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Effectiveness of Problem-Based Learning Model on Students' Learning Outcomes in Embedded Systems Subject

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Abstract

This study aims to evaluate the effectiveness of implementing the Problem-Based Learning (PBL) model in enhancing student learning outcomes in the Embedded Systems course at State Vocational High School (SMKN) 10 Makassar. Traditional lecture-based teaching methods, which still dominate learning activities, are considered less effective in promoting student engagement and deep understanding of the material. To address this limitation, the PBL approach was introduced as an alternative that emphasizes real-world problem-solving and student collaboration. The research employed a quasi-experimental design involving two groups: an experimental group that applied the PBL model and a control group that continued with conventional instructional methods. A validated multiple-choice test, reviewed by subject-matter experts, was used to assess students' cognitive performance. The findings demonstrate that the application of PBL significantly enhanced learning outcomes. The experimental group achieved a mean post-test score of 19.19, notably higher than the control group's average score of 12.96. Results from the t-test analysis indicated a statistically significant difference between the two groups (t = 9.821 > t-table = 1.669). Furthermore, the N-Gain score for the experimental group was categorized as moderate (0.53), while the control group's gain was classified as low (0.15). These results highlight that the PBL model not only strengthens students' conceptual mastery but also fosters critical thinking abilities and better prepares them to meet challenges in technology-oriented work environments. This study offers valuable insights for enhancing instructional practices within vocational education settings.

Keywords: Problem-Based Learning; Learning Outcomes; Embedded Systems; Vocational Education; Critical Thinking.

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Introduction

Education has a very strategic role in producing a superior, independent generation that is ready to face global challenges (Pakpahan et al., 2023). In the era of the Industrial Revolution 4.0 combined with the concept of Society 5.0, the education system is no longer sufficient in just teaching content mastery, but must also be able to develop 21st-century skills (Aprilisa, 2020). These skills include critical thinking, problem solving, collaboration, communication, creativity, and digital and technological literacy (Jayadi et al., 2023). This change requires reform in learning strategies to suit the needs of the world of work and the dynamics of digital society (Limbong et al., 2024).

The Ministry of Education, Culture, Research, and Technology responded to this challenge by implementing the Independent Curriculum (Mun'amah, 2023; Langoday et al., 2024). This curriculum gives freedom to educational units to design project-based, differentiated, and contextual learning according to the needs of students (Sembiring, 2022; Sappaile et al., 2024). Conventional learning models that are centered on teachers and have minimal active interaction from students are considered no longer relevant in the context of today's education (Fitrianti et al., 2024; Yanti et al., 2024). Therefore, the transformation of learning approaches is a necessity (Gilbert & White, 2018; Hasanah & Haryadi, 2022).

At State Vocational High School (SMKN) 10 Makassar, learning in the Embedded Systems subject is still dominated by lecture and demonstration methods from teachers. This causes students to only act as recipients of information, without being actively involved in the exploration and problem-solving process. This situation has an impact on low student participation, weak problem-solving skills, and a lack of conceptual understanding, especially in materials that require the application of logic and embedded system programming techniques. These problems require a learning model that is able to activate students cognitively, affectively, and psychomotorically. One model that is considered

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capable of answering this challenge is Problem-Based Learning (PBL). Problem Based Learning (PBL) is an innovative teaching approach that improves critical thinking skills and independent learning through solving real-world problems (Saputra et al., 2019). PBL emphasizes communication, collaboration, and the use of resources to develop reasoning skills (Susetyarini et al., 2022). This model has proven to be effective in building high-level thinking skills, especially in the context of 21st-century learning, because it supports the integration of critical and collaborative thinking skills simultaneously (Dewi et al., 2024). According to Barrows et al. (1980), PBL has main characteristics such as the existence of real problems as learning triggers, collaborative processes between students, and reflection on the learning process. In the context of vocational education, PBL is very relevant because it integrates practical and theoretical skills in facing the challenges of the world of work.

Recent studies have shown the effectiveness of Problem-Based Learning (PBL) in improving higher-order thinking skills and student learning outcomes at various levels of education. PBL significantly improves critical thinking, analysis, and problem-solving skills in both primary and secondary education (Abdullah & Munawwaroh, 2024). Research shows that PBL has a positive impact on students' ability to identify problems, analyze information, and develop solutions logically (Ramadhani & Sukenti, 2023). In addition, PBL also improves collaboration skills and creates a more interactive and contextual learning environment (Kamid & Sinabang, 2019). Although there are challenges, such as time constraints, proper teacher training, and curriculum adjustments, can overcome these obstacles, making PBL an effective model in preparing students to face the challenges of the 21st century (Naufal et al., 2024). Based on the results of the researcher's observations during the implementation of the Merdeka Belajar Kampus Merdeka (MBKM) program at SMKN 10 Makassar, it was found that most students still showed high dependence on teacher explanations and were not yet able to work effectively in groups. The learning process did not provide enough space for students to explore, ask questions, and develop solutions to the problems they faced. This indicates a gap between the learning approach applied and the actual needs of students in the digital era.

Therefore, the implementation of the PBL model is expected to be a solution to overcome these problems. By providing challenges in the form of case studies or real problems that are relevant to the industrial world, students are expected to be able to think critically, develop problem-solving strategies, and collaborate in completing joint projects. Learning activities are not only focused on achieving academic grades, but also on character building and work competencies. The urgency of implementing PBL in Embedded Systems subjects is not only aimed at improving understanding of technical materials, but also encouraging the creation of meaningful learning that equips students with the ability to think and act independently. The advantage of this model lies in its learning process, which encourages active involvement, independent information search, group discussions, and joint evaluations. This process not only enriches students' learning experiences but also develops soft skills that are very much needed in the world of work.

The purpose of this study was to determine the effectiveness of the Problem-Based Learning model in improving student learning outcomes in the Embedded System subject at SMKN 10 Makassar. In addition, this study also aims to provide an empirical overview of the application of PBL in the context of vocational education, as well as provide practical recommendations for teachers and policymakers in developing adaptive and transformative learning models. Through this research, it is expected to provide a real contribution to the development of learning strategies in vocational schools, especially in facing the challenges of implementing the Merdeka Curriculum and the demands of the 21st-century world of work. This research is also expected to be a reference in the application of a more relevant, participatory, and contextual learning approach in the era of competency-based education.

Method

The type of research used in this study is quantitative research with a quasi-experimental approach. This approach was chosen because it allows researchers to evaluate the effect of a treatment on a particular variable, although not all ideal conditions of a pure experiment can be met, such as full randomization of subjects (Abraham & Supriyati, 2022; Krass, 2016). Quasi-experimental research still provides quite high validity in identifying cause-effect relationships, especially in the educational context, where strict control of variables is often difficult due to practical limitations in the field (Shadish, 2005; Yuwanto, 2019).

The specific design used in this study is the Non-Equivalent Control Group Design. This design involves two groups, namely the experimental group that receives a certain treatment and the control group that does not receive the treatment (Mohr, 1982; Mulyatiningsih, 2015). The two groups were not selected randomly, but were determined based on existing classes (Hong, 2010). Therefore, it is important to ensure that the initial characteristics of the two groups are comparable, which is usually done through prerequisite tests such as the homogeneity test and the normality test.(Ojeda, 2024). With this design, researchers can compare the results between the two groups after treatment is given, thus allowing for an objective and systematic analysis of the effectiveness of the treatment (Krishnan, 2019).

The study was carried out at SMKN 10 Makassar during the even semester of the 2024/2025 academic year. The research population included all eleventh-grade students majoring in Industrial Electronics Engineering. Two classes were selected as samples: class XI TELI 1 served as the experimental group, consisting of 31 students, while class XI TELI 2 acted as the control group, comprising 32 students. A 25-item multiple-choice test was utilized as the data collection instrument. The instrument underwent validation by two experts specializing in engineering education. Its validity was assessed using product-moment correlation analysis, while reliability was determined through Cronbach's Alpha, yielding a coefficient of 0.722, which indicated a high level of reliability. The research procedure began with the administration of a pretest to both groups. Subsequently, the experimental group received instruction using the Problem-Based Learning (PBL) model, whereas the control group continued with conventional teaching methods. Upon completion of the instructional period, a posttest was administered to both groups. The collected data were analyzed using normality and homogeneity tests, independent t-tests, and N-Gain analysis to evaluate the improvement in students' learning outcomes. An overview of the study design is presented in Table 1.

Table 1. Quasi-experimental research design

Group	Pretest (O1)	Treatment (X)	Posttest (O2)
Experiment (TELI 1)	√	√	√
Control (TELI 2)	√	-	√

Information:
O_1: Pretest before treatment
X: Treatment using the PBL model
O_2: Posttest after treatment

The selection of the PBL model in this study is based on its relevance in improving students' critical thinking skills, collaboration, and analytical abilities in solving real problems, especially in Embedded System learning, which requires integration between theoretical concepts and technical practices. Therefore, this method is considered appropriate to answer the needs of competency-based learning in the Merdeka Curriculum era.

Results and Discussion

Results

This section provides a detailed analysis of the collected data, encompassing instrument validation and reliability, descriptive statistics, and inferential analysis. The primary objective is to assess the impact of the Problem-Based Learning (PBL) model on enhancing student achievement in the Embedded Systems course at SMKN 10 Makassar.

Instrument Validity
Validity reflects the extent to which an instrument accurately measures the intended construct. The validation process was carried out in two stages:

a. Content Validity via Expert Review
   The test instrument, consisting of 25 multiple-choice items, was evaluated by two experts specializing in engineering education. The validation focused on three aspects: content relevance, question construction, and language clarity. The experts' assessments yielded an average score of 3.57 on a 4-point scale, categorizing the instrument as "very valid," in accordance with the criteria proposed by (Sahir & Koryati, 2021).
b. Empirical Validity (Construct) through Product-Moment Correlation
   Following expert validation, the instrument was trialed with 30 students. Data were analyzed using SPSS version 26, employing Pearson's Product-Moment correlation. The results revealed that each item's calculated r-value exceeded the critical r-value of 0.361 at a 5% significance level, confirming that all items met the criteria for statistical validity.

Reliability Test

The reliability assessment utilized Cronbach's Alpha, processed through SPSS 26. The analysis produced an Alpha coefficient of 0.722, surpassing the critical r-value of 0.355. These findings demonstrate that the instrument exhibits strong internal consistency, making it appropriate for assessing student performance on both pretest and posttest measures (Sujarweni, 2014).

Descriptive Statistical Analysis

The experimental group's mean pretest score was 12.42, which increased to 19.19 on the posttest. In contrast, the control group's average pretest score of 10.84 rose to 12.96 post-intervention. These results suggest that students exposed to the PBL model experienced more substantial learning gains.

Normality and Homogeneity Test

The Shapiro-Wilk normality test indicated that the data followed a normal distribution ($p > 0.05$). Similarly, the homogeneity test produced p-values above 0.05, confirming that the data sets exhibited homogeneous variances.

Independent t-test Analysis

The independent t-test revealed that the calculated t-value (9.821) exceeded the critical t-table value (1.669), with a significance level of 0.000 ($p < 0.05$). This outcome indicates a statistically significant difference in learning outcomes between the experimental and control groups. As the calculated t-value was greater than the t-table value and the p-value was less than 0.05, the null hypothesis (H_0) was rejected, confirming the significant positive effect of the PBL model on student learning outcomes.

N-Gain Analysis

The results of the quantitative analysis of the effectiveness of the PBL model, the N-Gain calculation was carried out as in Table 2.

Table 2. Results of the analysis of the effectiveness of the PBL model

Group	Pretest	Posttest	N-Gain	Category
Control	10.84	12.96	0.15	Low
Experiment	12.42	19.19	0.53	Currently

The N-Gain score for the experimental group reached 0.53, placing it within the medium improvement category, while the control group obtained a score of only 0.15, categorized as low. This indicates that students exposed to the PBL model experienced a more substantial improvement in learning outcomes compared to those in the conventional learning group. The findings suggest that the application of the PBL approach contributes to a more meaningful and effective enhancement of students' academic performance.

Discussion

The Problem-Based Learning (PBL) learning model has been proven to have a significant positive impact in improving students' conceptual understanding. Through an approach that places contextual problems as the starting point of learning, students are encouraged to be more active in the critical thinking process, analyze problems, explore information independently, and formulate solutions based on logic and evidence that can be accounted for. Learning activities are no longer one-way, but have become interactive, where students are involved in group discussions, share perspectives, and build knowledge collectively. PBL naturally creates a collaborative and participatory learning environment. Through discussion and exploration, students not only strengthen their conceptual understanding but also develop social skills, communication, and the ability to work in a team. This is in line with the view Abraham & Supriyati (2022), which emphasizes the importance of designing learning that allows students to play an active and reflective role in constructing their own knowledge.

The improvement in learning outcomes obtained in this study also indicates that the PBL model is very relevant to be applied in the context of vocational education. Subjects such as Embedded Systems, which require an understanding of programming logic, technical problem solving, and integration of abstract concepts with real-world practices, are greatly assisted by the application of PBL. With project-based learning scenarios and case studies, students gain hands-on experience in solving real-world challenges, which ultimately leads to an improvement in their cognitive and technical abilities. Furthermore, these results confirm that the PBL approach is not only effective in the cognitive aspect, but also contributes to strengthening soft skills that are highly needed in the modern workplace, such as collaboration, leadership, and time management. Therefore, the implications of these findings are very strategic, namely the need to adopt the PBL model more widely in vocational learning systems, especially in the era of Industry 4.0 and Society 5.0 which require adaptive and problem-solving learners.

Research shows that Project-Based Learning (PBL) and Problem-Based Learning are effective approaches for vocational education in the 21st century. A meta-analysis of 23 studies found that PBL had a high effect size (1.09) in vocational education, indicating its effectiveness in preparing students for the world of work (Fadillah et al., 2021). Implementation of PBL in desktop programming courses significantly improves student learning outcomes and engagement (Sopandi, 2019). A literature review of 29 articles also revealed that PBL can improve pre-vocational skills, student engagement, and learning motivation in Vocational High Schools (Fitri et al., 2025). In addition, a study on vocational students in Bekasi found that Problem-Based Learning was effective in ensuring mastery of competencies (Rizaldi & Putri, 2021). These findings as a whole indicate that PBL and Problem-Based Learning are highly relevant for vocational education, especially in developing critical thinking skills, practical skills, and preparing students to face the challenges of the Industry 4.0 era.

However, the effectiveness of PBL implementation is greatly influenced by the teacher's pedagogical competence. Teachers are required to have the ability to design authentic and challenging problem scenarios, be able to facilitate group dynamics effectively, and provide targeted guidance without reducing student independence. Therefore, ongoing training is needed for educators so that they are ready to adopt the role of effective learning facilitators in the PBL model. Thus, the results of this study not only confirm the benefits of PBL in improving student learning outcomes but also provide practical recommendations for teacher professional development and strengthening active learning-based curriculum policies in vocational schools.

Conclusions and Suggestions

Conclusions

Based on the results of data analysis and discussion that have been carried out, it can be concluded that the application of the Problem-Based Learning model has a positive and significant influence on student learning outcomes in the Embedded System subject at SMKN 10 Makassar. This is evidenced by the increase in the average post-test score of students and the results of statistical analysis, which show a significant difference between the experimental class and the control class. In addition, the results of the N-Gain analysis also show that the increase in student learning outcomes in the experimental class is in the moderate category, while the control class is in the low category. This finding strengthens the argument that a student-centered and problem-solving-based learning approach is more effective in improving the quality of vocational learning.

Suggestions

1. Teachers are advised to integrate the Problem-Based Learning model in the learning process, especially in subjects that are practical and applicable.
2. Schools should provide training or workshops to teachers to improve their understanding and skills in implementing the PBL model optimally.
3. Further research can be conducted by expanding the variables studied, such as the influence of PBL on learning motivation, creative thinking skills, and student collaboration.
4. The development of PBL-based learning modules in various subjects can be a strategic step in supporting the Independent Curriculum.
5. It is necessary to replicate the research at different levels and educational contexts to see the consistency of the results and the expansion of the application of the model.

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