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Project Based Learning in the Subject of Embedded System Programming: Students' Conceptual Understanding and Learning Outcomes

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ABSTRACT

This research is motivated by the low conceptual understanding and learning outcomes of students in the Embedded Systems Programming subject, which is often considered difficult due to the complexity of the material. The main objective of this study is to determine the effectiveness of the project-based learning model (PjBL) in improving conceptual understanding and learning outcomes among students at Vocational School 10 Makassar. The method used is a quasi-experiment with a Nonequivalent Control Group Design. The study population comprises all students from Vocational School 10 Makassar, with samples deliberately chosen: class XI Teli 1 serving as the experimental group and class XI Teli 3 as the control group. Data were collected through test instruments (pre-test and post-test) and student activity observation sheets. The findings showed a significant increase in the experimental class compared to the control class. The experimental class's average score on the post-test went from 41.36% to 83.10%, while the control class's score went from 42.66% to 45.62%. The t-test results showed a significance value <0.05, proving that the PjBL model effectively improved student learning outcomes. This research contribution provides recommendations for educators to implement the PjBL model sustainably as an innovative solution in teaching complex technical materials and its development in other subjects to improve the quality of vocational education.

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1. INTRODUCTION

Entering the era of the Industrial Revolution 4.0 and Society 5.0, the world of education, particularly vocational high schools, faces increasingly complex challenges (Ali, 2021; Mourtzis et al., 2022). The integration of physical systems, computing, and networks demands that vocational high school graduates possess high technical competencies, particularly in the fields of automation and intelligent systems (Fitrihana et al., 2024; Vieira et al., 2022). One of the key pillars of future technology is embedded systems (Rosca, 2024). However, the reality on the ground shows that the gap between the competencies taught in schools and industry needs remains quite wide.

Vocational education ought to be the principal catalyst in cultivating a proficient workforce (Yoto et al., 2024). However, conventional teacher-centered teaching methods often fail to equip students with real problem-solving skills (Martin-Alguacil et al., 2024). This impacts the low competitiveness of vocational high school graduates in the global job market. One of the hardest classes in vocational high schools that offer Industrial Electronics Engineering or Computer and Network Engineering is Embedded Systems Programming (Bal et al., 2024). This subject requires mastery of multidisciplinary skills: programming logic, microcontroller architecture, and an understanding of hardware.

A common problem is that students tend to memorize code syntax without becoming familiar with the basic concepts of how the code interacts with physical components (Morales-Navarro et al., 2025). This weak conceptual understanding results in students struggling when faced with system modification or troubleshooting scenarios (Qian & Lehman, 2017). Without a strong conceptual understanding, student learning outcomes typically stagnate at the lower cognitive level (C1-C2), rather than at the application or creation level (C4-C6).

In a preliminary study by the author with observations at vocational school 10 Makassar, it was found that lectures and structured practice exercises still dominate the learning process. Students often feel bored and unmotivated because they don't see the direct relevance between the lines of code they write and solutions to real-life problems. Grade data shows that the average student learning outcome is still below the minimum completion criteria. This is exacerbated by limited active interaction between students in exploring independent projects.

The Project-Based Learning (PjBL) model has emerged as a promising alternative. PjBL is a student-centered learning model that organizes learning around projects (Ali et al., 2025; Fanani & Rizal, 2025; Wansyah et al., 2025; Yuyung, 2025). In the context of embedded systems, PjBL allows students to build real-world products, such as an automated plant watering system or an IoT-based home security system (Bunyamin, 2023). Through PjBL, students learn not only "what" a microcontroller is, but also "how" to use it to solve problems. The process of designing, assembling, and testing the project creates a deep learning experience. Group work in PjBL also fosters soft skills such as collaboration and communication, which are crucial in the workplace (Busnawir et al., 2025).

It is important to distinguish between simply "knowing" and "understanding conceptually." Conceptual understanding in embedded systems encompasses knowledge of data flow, interruptions, memory management, and sensor-actor integration. This study emphasizes that learning success is measured not only by final exam scores (learning outcomes), but also by the transformation in students' thinking in constructing technical solutions.

Although extensive research on PjBL has been conducted (Alhayat et al., 2023; Azzahra et al., 2023; Saad & Zainudin, 2022), this article has several novelties that distinguish it from previous research. Much PjBL research focuses on general subjects or science (Markula & Aksela, 2022; Wardah et al., 2022). This research specifically addresses the realm of embedded systems, which possess unique characteristics of tight hardware-software integration, and require the simultaneous synthesis of programming logic and circuit understanding. This research not only measures students' final grades (cognitive aspects) but also examines how PjBL impacts the structure of students' conceptual understanding of complex system architectures. Furthermore, this research fills a gap in the literature regarding the effectiveness of active learning models in vocational high schools in Eastern Indonesia, which face specific infrastructure challenges and student input backgrounds.

The urgency of implementing the PjBL model in the Embedded Systems Programming course at Vocational School 10 Makassar cannot be postponed any longer. This effort represents a strategic step to shift the learning paradigm from mere knowledge transfer to a competency construction process. It is hoped that the results of this research can serve as a reference for schools and teachers in implementing learning strategies that can improve student competitiveness in the future technological era.

2. METHOD

This study used a quantitative approach with a quasi-experimental design, a Nonequivalent Control Group Design, to test the effect of the Project-Based Learning (PjBL) model on student learning outcomes. The study was conducted in the odd semester at Vocational School 10 Makassar, Makassar City. The study design involved two groups: an experimental group learning using the PjBL model and a control group learning using conventional learning. The following is a nonequivalent control group design in Figure 1.

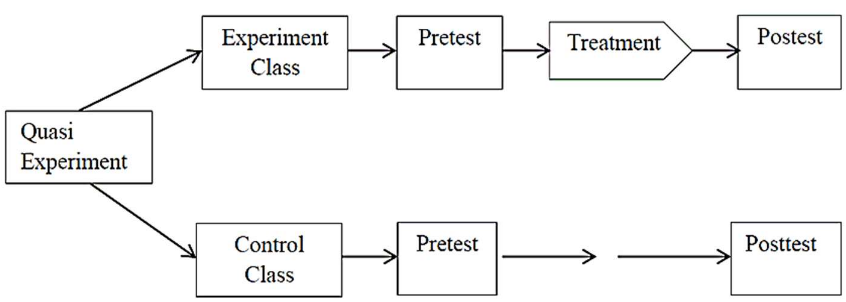

Figure 1. Nonequivalent Control Group Design

The study population was all students at Vocational School 10 Makassar. The sample was selected using a purposive sampling technique, considering class characteristics that aligned with the research objectives. The sample consisted of 52 students divided into two classes: 29 students from class XI Teli 1 as the control group and 23 students from class XI Teli 3 as the experimental group. The independent variable in this study was the learning model (PjBL for the experimental group and conventional for the control group), while the dependent variable was student learning outcomes, measured through pre-tests and post-tests.

The research instrument consisted of a multiple-choice or descriptive learning outcome test and an observation sheet to assess the implementation of the PjBL program. The instrument was validated through expert judgment by two validators, both lecturers in electronic engineering education. Validation was done on three levels: construction, material, and language, with a scale of 1 to 4. Validation results showed that validator 1 gave an average score of 3.77 (very valid) and validator 2 gave an average score of 3.66 (very valid), thus declaring the instrument suitable for use.

Data collection was conducted using three techniques. First, participant observation watches the PjBL learning process in the classroom and records student interactions, the role of the educator, and class dynamics. Second, a pre-test was administered before the treatment, and a post-test was administered after the treatment to both groups to measure learning outcomes. Thirdly, a documentation study was conducted to gather supporting data, specifically documents on the learning process and student project results.

Data analysis used a t-test with the aid of statistical software. Before the t-test was conducted, the data were tested for normality and homogeneity to ensure that parametric requirements were met. The independent sample t-test is used to compare learning outcomes between the experimental group and the control group.

3. RESULTS AND DISCUSSION

Results

To assess the enhancement in student learning outcomes via the implementation of the PjBL model, researchers administered a preliminary test (pre-test) and a concluding test (post-test) to both the experimental and control groups.

Table 1. Pre-test and Post-test Results of the Experimental and Control

No	Group	Average Pre-test Score	Post-test Average Score	Point increase
1.	Experiment	41,36%	83,17%.	18 points
2.	Control	42,66%	45,61%	3 points

Table 1 indicates that the mean pre-test score for students in the experimental group was 41.36%, but the mean post-test score rose to 83.17%. This signifies an 18-point enhancement following the implementation of the PjBL model. This enhancement signifies that students demonstrated considerable advancement in their comprehension following engagement in project-based learning.

In contrast to the experimental class results, the control class, which employed traditional learning methods, achieved an average pre-test score of 42.66% and a post-test score of 45.61%, suggesting no significant improvement post-test.

Table 2. Two-class Normality Test Results

Group	Statistics	Sig. (p)	Information
Pre-test Experiment	Shapiro-Wilk	0.188	Normal

Group	Statistics	Sig. (p)	Information
Post-test Experiment	Shapiro-Wilk	0.183	Normal
Pre-test Control	Shapiro-Wilk	0.73	Normal
Control Post-test	Shapiro-Wilk	0.121	Normal

According to the significance values in the Shapiro-Wilk table, all pre-test and post-test data in both the experimental and control groups had a Sig. value over 0.05. Consequently, it can be inferred that the data exhibits a normal distribution.

Table 3. Results of the two-class homogeneity test

Variable	Levene Statistics	Sig. (p)	Information
Experimental Pre-test and Control Pre-test	0.615	0.437	Homogeneous
Experimental Post-test vs. Control Post-test	3.716	0.60	Homogeneous

The homogeneity test findings in the Based on Mean section yielded a significant value (Sig.) of 0.437. Since the significance value exceeds 0.05 (0.437 > 0.05), it can be inferred that the data exhibits homogenous variance. The pre-test data of both classes exhibit same variance. The Homogeneity test results in the Based on Mean row yielded a significant value (Sig.) of 0.60. This number exceeds 0.05 (0.60 > 0.05), indicating that the variances of both data groups are homogeneous. Consequently, the post-test data satisfies the assumption of homogeneity.

Table 4. Independent Sample T-Test Results

Variable	t	df	Sig. (2-tailed)	Information
Experimental Post test vs Control Post-test	9.772	50	0.60	There is a significant difference

According to Levene's Test for Equality of Variances, a significant value of 0.060 (> 0.05) was achieved, indicating that the variances of both groups are homogeneous; hence, the decision-making will utilize the Equal variances assumed row. The t-test findings indicate that the significance value (Sig. 2-tailed) is <0.001 (<0.05), demonstrating a significant difference between the learning outcomes of the experimental class and the control class.

Tabel 5. Uji Paired Sample t-Tes

Variable	t	df	Sig. (2-tailed)	Information
Control Post-test vs Experiment Post-test	-16.988	22	<0.001	There is a significant difference

The paired sample t-test yielded a significance (2-tailed) value of <0.001 (<0.05), showing a substantial difference between the pre-test and post-test scores in the experimental group. Consequently, the application of the project-based learning paradigm significantly enhanced conceptual comprehension and student performance outcomes. The computed t-value in the paired sample t-test was negative due to SPSS determining the difference as pre-test minus post-test. This discrepancy yielded a negative value, as the post-test score exceeded the pre-test score.

Observations indicated that the student activity component was exceptionally effective. Students attentively listened to the teacher's explanations, participated in discussions, collaborated in groups, identified components based on their roles, produced reports, and presented the outcomes of group work. This signifies that the execution of the project-based learning model was successful and corresponds with the intended learning objectives. The application of the PjBL model enhanced student participation and active engagement in learning.

A score of 27-28 was derived from the observations of teacher activity undertaken by four observers. The conversion to percentages produced a score between 96.42% and 100%, all of which were placed in the very effective group.

Despite uniformity in the scoring of indicators among all observers, discrepancies were evident in the observation ratings. This results from the dynamic nature of learning observations, enabling observers to capture varying moments and intensities of activity. The disparities fall within an acceptable range and do not suggest substantial variations in significance. Additionally, the elevated degree of student engagement and activity, as evidenced by the observation sheets, and the enhancement in learning outcomes reflected in the pre- and post-test findings, substantiates the successful execution of PjBL.

Discussion

The study's results indicated a substantial improvement in student learning outcomes in experimental class relative to the control class. The measurements indicate that the experimental class exhibited a substantial enhancement in learning outcomes following the implementation of the PjBL paradigm. Concurrently, the control group observed a slight increase. The disparity in performance between the two classes suggests that the application of the PjBL model facilitates a significantly superior enhancement of conceptual comprehension relative to traditional learning methods.

The t-test results indicated a statistically significant value of <0.001, establishing that a notable difference existed in student learning outcomes before and after the treatment, as well as between the experimental and control groups. This finding aligns with research Goyal et al. (2022) demonstrating that PjBL improves conceptual understanding through exploration, investigation, and real-world problem-solving activities. Project-based learning requires students to understand subjects not only declaratively but also procedurally and applicatively, thereby deepening their comprehension through real-world applications.

Observations indicate that student engagement in the experimental class yielded an average score between 80 and 90, categorizing it as satisfactory to excellent. Students participated actively in discussions, collaborative work, project creation, execution, and presentations. This heightened activity illustrates that project-based learning cultivates active student engagement, encourages participation, and instills a sense of responsibility in fulfilling project tasks. This observation corresponds with a study

Gaviria Alzate et al. (2025), which indicates that enhanced collaboration reflects students' cooperative efforts and social interactions, a vital component of active involvement within a socio-constructivist framework. Project-Based Learning (PjBL) facilitates social engagement, group discourse, and collective accountability (Sugiyanto et al., 2020).

Moreover, the problem-solving and collaboration-focused attributes of PjBL facilitate the cultivation of 21st-century competencies, including critical thinking, creativity, cooperation, and communication. Consequently, the application of Project-Based Learning (PjBL) can enhance both conceptual comprehension and social competencies, as well as foster students' autonomy in learning.

The findings indicated a substantial rise of 18 points in post-test scores among students in the experimental class utilizing the Project-Based Learning (PjBL) approach. This illustrates the efficacy of Project-Based Learning (PjBL) in enhancing conceptual comprehension and student performance outcomes. These findings correspond with Sappaile et al. (2023) research, which shows that constructivism-based project-based learning enhances students' conceptual comprehension and collaborative abilities. Project-Based Learning (PjBL) markedly enhances students' conceptual comprehension relative to traditional methods, chiefly because of students' active engagement in problem investigation, collaborative discussions, and project execution that necessitate the application of real-world concepts. These findings substantiate the assertion that Project-Based Learning (PjBL) is efficacious in promoting meaningful learning (Almulla, 2020), wherein students actively construct knowledge rather than passively assimilating information through real learning situations. Project-Based Learning (PjBL) is an exceptionally successful educational technique, demonstrated to significantly enhance learning skills (Tafakur et al., 2023). The primary benefit of PjBL is its capacity to integrate real-world scenarios from the field into the educational experience. This technique is particularly beneficial as it enables students to collaborate in teams, plan, organize, negotiate, and eventually convert their ideas into concrete, experimentally derived outcomes.

The findings of this study align with theoretical frameworks and prior research, indicating that Project-Based Learning (PjBL) is beneficial in enhancing conceptual comprehension and student performance in practice-oriented disciplines (Hidayat et al., 2025). The enhancement in conceptual understanding and learning outcomes can be attributed to several factors: necessitating active student engagement in the learning process, promoting experiential learning, offering opportunities to apply programming concepts to real-world projects, fostering critical thinking, creativity, and collaboration skills, encouraging autonomous and exploratory learning, and motivating students through the creation of tangible products.

In embedded systems education, students require not only theoretical comprehension but also the ability to create, test, and enhance programs and devices. PjBL facilitates this process. This observation corresponds with Vygotsky's constructivist theory, which posits that knowledge is constructed via activity, interaction, and experiential learning, rather than through passive instruction (Mitry, 2021; Zajda, 2021).

Additionally, research findings indicate that the implementation of the PjBL model markedly enhances student learning outcomes in embedded systems programming courses. The increase in the average post-test score of the experimental class indicates a significant difference in learning outcomes between students instructed through PjBL and those taught via conventional methods, as demonstrated by the t-test results, which reveal a significant value of less than 0.05. This affirms that Project-Based Learning (PjBL) is superior to traditional education in enhancing content mastery and fosters students' conceptual comprehension. By engaging in project design, coding, and testing of embedded system programs, students can directly link theoretical concepts to practical application, thus enhancing the depth and significance of their conceptual understanding.

The implementation of Project-Based Learning (PjBL) fosters the enhancement of students' 21st-century competencies, including cooperation, communication, problem-solving, and creativity (Gabuardi, 2021; Rochmawati et al., 2019). Students exhibit proficiency in collaborative teamwork, surmounting technical challenges, and confidently presenting project outcomes. Engagement in learning activities consistently escalates during the implementation of Project-Based Learning (PjBL). Observation results indicate that students are actively engaged in the learning process from the planning phase, through group discussions, investigations, and project execution, to the presentation of outcomes. The observation scores, which range from 3 to 4, are in the good to very good range.

4. CONCLUSION

The implementation of the PjBL learning model has proven significantly more effective in improving conceptual understanding and student learning outcomes compared to conventional learning models. This improvement is evidenced by the experimental class's average post-test score of 83.10%, significantly exceeding the control class's score of 45.62%. There was a striking difference in learning outcomes, with the experimental class experiencing an increase from 41.36% to 83.10%. The t-test results, showing a significance value of <0.05, provide strong proof that using real-world projects can help students understand the complicated material of Embedded Systems Programming. Furthermore, the PjBL model provides space for students to actively engage in technical problem-solving so that understanding is formed not through mere theoretical memorization but rather through in-depth conceptual understanding gained through practical experience.

As a recommendation, teachers of productive subjects, particularly Embedded Systems Programming, are advised to adopt the PjBL model as a primary alternative in teaching complex material. Teachers should design project modules that align with industry needs to enhance student motivation and understanding. Further researchers can expand the scope of their research to other subjects or examine other variables, such as the influence of PjBL on soft skills (teamwork and leadership) or students' critical thinking skills.

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