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Research Article

Optimising Student Learning Outcomes through Problem-Based Learning to Develop Analytical Skills

Muhtadin, Gunadi, Putu Sudira, Daniel Ngolu Jiledo Maringga, Ridho Azahar*

Universitas Negeri Yogyakarta, Sleman, Indonesia, 55281
*Corresponding Author: ridhoazahar.2023@student.uny.ac.id | Phone: +6282272746329

ABSTRACT

The low ability of students to identify damage to the Fuel Injection (EFI) electrical system remains a problem in automotive learning at Vocational High Schools (SMK). Students have difficulty analysing damage symptoms, determining the components causing the damage, and comprehensively understanding the EFI system workflow. This condition indicates the need for an effective, contextual, and problem-solving learning model. This study aims to analyse the effect of the Problem-Based Learning (PBL) model on improving students' learning outcomes in identifying damage to the EFI electrical system. The method used was a quasi-experiment with a sample of students from class XII TKR 1 as the experimental class and XII TKR 2 as the control class, each consisting of 36 students. Data analysis used the independent sample t-test and Cohen's d effect size test to see the differences and effects on student learning outcomes. The results showed a significant difference in learning outcomes with a value of ($p = .00 < .05$). The effect size value was ($d = 4.311$), indicating that the application of PBL had a strong influence on students' ability to identify EFI system damage. Thus, the PBL learning model was proven to improve the learning outcomes of vocational school students.

Keywords: Problem-Based Learning; Learning Outcomes; Electric Fuel Injection

1. INTRODUCTION

Advances in automotive technology require vocational school graduates to have competencies that are relevant to industry needs (Isnadar & Budiman, 2023; Sugiarto et al., 2019). One important competency in the field of Light Vehicle Engineering is the ability to understand and handle Electronic Fuel Injection (EFI) systems. EFI systems are electronic-based technologies that integrate sensors, actuators, and control units to regulate fuel supply with precision (Diep et al., 2023; Reddy et al., 2021). The complexity of this system requires students to have a good command of theory and practical skills, especially in identifying faults in interconnected electrical components (Kucera et al., 2025; Nasrudi et al., 2021). However, the reality in the field shows that many students still experience difficulties in diagnosing EFI faults due to their low mastery of basic concepts and limited practical experience.

Poor learning outcomes in EFI electrical system fault identification are often caused by teaching methods that are still teacher-centred and predominantly theoretical (Anwar et al., 2021; Nasrudi et al., 2021). Students are given few opportunities to explore problems, analyse components, and practise fault inspection procedures directly. As a result, students experience a gap between the material they learn in class and the real conditions in the workshop (Priyono et al., 2024; Ridwan & Nurmanita, 2025). Mastery of learning outcomes in this competency is very important because the ability to identify damage is a basic skill that students must have in order to be ready to enter the world of work and be able to adapt to developments in modern vehicle technology.

One learning approach that can improve student learning outcomes is Problem-Based Learning (Cahyani et al., 2021; Cuhanazriansyah et al., 2023). The PBL model places students at the centre of learning activities by presenting real problems that must be analysed and solved independently or in groups (Hartatik, 2023; Mahendra et al., 2025). In the context of EFI systems, the application of PBL provides opportunities for students to be directly involved in the diagnostic process, such as reading trouble codes, observing damage symptoms, analysing possible causes, and determining the appropriate inspection procedures. PBL also encourages students to actively discuss, collaborate, and connect theory with practice in a more meaningful way, thereby potentially improving their conceptual understanding and technical skills (Pohan & Rambe, 2022; Tohadi et al., 2020; Widiawati et al., 2024).

Although there has been extensive research on the effectiveness of PBL, studies specifically examining its application to the competency of identifying EFI electrical system damage are still rare. The majority of studies focus on improving learning outcomes in general, but have not discussed in depth how problem-based learning models can improve students' mastery of diagnosing complex and systemic vehicle damage. This creates an important research gap that needs to be explored, especially given the automotive industry's need for workers who are able to understand modern electrical systems. Therefore, this study aims to analyse the effectiveness of the Problem-Based Learning model in improving student learning outcomes in the competency of identifying EFI electrical system vehicle damage. The results of this study are expected to contribute theoretically to the development of learning models in technical education, as well as provide practical recommendations for vocational school teachers in designing more contextual, applicable learning that meets the demands of the modern automotive industry.

2. RESEARCH METHOD

2.1 Research Design

This study used a quantitative method with a quasi-experimental approach to measure the effect of the Problem-Based Learning (PBL) model compared to the conventional model in improving students' learning outcomes. The research population consisted of Light Vehicle Engineering (TKR) students at SMK Ma'arif Ayah 6 Kebumen, with the research sample consisting of 36 students from two Year 12 TKR classes. The experimental class was taught using the PBL model, while the control class used conventional learning. The sample was selected using purposive sampling based on student homogeneity and material suitability. The study lasted for 30 days with four meetings. In the experimental class, learning was carried out through PBL steps, namely problem orientation, group investigation, solution discussion, and presentation of results. Students were involved in analysing real cases related to the Electric Fuel Injection (EFI) system. Meanwhile, the control class followed conventional learning through teacher lectures. The research instrument was a case study-based cognitive ability test, administered before (pre-test) and after (post-test) learning.

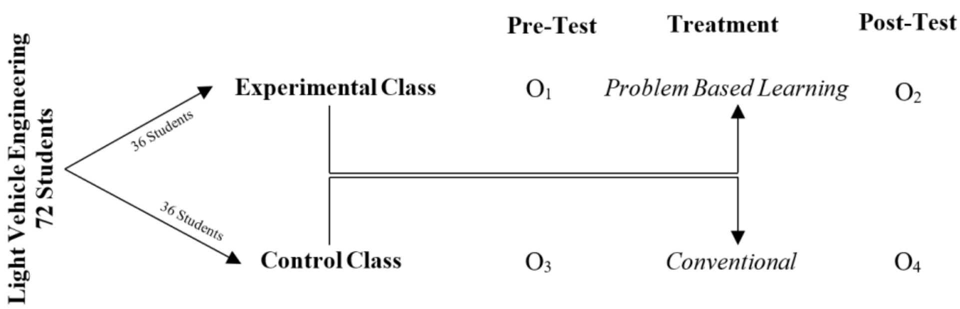

Figure 1. Quasi Experimental Research Design

2.2 Research Instruments

Before the research instrument was used to measure student learning outcomes in identifying damage to the Fuel Injection (EFI) electrical system, the instrument was developed through a series of validation and testing stages to ensure its quality, accuracy, and suitability for the research objectives. This step was taken to ensure that the instrument used was truly capable of measuring students' abilities accurately, objectively, and in an academically accountable manner. The first stage was expert validation. The research instrument, consisting of five essay questions oriented towards levels C4 to C5, was validated by experts with competence in the fields of automotive engineering and learning evaluation. The validation process aims to assess the suitability of the material, the accuracy of the question construction, and the clarity of the language. The content aspect is assessed based on the relevance of the questions to the basic competencies and learning indicators related to the identification of EFI system damage. The experts also evaluate the accuracy of the questions to ensure that they stimulate students' analytical and evaluative abilities in accordance with the characteristics of vocational learning.

In addition to content, experts assessed the construction aspects, namely the appropriateness of the question format, the accuracy of the stimuli, and the clarity of the instructions. The language aspects were also validated to ensure that there was no ambiguity that could interfere with students' understanding. The validation results showed that the instrument was deemed feasible and only required a few minor revisions, such as simplifying sentences, refining damage indicators on EFI components, and improving the logical flow of questions to better align with the Light Vehicle Engineering (TKR) competency standards. After the revisions were made, the instrument was declared valid by all validators with a very good rating. This indicates that the instrument has met the theoretical and substantive eligibility requirements before being applied in research. The following are the question indicators and competencies measured in conducting this research:

Table 1. Indicators of Questions and Competencies Achieved by Students

Variable	Competency Achievement Indicators	Competencies Achieved by Students	Question Number
Fuel consumption is excessive	Able to identify symptoms of abnormal fuel consumption. Analyse possible causes based on EFI working principles. Formulate logical and technical repair solutions.	Mastery of sensors, ECUs, and actuators. Ability to perform data- and symptom-based fault analysis. Ability to propose corrective actions in accordance with EFI service standards.	1
Engine is difficult to start when cold	Explain the function of sensors in engines. Be able to identify which sensors are potentially damaged. Explain the steps for repairing/checking sensors.	Master the working principles of temperature sensors in EFI systems. Be able to read sensor data (real-time data). Master sensor inspection procedures.	2
Engine sputters at low RPM	Able to identify the cause of sputtering at low revs. Perform checks on the injector, idle system, and sensor. Determine corrective measures based on the inspection results.	Mastering damage analysis techniques at low engine speeds. Able to use basic measuring instruments. Able to perform minor repairs such as cleaning injectors, throttle bodies, or checking sensors.	3
Check engine light is on	Understand the diagnostic procedure using a scan tool. Identify the DTC. Determine the relevant components based on the fault code.Propose effective corrective actions.	Able to operate EFI scan tools. Interpret fault codes according to OBD standards. Develop data-driven diagnostic thinking skills.	4
High exhaust emissions	Analyse the emission test results. Determine the causes from the fuel mixture, sensors, catalytic converter, and combustion system.Develop corrective measures to reduce emissions.	Understand the relationship between the EFI system and the vehicle's emission system. Be able to perform diagnostics based on emission test results. Be able to plan repairs (tune-ups, sensor checks, AFR checks).	5

2.3 Research Instrument Trial

The next stage was to test the instrument. The instrument was tested on 36 students in class XII TKR 1 in the previous semester. This stage was very important to identify whether the instrument worked consistently and was able to accurately measure students' abilities in the field.

2.4 Data Analysis

The research data was analysed using an independent samples t-test to examine the differences in learning outcomes between the experimental and control groups, as well as the effect size to determine the magnitude of the influence of the Problem-Based Learning (PBL) model on students' ability to identify damage to the Fuel Injection (EFI) electrical system. Before the instruments were used in the main study, a series of instrument quality tests were conducted to ensure their feasibility and accuracy. A validity test was conducted to ensure that each item truly measured the intended competency, followed by a reliability test to assess internal consistency between items. In addition, a difficulty level test was applied to determine the degree of difficulty of each item, and a discrimination power test was used to ensure the ability of each item to distinguish between high and low ability students. This entire series of tests ensures that the research instruments are of good quality so that the results of the t-test analysis and effect size can be interpreted objectively and are methodologically accountable.

3. RESULTS AND DISCUSSION

3.1 Validity Test

Based on the results of the validity test analysis using Pearson's correlation, all essay items tested showed correlation coefficient values ranging from .753 to .948. These values are above the significance value of 0.05, so all items are categorised as empirically valid. The item with the highest correlation was the question about ‘Engine is difficult to start when cold’ ($r = .948$), which indicates that this item has the strongest level of construct representation of the entire instrument. Meanwhile, the lowest correlation value was found in the question about ‘High exhaust emissions’ ($r = .753$), but it still showed excellent validity. The high correlation values in all items indicate that each question is able to measure C4–C5 level cognitive abilities consistently in accordance with the measurement objectives.

Table 2. Validity Test Results on Essay Test

Variable	CL	Pearson Correlation	Reliability
Fuel consumption is excessive	C4	.774**	
Engine is difficult to start when cold	C4	.948**	
Engine sputters at low RPM	C4	.836**	.887
Check engine light is on	C5	.871**	
High exhaust emissions	C5	.753**	

Nb: ** = Significant (.01); CL = Cognitive Level

In terms of reliability, the instrument showed a reliability coefficient value of .887, which is classified as very high (α > .80), indicating that the instrument is reliable and has strong internal consistency. This reliability value indicates that the essay questions developed are capable of providing stable and reliable measurement results when used to assess students' competence in identifying problems in electric fuel injection (EFI) systems. Thus, overall, this assessment instrument meets the validity and reliability requirements for use in research and learning evaluation.

3.2 Question Difficulty Test

The results of the difficulty level analysis show that all essay questions have a difficulty index ranging from .248 to .295. These values are within the moderate category (.00-.30) and fall into the difficult category. This indicates that each question requires higher analytical and evaluative skills, in line with the C4 – C5 cognitive level, which is designed to measure learning outcomes, particularly in advanced thinking in the context of identifying the Fuel Injection (EFI) electrical system.

Table 3. Results of Difficulty Testing on Essay Test

Question 1	Question 2	Question 3	Question 4	Question 5
.295	.273	.285	.279	.248
Difficult	Difficult	Difficult	Difficult	Difficult

The questions as a whole require in-depth understanding, the ability to identify symptoms of damage, and the skill to provide accurate technical reasoning, so that only a small proportion of students are able to answer correctly. Thus, the level of difficulty indicates that the essay questions are effective in assessing students' abilities.

3.3 Differential Power Test Questions

The results of the discriminating power analysis show that all five essay questions have good to very good ability to distinguish between high- and low-ability students. The discrimination index values ranged from .611 to .907. Items 1 and 5 were in the 'good' category with indices of .698 and .611, respectively, indicating that these two items were quite effective in distinguishing the quality of students' understanding. Meanwhile, items 2, 3, and 4 had indices ranging from .721 to .907 and were classified as 'very good', indicating that these items were able to identify differences in student abilities more sharply and consistently.

Table 4. Results of Discrimination Power Tests in Essay Test

Question 1	Question 2	Question 3	Question 4	Question 5
.698	.907	.721	.779	.611
Good	Very Good	Very Good	Very Good	Good

These findings indicate that most of the essay questions met the criteria for strong discriminating power, making them suitable for use as an evaluation instrument to measure student learning outcomes in identifying faults in the Fuel Injection (EFI) electrical system. The high discriminating power also confirms that the questions were designed with good construction quality and were able to accurately describe the variation in the level of mastery of concepts among students.

3.4 Normalitas Test

The normality test results show that all data in both the experimental and control classes have a significance value greater than .05. Thus, the data distribution in all groups can be declared normally distributed. This finding indicates that the data meets the normality assumption and is therefore suitable for analysis using parametric statistical techniques in the next stage of hypothesis testing.

Table 5. Normality Test Results

Value	Kolmogorov-Smirnova		
	Statistic	df	Sig.
Experimental Pre-Test	.115	36	.200*
Experimental Post-Test	.133	36	.106
Control Pre-Test	.094	36	.200*
Control Post-Test	.123	36	.187

3.5 Homogenitas Test

The results of the homogeneity of variance test based on the mean, median, median with adjusted df, and trimmed mean show a significance value greater than .05. These results indicate that the variance between the experimental class and the control class is homogeneous. Thus, it can be concluded that the post-test data from both groups have the same variance, thereby fulfilling the assumption of homogeneity of variance for the use of parametric statistical tests.

Table 6. Homogeneity Test Results

Post-Test Value	Levene Statistic	df1	df2	Sig.
Based on Mean	2.510	1	70	.118
Based on Median	2.209	1	70	.142
Based on Median and with adjusted df	2.209	1	70	.142
Based on trimmed mean	2.317	1	70	.132

3.6 Independent Sample t-Test

The results of the Independent Sample t-test show that the significance value ($p = .00 < .05$), so it can be concluded that there is a significant difference in learning outcomes between the problem-based learning model and the conventional learning model. This difference indicates that the learning model applied in the experimental class has a significant effect on improving student learning outcomes.

Table 7. Independent Sample t-Test Results

	t-test for Equality of Means						
	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
						Lower	Upper
Equal variances assumed	7.532	70	.000	7.27778	.96625	5.35065	9.20491
Equal variances not assumed	7.532	59.683	.000	7.27778	.96625	5.34478	9.21078

This finding is reinforced by an effect size value using Cohen's d of 4.311. This value indicates that the influence of the learning model is not only statistically significant but also has a very large practical impact on improving student learning outcomes.

3.7 Comparison of Experimental and Control Class Values

The results of comparing the achievement scores between the experimental class and the control class show a very striking difference in the achievement of the Minimum Passing Criteria (KKM). In the experimental class, all students (100%) achieved scores above the KKM (> 75), indicating the effectiveness of the Problem-Based Learning model in improving students' ability to identify EFI system damage. In contrast, in the control class, only 21 students achieved the MPC, while 15 students (41.7%) did not. This difference in the distribution of learning outcomes confirms that conventional learning strategies are less able to encourage all students to achieve the specified competencies. The dominance of mastery in the experimental class reinforces the findings of statistical analysis that the PBL model has a significant and strong impact on improving learning outcomes.

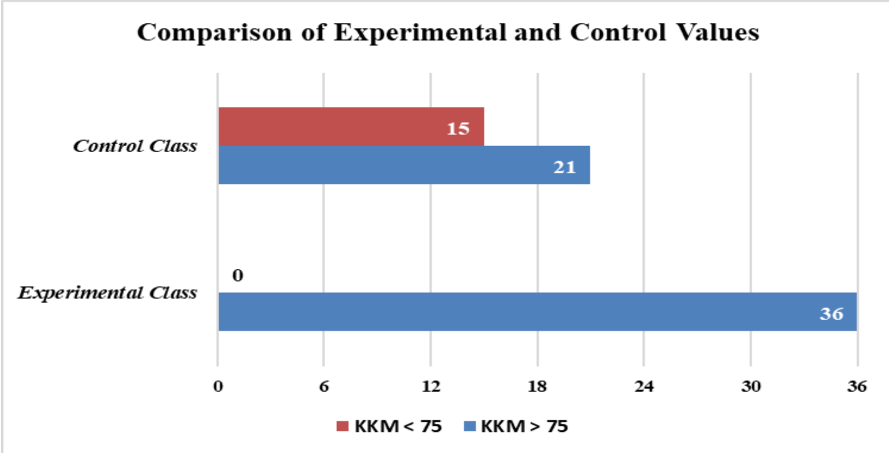

Figure 2. Comparison of Scores Between the Experimental Class and the Control Class

3.8 Improvement in Learning Outcomes in Identifying EFI Damage

The results of the analysis show that the application of the Problem-Based Learning model has a significant effect on improving student learning outcomes in identifying vehicle damage to the Fuel Injection (EFI) electrical system. This empirical evidence can be seen from the statistically significant difference in learning outcomes between the experimental class and the control class with a significance value ($p = .00 < 0.5$). In addition, Cohen's d effect size of 4.311 indicates that the impact of the Problem-Based Learning model is very large in practical terms. This finding confirms that problem-based learning is able to create a more meaningful and in-depth learning experience compared to conventional learning.

The findings of this study are in line with various studies showing that PBL can improve analytical skills and problem-solving abilities in the context of vocational learning (Jumhur et al., 2024; Nurul Iskandar et al., 2021; Sakti & Luthfiyah, 2024). In the EFI system material, students are required to understand the relationship between damage symptoms, such as excessive fuel consumption, difficulty starting the engine when cold, sputtering at low RPM, check engine light, and high emissions, with the working principles of sensors, actuators, and ECUs (Diep et al., 2023). Difficulties in understanding cause-and-effect relationships in EFI systems are a major challenge for students, especially in the diagnosis process (Singureanu & Copae, 2020). The results of this study indicate that students in the experimental class were better able to relate symptom information to EFI system components than students in the control class, who tended to rely solely on the teacher's explanations without conducting independent investigations.

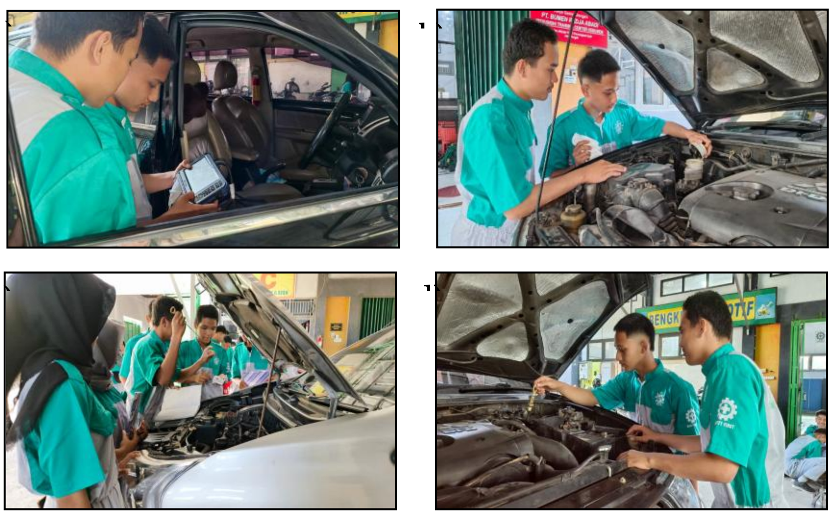

Figure 3. Car Inspection Process: a) Scanning Damage to the EFI System; b) Checking the Oil; c) Engine Oil Check; d) Re-examination

One of the challenges found in this study was the low ability of some students to conduct in-depth analysis of technical issues in EFI systems. In the control class, students often had difficulty determining the components causing the damage because they were not accustomed to systematically analysing symptom data. This phenomenon is similar to the difficulties students encountered in understanding the context of questions in previous HOTS studies, namely that students were not accustomed to working on questions that required layered analysis and logical reasoning (Wahyuddin et al., 2021). Students prefer direct and explicit questions, so when given diagnostic problems that require conceptual understanding, they tend to experience obstacles (Erni et al., 2024; Purwasih, 2020).

Another difficulty found was the low ability to transform technical information into appropriate diagnostic steps (Ogata et al., 2020). This was evident in the answers of the control class students, who often incorrectly determined the cause of damage in cases such as engine sputtering at low RPM or high emission levels (Natalia & Hermawan, 2024). These errors indicate that students are not yet able to integrate the concept of sensor operation with real conditions in vehicles. In contrast, students in the experimental class were better able to understand the relevance of data such as sensor signals, engine operating temperature, and air-fuel ratio, because they were accustomed to discussing and solving these problems through group discussions and structured investigations during PBL learning. Processing ability was also a distinguishing factor between the two groups. In the control class, students still often made mistakes in technical reasoning, such as misinterpreting signs of damage or incorrectly concluding the function of EFI components. These obstacles indicate that conventional learning has not been able to provide learning experiences that encourage students to practise analysing technical data in depth. Meanwhile, the application of PBL in the experimental class successfully trained students in formulating hypotheses, testing possible causes of damage, and drawing logical conclusions based on the symptoms given.

In addition to cognitive aspects, this study also found that control class students tended to show lower levels of interest and persistence in completing case-based questions. Many students did not complete the questions thoroughly or provided answers without adequate analysis. This shows that students are not yet accustomed to questions that require complex reasoning (Azahar, Abdulloh, et al., 2025; Erni et al., 2024). In contrast, in the experimental class, students appeared to be more challenged and actively involved, mainly because PBL provides space for group work, discussion, and investigative activities that resemble real diagnostic practices in the automotive industry (Nurtanto et al., 2018; Wilantara, 2018).

To overcome these various obstacles, the quality of learning needs to be continuously improved, particularly in terms of understanding the basic concepts of EFI systems and the ability to analyse malfunctions. Teachers can strengthen learning through the use of simulation media (Azahar, Hilhamsyah, et al., 2025), demonstrations of real components (Handika et al., 2024), or more varied vehicle damage scenarios. In addition, it is important for teachers to familiarise students with problem-based questions so that their analytical skills develop gradually. Thus, the results of this study not only demonstrate the success of PBL in improving learning outcomes but also provide important directions for the development of more effective learning strategies for EFI system subjects in vocational schools. In its implementation, PBL encourages students to actively participate in the learning process through solving real-world problems (Putri, 2021). In the context of the EFI system, students are faced with problems such as inefficient vehicles or certain technical malfunctions. This process requires students to identify problems, analyse data, use tools, and formulate appropriate solutions. PBL also involves teamwork, which not only improves critical thinking skills but also communication and collaboration skills (Karlina & Wirdati, 2023; Mukhlisin et al., 2025).

One of the advantages of PBL is its ability to integrate theory and practice (Mukhlisin et al., 2025). Through this approach, students not only learn to understand technical concepts but also apply them in real-life situations (Karlina & Wirdati, 2023). For example, students faced with a case study of EFI system failure must use their knowledge of electrical components and diagnostic tools to determine the source of the problem. This problem-based approach directly trains critical analysis, evaluation, and decision-making skills. The results of this study are also relevant to the needs of the automotive industry, which demands graduates with good problem-solving skills. In their daily work, technicians are often faced with problems that require quick and accurate diagnosis. By implementing PBL, students are trained to think systematically and logically, skills that are very important in a dynamic work environment (Karlina & Wirdati, 2023; Nugrahani & Asri Hardini, 2021). However, the effectiveness of PBL cannot be separated from the role of the teacher as a facilitator (Jumhur et al., 2024). Teachers must be able to design relevant and challenging problem scenarios, provide appropriate guidance, and create a supportive learning environment (Saputri & Kesumawardani, 2021). In addition, the availability of facilities such as diagnostic tools, practice vehicles, and adequate learning materials are also important factors in the successful implementation of PBL (Putri, 2021).

4. CONCLUSION

This study concludes that the problem-based learning model has a significant effect on improving student learning outcomes in identifying vehicle damage to the Fuel Injection (EFI) electrical system. This is evidenced by the significance value ($p = .00 < 0.5$) and effect size (Cohen's d) which indicates a high category ($d = 4.311$), meaning that the learning intervention has a strong practical and statistical impact. The improvement in learning outcomes was evident in the students' ability to understand the working principles of the EFI system, identify symptoms of damage, determine the problematic components, and perform a simple analysis of the causes of damage. These findings indicate that structured, case-based learning that provides more extensive practice opportunities can improve students' overall technical diagnostic skills. This study confirms that the success of learning outcome improvement is not only influenced by learning materials or tools, but also by appropriate pedagogical strategies, active student participation, and direct involvement in solving authentic problems. Therefore, teachers and schools need to continue to develop learning approaches that are relevant to the needs of the modern automotive industry so that students have the competencies required by the world of work.

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