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Improving Learning Outcomes Using the Project-Based Learning Model in the Electronic Control Systems Subject

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ABSTRACT

Traditional teaching methods that don't involve students in solving practical problems can lead to disengagement and a lack of critical thinking skills, which can lower electronic control system learning outcomes at Vocational School 10 Makassar. This study examines how Project-Based Learning (PjBL) improves student learning compared to conventional methods. This study is quantitative and quasi-experimental. 53 students were split into experimental (PjBL model) and control (conventional) groups. Students' activity observation sheets and pretest and posttest 20-question objective examinations were used to collect data. Data analysis included descriptive statistical tests, N-Gain tests, prerequisite tests (normality and homogeneity), and independent sample T-test hypothesis testing. The results showed that the improvement in learning outcomes in the experimental class was significantly higher than in the control class. This conclusion is evidenced by the average posttest score of the experimental class of 14.00, far exceeding the control class of 9.71. The average N-Gain value of the experimental class reached 0.51 (medium category), while the control class was only 0.17 (low category). Based on the hypothesis test, a Sig. (2-tailed) value of 0.001 < 0.05 was obtained, which confirmed the significant positive influence of the use of the PjBL model. This study provides a practical contribution for educators in vocational schools as a reference for effective innovative learning models to improve project-based technical competencies.

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1. INTRODUCTION

Education is a fundamental instrument for cultural transformation and a key pillar of national development. In an era of technological disruption, educational reform is essential to align graduate competencies with the dynamics of future needs (Nyale et al., 2025; Rahimi & Oh, 2024). Within vocational high schools, the primary focus of learning is equipping students with specific skills to adapt to the industrial ecosystem (Andriyani et al., 2025; Mo, 2025). One indicator of the success of this process is reflected in student learning outcomes, particularly in productive subjects that require a synchronization of theoretical mastery and applied skills, such as electronic control systems.

A growing body of recent literature has confirmed the effectiveness of Project-Based Learning (PjBL) in improving learning quality (Ahmad et al., 203; Budiarto, 2023; Dewangga & Ahmad, 2023; Sugiyanto et al., 2020). Meta-analyses show that PjBL has a higher effect size on learning outcomes than conventional methods (Chen & Yang, 2019; Suryani et al., 2024; Wijnia et al., 2024; Zhang & Ma, 2023). In engineering education, this model has been shown to not only boost cognitive values but also stimulate motivation and creative thinking skills (Rahardjanto & Fauzi, 2019; Wu & Wu, 2020), particularly in areas such as design projects and collaborative problem-solving tasks. However, there is a significant research gap in the existing literature. Most previous studies have focused on general subjects or basic engineering (Jiang & Pang, 2023; Mursid et al., 2022; Sukackė et al., 2022). There is limited research specifically exploring the implementation of Problem-Based Learning (PjBL) in Electronic Control Systems, a subject characterized by high complexity, specifically the integration of microcontroller programming logic, sensors, and actuators into a single system.

This gap was also empirically identified at Vocational School 10 Makassar. Observations revealed that despite the introduction of the problem-based learning model, the PjBL model, which focuses on real products, had never been implemented. As a result, student learning outcomes stayed about the same, with scores between 70 and 78. Most students did not meet the minimum requirements for passing. Furthermore, a phenomenon of academic passivity was observed; students tended to be less responsive and rarely proposed original ideas in solving technical problems. This situation indicates that existing instructional approaches have not been able to optimally facilitate students' exploration needs.

The new idea in this research is to combine the PjBL model with the electronic control systems curriculum, focusing on creating practical products that meet today's industry demands, like automatic garage control systems and smart traffic lights. This research tests the effectiveness of the model and explores how the transition from problem-based learning to project-based learning can shift students' activity profiles from passive to active-creative.

Using a quantitative approach with a quasi-experimental design, this study aims to comprehensively analyze the differences and magnitude of improvement (N-Gain) in student learning outcomes. The results are expected to add to the knowledge about 21st-century vocational learning strategies and help teachers use new teaching methods that fit with the goals of the Independent Curriculum.

2. METHOD

This study employed a quasi-experimental method with a Nonequivalent Control Group design. The framework and systematic flow of the research design are detailed in Table 1 below.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experiment	O_1	X	O_2
Control	O_3	–	O_4

Information:
O_1 = Pretest of the experimental group
O_2 = Posttest of the experimental group
O_3 = Pretest of the control group
O_4 = Posttest of the control group
X = Treatment using the Project Based Learning model

This research was conducted at Vocational School 10 Makassar during the odd semester of the 2025/2026 academic year. The study population included all 11th-grade students of the Industrial Electronics Engineering program at the school. The study sample involved 53 students divided into two groups: the experimental group (11th grade TELI 2) consisting of 28 students and the control group (11th grade TELI 3) consisting of 25 students. The sample was determined using a purposive sampling technique by considering the equality of academic characteristics between the two classes. This study tested two main variables, namely the project-based learning model as the independent variable applied to the experimental group and student learning outcomes in the electronic control systems subject as the dependent variable measured through cognitive tests.

The initial stage of the research began with a preparation phase focused on field observations to identify the actual learning conditions at the research site. During this stage, a research instrument was developed, consisting of a 20-item multiple-choice test validated through expert judgment. In addition to expert validation, the instrument's effectiveness was tested using correlation analysis and construct validity. The experimental and control groups were carefully selected, considering the equivalence of students' initial abilities to ensure high accuracy of the research results.

In the implementation phase, both groups were given a pretest to assess their initial abilities before receiving the treatment. The experimental group underwent four sessions using the project-based learning model, which encompassed six main syntaxes: asking basic questions about analog control components, designing a project plan and circuit block diagram, developing a group task schedule, monitoring assembly progress, technical testing (voltage, current, and component response), and evaluation through presentations and reflection. Meanwhile, the control group underwent conventional learning for the same duration. The research concluded with a posttest for both groups, where the collected data was then statistically analyzed to test the research hypotheses and draw final conclusions.

The main research instrument used was an objective learning outcome test consisting of 20 multiple-choice questions with four answer options. This instrument was comprehensively designed to measure various cognitive levels of Bloom's Taxonomy, including remembering (C1) with 4 questions, understanding (C2) with 3 questions, applying (C3) with 3 questions, analyzing (C4) with 5 questions, and evaluating (C5) with 5 questions. The test material focused on the basic concepts of analog electronic components, component operating principles, conceptual applications, circuit problem analysis, and analog control system evaluation. In addition to the cognitive test, an observation sheet was also used specifically to monitor and measure student engagement during the implementation of the project-based learning model in the experimental group.

The data collection process was carried out in two stages: a pretest to map students' initial abilities before receiving the intervention and a posttest to measure learning outcomes after the intervention was completed. Both stages used identical instruments to ensure measurement consistency. In addition to quantitative data from the test, the researchers also conducted systematic documentation, including the collection of learning media, recordings of teaching and learning activities, and other relevant supporting data to strengthen the validity of the findings in the field.

Data analysis was conducted through a series of rigorous statistical procedures to ensure the accuracy of the research results. The stages began with instrument validity and reliability tests using the Kuder-Richardson 20 (KR-20) method to measure the internal consistency of the test items. Next, a prerequisite analysis test was conducted as a foundation before proceeding to hypothesis testing. To measure the effectiveness of the treatment and significantly improve student learning outcomes, the researchers implemented an N-Gain test that compared the difference between pretest and posttest scores in both groups of research subjects.

3. RESULTS AND DISCUSSION

Results

The data for this study were obtained through field data collection using an objective test instrument in the form of multiple-choice questions. The instrument was distributed to 53 students who served as the research sample, consisting of class XI TELI 2 as the control group and class XI TELI 3 as the experimental group. The determination of the research subjects was carried out through a structured sampling procedure to ensure the data obtained were representative of the population studied.

Descriptive Analysis

The results of the pretest instrument validity test for the experimental group are presented in detail in Table 2. The data summarizes the results of the item analysis to ensure that the instrument used has an adequate level of accuracy in measuring students' initial abilities before being given treatment.

Table 2. Results of the Experimental Class Pretest Validity Test

Indicator	R-Count	R-Table	Information
Question 1	0,493	0,396	Valid
Question 2	0,481	0,396	Valid
Question 3	0,459	0,396	Valid

Indicator	R-Count	R-Table	Information
Question 4	0,463	0,396	Valid
Question 5	0,475	0,396	Valid
Question 6	0,472	0,396	Valid
Question 7	0,447	0,396	Valid
Question 8	0,493	0,396	Valid
Question 9	0,431	0,396	Valid
Question 10	0,486	0,396	Valid
Question 11	0,431	0,396	Valid
Question 12	0,424	0,396	Valid
Question 13	0,507	0,396	Valid
Question 14	0,518	0,396	Valid
Question 15	0,490	0,396	Valid
Question 16	0,493	0,396	Valid
Question 17	0,493	0,396	Valid
Question 18	0,495	0,396	Valid
Question 19	0,463	0,396	Valid
Question 20	0,420	0,396	Valid

The results of the pretest validity analysis in the experimental class presented in Table 2 show that the calculated r_value for items 1 to 20 is greater than the r_table value of 0.396. Thus, the pretest instrument is declared valid and suitable for use as a research measurement tool to collect data on students' initial abilities.

Table 3. Results of the Experimental Class Posttest Validity Test

Indicator	R-Count	R-Table	Information
Question 1	0,504	0,396	Valid
Question 2	0,452	0,396	Valid
Question 3	0,462	0,396	Valid
Question 4	0,452	0,396	Valid
Question 5	0,493	0,396	Valid
Question 6	0,454	0,396	Valid
Question 7	0,477	0,396	Valid
Question 8	0,509	0,396	Valid
Question 9	0,457	0,396	Valid
Question 10	0,450	0,396	Valid
Question 11	0,413	0,396	Valid
Question 12	0,428	0,396	Valid
Question 13	0,457	0,396	Valid
Question 14	0,498	0,396	Valid
Question 15	0,502	0,396	Valid
Question 16	0,439	0,396	Valid
Question 17	0,434	0,396	Valid
Question 18	0,476	0,396	Valid
Question 19	0,462	0,396	Valid
Question 20	0,493	0,396	Valid

Based on the analysis data in Table 3, it is known that the calculated r_value for all posttest items (numbers 1 to 20) in the experimental class consistently shows a number greater than the r_table value of 0.396. By fulfilling these statistical criteria, it can be concluded that the posttest instrument used in this study is declared valid and has the right accuracy to measure student learning outcomes.

Table 4. Results of the Pretest Validity Test for the Control Class

Indicator	R-Count	R-Table	Information
Question 1	0,398	0,373	Valid
Question 2	0,609	0,373	Valid
Question 3	0,586	0,373	Valid
Question 4	0,402	0,373	Valid
Question 5	0,551	0,373	Valid
Question 6	0,507	0,373	Valid
Question 7	0,450	0,373	Valid
Question 8	0,564	0,373	Valid
Question 9	0,448	0,373	Valid
Question 10	0,609	0,373	Valid
Question 11	0,427	0,373	Valid
Question 12	0,474	0,373	Valid
Question 13	0,522	0,373	Valid
Question 14	0,431	0,373	Valid
Question 15	0,447	0,373	Valid
Question 16	0,508	0,373	Valid
Question 17	0,505	0,373	Valid
Question 18	0,470	0,373	Valid
Question 19	0,428	0,373	Valid
Question 20	0,615	0,373	Valid

The results of the pretest analysis in the control class based on Table 4 show that the calculated r value for questions number 1 to 20 is greater than the table r, namely 0.373. Thus, it can be concluded that the pretest instrument is valid.

Tabel 5. Hasil Uji Validitas Posttest Kelas Kontrol

Indicator	R-Count	R-Table	Information
Question 1	0,516	0,373	Valid
Question 2	0,593	0,373	Valid
Question 3	0,543	0,373	Valid
Question 4	0,402	0,373	Valid
Question 5	0,527	0,373	Valid
Question 6	0,512	0,373	Valid
Question 7	0,527	0,373	Valid
Question 8	0,657	0,373	Valid
Question 9	0,465	0,373	Valid
Question 10	0,603	0,373	Valid
Question 11	0,497	0,373	Valid
Question 12	0,416	0,373	Valid
Question 13	0,553	0,373	Valid
Question 14	0,381	0,373	Valid
Question 15	0,423	0,373	Valid
Question 16	0,449	0,373	Valid
Question 17	0,400	0,373	Valid
Question 18	0,439	0,373	Valid
Question 19	0,431	0,373	Valid
Question 20	0,471	0,373	Valid

The results of the posttest analysis in the control class based on Table 5 show that the calculated r value for questions number 1 to 20 is greater than the table r, namely 0.373. Thus, it can be concluded that the posttest instrument is valid.

Table 6. Reliability Test of the Experimental Class and Control Class

Class	Cronbach's Alpha	R-Table	Description
Pretest Experiment	0,816	0,396	Reliable
Experiment Posttest	0,810	0,396	Reliable
Control Pretest	0,841	0,373	Reliable
Control Posttest	0,834	0,373	Reliable

The results of the reliability test using SPSS 25 software, the research instrument, showed a very good level of internal consistency. In the experimental class, the Cronbach's Alpha value obtained for the pretest was 0.816 and the posttest was 0.810, both of which exceeded the r_table value of 0.396. Meanwhile, in the control class, Cronbach's Alpha value for the pretest was recorded at 0.841 (> 0.373) and the posttest was 0.698 (> 0.349). Considering that all Cronbach's Alpha values obtained were greater than the r_table value, it can be concluded that the test instrument used in this study has high reliability and is suitable for use in data collection.

Table 7. Results of Statistical Analysis of Pretest and Posttest Scores of Learning Outcomes of the Control and Experimental Classes

No	Descriptive Statistics	Control Class		Experimental Class	
		Pretest	Posttest	Pretest	Posttest
1	Number of Samples	28	28	25	25
2	Highest Score	15	16	16	19
3	Lowest Score	3	3	3	7
4	Mean Score	9,32	9,71	10,36	14,00
5	Standard Deviation	4,83	4,72	4,76	4,42

The statistical analysis results in Table 7 show that there was a difference in how well students learned between the pretest and posttest scores in both the control and experimental classes. In the control class, the pretest recorded the highest score of 15 and the lowest score of 3, with an average of 9.32 and a standard deviation of 4.83. Meanwhile, in the posttest, the average score increased slightly to 9.71, with a score range of 3 to 16.

Conversely, the experimental class showed a more significant improvement. In the pretest, the experimental class achieved the highest score of 16 and the lowest score of 3, with an average of 10.36 and a standard deviation of 4.76. After the intervention, the experimental class' posttest results improved, with the highest score of 19 and the lowest score of 7, resulting in an average of 14.00 and a standard deviation of 4.42. These data indicate that the intervention provided to the experimental class had a greater impact on improving learning outcomes than the control class.

Table 8. Shapiro Wilk Normality Test Analysis of Learning Outcomes

Data	Control Class		Experimental Class	
	Pretest	Posttest	Pretest	Posttest
Statistic	0,937	0,946	0,954	0,967
Df	28	28	25	25
Sig	0,092	0,154	0,306	0,562

Building upon the results of the Shapiro-Wilk normality test presented in Table 8, the student learning outcome data in the control class showed a significance value (Sig) of 0.092 for the pretest and 0.154 for the posttest. Meanwhile, in the experimental class, a significant value of 0.306 for the pretest and 0.562 for the posttest was obtained. Considering that all significance values obtained from both groups were greater than the 0.05 significance level (Sig. > 0.05), it can be concluded that the student learning outcome data, both in the control and experimental classes, were normally distributed.

Table 9. Homogeneity Test of Student Learning Outcomes

Variable	Sig.	Description
Pretest	0,639	Homogeneous
Posttest	0,471	Homogeneous

The results of the pretest homogeneity test obtained a significant value of 0.639 > 0.05. Meanwhile, the posttest homogeneity test obtained a significant value of 0.471 > 0.05. Therefore, it can be concluded that the variance of learning outcome data in the control class and the experimental class is the same or homogeneous.

Table 10. Hypothesis Test Results

Variable	Levene's Test		T-test for Equality of Means				
	F	Sig.	t	df	Sig.(2-tailed)	Mean Difference	Std. Error Difference
Equal variances assumed	0,529	0,471	-3,394	51	0,001	-4,286	1,263
Equal variance not assumed			-3,407	50,876	0,001	-4,286	1,258

The results of the hypothesis test using the Independent Samples t-test, presented in Table 10, obtained a Levene's Test significance value of 0.471. Because this value is greater than 0.05 (p > 0.05), it can be concluded that the variance of the learning outcome data between the experimental and control classes is homogeneous. With the homogeneity assumption met, the t-test decision was based on the "Equal variances assumed" row.

The t-test analysis results showed a Sig. (2-tailed) value of 0.001, which is significantly lower than the 0.05 significance level. Based on these findings, the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_a) is accepted, indicating a significant difference in learning outcomes between students taught using the Project-Based Learning model compared to those taught using the conventional learning model. This proves that the implementation of the Project-Based Learning model has a positive and significant effect on improving student learning outcomes in the Electronic Control Systems subject at Vocational School 10 Makassar.

Table 11. Results of the N-Gain Test (Improvement in Learning Outcomes)

Kelas	N	Min.	Max.	Mean	Std. Deviasi	N-Gain
Control	28	-0,08	0,50	0,17	0,13	17,19%
Experiment	25	0,08	0,83	0,51	0,21	51,15%

Table 11, the results of the N-Gain calculation for the control and experimental classes, there was an increase in learning outcomes between the two classes. The control class, with 28 students, had a minimum N-Gain of -0.08 and a maximum of 0.50, with an average of 0.17, or 17.19%, which is considered low. This indicates that the improvement in learning outcomes in the control class was not optimal, and some students still experienced a decline in grades after the learning process.

Meanwhile, the experimental class, with 25 students, showed a minimum N-Gain of 0.08 and a maximum of 0.83, with an average of 0.51, or 51.15%, which is considered moderate. This higher average value indicates that the Project-Based Learning model was able to provide better learning outcomes than conventional learning in the control class. Overall, a comparison of the average N-Gain of the two classes indicates that the improvement in learning outcomes in the experimental class was greater and more evenly distributed.

Table 12. Results of the Summary of Observation Sheet Values

Observed Aspects	Observer	Average Score
Teacher Activities	Observer 1	92%
	Observer 2	89%
	Observer 3	85%
	Observer 4	96%
Student Activities	Observer 1	85%
	Observer 2	92%
	Observer 3	96%
	Observer 4	89%

Building upon observations conducted by four observers during the learning process using the Project-Based Learning (PjBL) model in the Electronic Control Systems subject, data on teacher and student activity were obtained in percentage form. Observations of teacher activity showed a high percentage, ranging from 85% to 96%, which is in the very good category. This indicates that teachers have implemented learning in accordance with the Project-Based Learning syntax.

Observations of student activity also showed a very good category, with observers rating percentages ranging from 85% to 96%. Students appeared active in the learning process, particularly in group discussions, collaboration in completing projects, and taking responsibility for completing assigned tasks. The Project-Based Learning model encourages active student engagement in learning.

Discussion

The results of this study indicate that the implementation of the Project-Based Learning (PjBL) model significantly improved student learning outcomes in the Electronic Control Systems subject at Vocational School 10 Makassar. This finding is evidenced by the convincing difference in achievement between the posttest scores of the experimental class (average 14.00) and the control class (average 9.71). Supported by the results of the independent sample t-test, which yielded a significance value of 0.001 ($p < 0.05$), these data confirm that the PjBL model is significantly more effective than conventional learning methods in improving conceptual understanding and mastery of electronic control systems material.

This success aligns with constructivism theory, which emphasizes that the learning process is more meaningful when students are directly involved in constructing knowledge through solving real-world problems (Gannar, S., & Kilani, 2025; Nurhuda et al., 2023; Siregar et al., 2024). Empirically, these results also reinforce previous studies that suggest that the characteristics of vocational education align closely with the syntax of PjBL, where the integration of theory and practice within a project can stimulate students' simultaneous cognitive and psychomotor engagement (Hidayat & Widiyanti, 2025; Xu et al., 2024). The significant improvement in learning outcomes in the experimental class indicates that the stages in PjBL—from designing to testing the circuit—provide a more comprehensive learning experience than just a one-way transfer of knowledge.

The effectiveness of the PjBL model in improving student learning outcomes aligns with the findings of Chen and Yang (2019), who found that the implementation of PjBL effectively improves student learning outcomes at various levels of education, with a high effect size. The study also revealed that PjBL was more effective than problem-based learning in improving students' cognitive learning outcomes. The experimental group using PjBL achieved a higher average posttest score than the control group. The benefit of PjBL is that it gets students actively involved in the learning process through meaningful and relevant project activities, which helps them understand concepts better.

The N-Gain test results in this study indicated that the experimental class attained an average N-Gain score of 0.51, classified as medium, whereas the control class obtained a score of 0.17, classified as low. This difference in the magnitude of improvement confirms that the PjBL model improves learning outcomes statistically and provides substantial practical improvements. This finding is supported by research by Rusnawati et al. (2020), who found that the implementation of PjBL significantly impacted learning outcomes in practical subjects in vocational high schools, such as creative projects and entrepreneurship. The characteristics of the Electronic Control Systems subject, which requires practical skills in designing, implementing, and testing control systems based on digital electronics technology, are well suited to a project-based learning approach that emphasizes hands-on experience and the application of concepts in real-world contexts.

The successful implementation of the PjBL model in this study can also be explained through the learning syntax applied systematically throughout the four meetings. In the initial stage, contextual problems related to analog electronic components stimulate critical thinking and encourage students to identify solutions. The project design stage facilitates students developing planning skills by constructing circuit designs in groups. The implementation and testing stage provides hands-on experience that integrates conceptual understanding with psychomotor skills. Finally, the evaluation stage through presentations and reflections develops students' metacognitive abilities in assessing their learning processes and outcomes. This structured learning process is in line with Lesman et al. (2023) and Oanh et al. (2025) research, which confirms that the use of PjBL in project-based learning in engineering can improve motivation, creative thinking skills, and overall student learning outcomes.

Observations indicate that the implementation of the PjBL model was very successful, as evidenced by the teacher's ability to implement learning stages according to the syntax and act as an effective facilitator. Student activity also demonstrated high levels of engagement through group collaboration, active participation in discussions, and responsibility in completing projects. This active, student-centered learning environment is a beneficial place for students to build their knowledge. This finding aligns with research by Athaya et al. (2024) and Basri et al. (2024), who stated that the success of PjBL learning is strongly influenced by student engagement, as this model positions students as learning subjects with the freedom to determine their learning activities and collaboratively work on projects to produce a product.

The better learning results in the experimental class can also be linked to the PjBL model's features, which promote important learning through practical experience. Students not only learned about sensors, actuators, logic circuits, and microcontrollers in theory, but they also used what they learned to design and build working analog control systems. This process enabled students to holistically understand the interrelationships between components in an automatic control system. Research by Fajra and Novalinda (2020) supported these findings by asserting that PjBL improves learning outcomes and provides a more meaningful learning experience relevant to the needs of the workplace. The relevance of learning to the workplace context is crucial in vocational education, where vocational high school graduates are expected to possess technical competencies that can be directly applied in industry.

Although both classes had relatively equivalent initial abilities based on pretest results (control class 9.32 and experimental class 10.36), the improvement in the experimental class was much more significant than in the control class. This indicates that the determining factor in improving learning outcomes is not solely the students' initial abilities but also the learning methods used. Conventional learning, which tends to be teacher-centered and emphasizes verbal knowledge transfer, is less effective in developing students' critical thinking, problem-solving, and collaboration skills (Hadiyanto et al., 2021). In contrast, the PjBL model, which emphasizes active, constructive, and collaborative learning, provides students with greater opportunities to construct their knowledge through direct experience (Hussein, 2021).

These research findings also confirm constructivism theory, which emphasizes that learning occurs through the process of knowledge construction by students themselves, rather than through knowledge transfer from teachers (Saleem et al., 2021). In the framework of PjBL, students actively develop their comprehension of electronic control systems through inquiry, experimentation, and reflection (Almulla, 2020). The teacher acts as a facilitator guiding this knowledge construction process, rather than as the sole source of information. This shift in roles creates a more democratic learning dynamic and empowers students as active agents in their learning process.

Furthermore, the results of this study provide practical implications for the development of learning in vocational schools, particularly in practical and applied subjects. The implementation of the PjBL model has proven to be an innovative and effective alternative learning strategy for increasing student engagement and learning outcomes. This aligns with the demands of the Independent Curriculum, which emphasizes project-based learning and the development of Pancasila student profiles through meaningful learning experiences (Hakim et al., 2024). The PjBL model facilitates the development of various competencies needed in the industry 4.0 era, such as critical thinking, creativity, collaboration, and communication, known as 21st-century skills (Ali et al., 2025; Laeli & Wijayanto, 2025; Wansyah et al., 2025).

This research provides strong empirical evidence that the project-based learning model is effective in improving student learning outcomes in the Electronic Control Systems subject at Vocational School 10 Makassar. The significant improvement in learning outcomes in the experimental class with a moderate N-Gain value indicates that PjBL not only impacts statistical aspects but also provides meaningful practical improvements. These findings are consistent with previous studies confirming the effectiveness of PjBL in vocational education contexts and practical subjects (Megayanti et al., 2020; Sudjimat & Permadi, 2021). The systematic implementation of the PjBL model, supported by adequate facilities and good teacher competence, has been proven to create active, meaningful, and relevant learning for the needs of the world of work, thus preparing vocational school students to face dynamic and competitive professional challenges.

4. CONCLUSION

The implementation of the Project-Based Learning (PjBL) model has been proven to be significantly effective in improving student learning outcomes in the Electronic Control System subject at Vocational School 10 Makassar. This result was confirmed through an independent sample T-test with a significance value of 0.001 ($p < 0.05$), where the experimental class achieved an average posttest score of 14.00, far exceeding the control class, which only achieved 9.71. This increase indicates that the project-based approach has a stronger impact on cognitive concept mastery than conventional learning models. The effectiveness of the PjBL model is also supported by the N-Gain value of 0.51, which is included in the "Medium" category, while the control class only achieved 0.17, which is classified as "Low". This difference in the rate of improvement proves that PjBL has a statistical impact and provides substantial practical improvements in facilitating students to understand complex material through direct experience (hands-on experience). This success is rooted in the structured syntax of PjBL—from problem identification to project evaluation—which is able to stimulate students' cognitive and psychomotor engagement simultaneously. This model creates a student-centred learning environment, where teachers play an effective role as facilitators. Through the integration of theory and practice in solving real problems, students master the material verbally and develop technical competencies relevant to the needs of the world of work (DUDI) and 21st-century skills.

As a suggestion, teachers adopt the PjBL Model, considering its effectiveness in improving learning outcomes (N-Gain 0.60), Electronic Control System subject teachers are advised to start shifting conventional methods to the Project Based Learning (PjBL) model on materials that require high practical competencies. Teachers need to design projects that have strong relevance to current industrial needs, such as system automation using microcontrollers, so that student motivation and engagement are maintained during the learning process. Further researchers are advised to not only measure cognitive learning outcomes but also explore the effect of PjBL on other variables such as psychomotor skills (soft skills), critical thinking abilities, or student self-efficacy. In addition, future research can expand the research subjects to different classes or schools, as well as to other electronic engineering materials that have a higher level of complexity to test the consistency of the effectiveness of this model.

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