modules as learning media. The post-test aims to obtain data on the final abilities of research subjects after the research activity has been conducted. The post-test data were obtained through test results from each student using the research instrument. This post-test data complements the data used for the effectiveness analysis in addition to the pre-test data that was previously obtained.

The results of the post-test data analysis showed that the minimum score for student learning outcomes after using the PBL-M was 65 and the maximum score was 90. The average score for the 36 students was 80 with a standard deviation of 6.775. A normality test was conducted on the post-test data as a prerequisite for analysis before it could be used for effectiveness analysis using effect sizes. The results of the post-test data normality test using the Kolmogorov-Smirnov Z formula are presented in Table 4.

The results of the normality test on post-test data in Table 4 showed a significance value of 0.767 which is greater than the standard alpha value of 0.05. Hence, it can be concluded that the post-test data is normally distributed ($\alpha = 0.767 > 0.05$) [7], [25]. Consequently, the post-test data can be further analyzed, which is the analysis of the effectiveness of using PBL-M in the PLC learning process.

Table 3. The Results of Normality Test Analysis of Pre-test Data

		Pre-test Score
N		36
Normal Parameters[a,b]	Mean	65,00
	Std. Deviation	8,769
Most Extreme Differences	Absolute	0,100
	Positive	0,074
	Negative	-0,100
Kolmogorov-Smirnov Z		0,548
Asymp. Sig. (2-tailed)		0,627

a. Test distribution is Normal.

b. Calculated from data.

Table 4. The Results of Normality Test Analysis of Post-test Data

		Post-test Score
N		22
Normal Parameters[a,b]	Mean	80,00
	Std. Deviation	6,775
Most Extreme Differences	Absolute	0,135
	Positive	0,079
	Negative	-0,135
Kolmogorov-Smirnov Z		0,737
Asymp. Sig. (2-tailed)		0,649

a. Test distribution is Normal.

b. Calculated from data.

4.1.3. Effectiveness of PBL-M

The effectiveness of using PBL-M as a learning medium in the PLC learning process was initially evaluated through a paired sample t-test analysis to determine significant differences in student learning outcomes before and after following the PLC learning process using PBL-M. The results of the paired sample t-test analysis revealed that the t-value was greater than the t-table value (6.567 > 1.697) and the alpha significance value was less than 0.05 (0.000 < 0.05) [7], [25]. Therefore, it can be concluded that there is a significant difference between student learning outcomes on the pre-test and post-test [7], [25], [26], where student learning outcomes on the post-test were better than those on the pre-test. This is supported by the higher post-test average compared to the pre-test average (80 > 65). Thus, it can be concluded that PBL-M is an effective learning medium in the PLC learning process for VHS students.

The effect of using PBL-M as a learning medium in the PLC learning process was analyzed using Cohen's d Effect Size analysis. The effect size analysis between the pre-test and post-test data resulted in an effective index value of 1.75 (d = 1.75). Interpreted with the effect size criteria table, this effect is considered to have a large/high category influence. The results of the effect size analysis and the interpretation of the effect size categories indicate that PBL-M is an effective learning medium in the PLC learning process, with a high/large magnitude of effect. Thus, the use of PBL-M in the learning process can be an option for implementing effective learning in vocational education, especially at the VHS level.

4.2. Discussion

The PBL-M is a learning approach that utilizes problems as a starting point to enhance students' comprehension of a particular subject matter. In the context of PLC learning in vocational education, PBL-M can be utilized to aid students in understanding and mastering fundamental concepts associated with PLC programming[19], [20]. In PBL-M for PLC learning, students will be presented with problems or scenarios related to the utilization of PLC in the industrial or manufacturing field [19]–[21]. They will then be required to analyze the problem, devise a solution, and apply PLC programming to resolve the issue. For instance, students could be presented with a problem of how to automate a conveyor system in a factory. They must comprehend the role of a PLC and then develop an appropriate program to meet the requirements of the conveyor system [4], [16], [23], [27]. In this case, the PBL-M can help students refine their problem-solving abilities and PLC programming skills in a practical and meaningful manner [4], [16].

The results have shown that the PBL-M was effective as a learning medium in the PLC learning process at the vocational school (VHS) level, with a large effect in the high/large category. The effectiveness of this project-based learning module is supported by two analytical results: (1) there is a significant difference in student learning outcomes before and after using the PBL-M, where the learning outcomes after using the PBL-M are better than before using the problem-based learning module; (2) the effect size criterion indicates that the effect size of the use of the PBL-M in the PLC learning process falls under the large/high category. Moreover, the PBL-M has the potential to increase students' interest and motivation in the learning process. This learning method can also be considered an alternative choice for implementing effective and innovative learning in vocational education[4], [12], [16]. The use of PBL-M as a learning medium at the secondary education level would lead to a more diversified learning process, thereby increasing students' interest and motivation in the learning process[12], [17], [18].

5. CONCLUSIONS

PBL-M can serve as a tool to aid students in understanding and mastering the fundamental concepts of PLC programming. In PBL-M for PLC learning, students are presented with problems or situations that are relevant to the application of PLC in the industrial or manufacturing industry. The study demonstrated that PBL-M was effectively employed as a learning medium in the PLC learning process at VHS, with the effect size categorized as high/large. This finding indicates that

PBL-M has the potential to enhance student learning outcomes in the learning process, making it a viable alternative for implementing innovative and effective learning in vocational education.

The limitations of this study are: (1) The study subjects were limited to only VHS students in the electrical power installation engineering expertise program. Thus, more complex research with different subjects is necessary to generalize the results of this study to a wider population of vocational students; (2) This study only measures the effectiveness of PBL-M in the PLC learning process at VHS. Therefore, further research is needed to examine the effectiveness of PBL-M on different subjects or topics in vocational education; (3) This study only measured student learning outcomes after using PBL-M. Thus, it cannot be concluded with certainty that PBL-M has a long-term impact on students' understanding of PLC learning concepts. Future research directions for this study include: (1) Developing more specific and complex PBL-M for PLC learning in vocational high schools, covering more topics and diverse case studies as follow-up research; (2) Broadening the research subject by involving students from different vocational high schools in a wider area in future studies; (3) Measuring the long-term impact of using PBL-M on students' understanding and mastery of PLC learning concepts, both in the context of education and the industry, in future studies.

AUTHORS' CONTRIBUTIONS

Conceptualization: H., D.T.P.Y, Z.L.; Methodology: H. & D.T.P.Y.; Validation: H., D.T.P.Y., Z.L.; Formal Analysis: H. & Z.L.; Original Draft Preparation: D.T.P.Y. & Z.L.; Writing Review and Editing: H. & D.T.P.Y.

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