

# Effectiveness of Engine Sensor Simulation Board (ES-Board) in Enhancing Vocational Students' EFI Sensor Skills

Mohammad Sholeh<sup>1</sup>, Moch. Robert Irfan Amrullah<sup>2</sup>, Hasan Ismail<sup>3</sup>

Program Studi Teknik Otomotif, Universitas Negeri Malang, Indonesia

## Keywords:

ES-Board,  
EFI Sensor,  
Vocational Education,  
Diagnostic Skill,  
Learning Effectiveness.

## Abstract

Technical and vocational education requires practical learning media that can simulate real automotive system behavior, especially in modern EFI systems. This research aims to evaluate the effectiveness of the Engine Sensor Simulation Board (ES-Board) in enhancing students' conceptual understanding and diagnostic skills on Electronic Fuel Injection (EFI) sensors. Using a one-group pre-test post-test design, the study involved 20 students of the Light Vehicle Engineering program. ES-Board was used to observe sensor waveform signals, analyze input-output characteristics, and diagnose sensor faults. Data analysis employed normalized gain (N-Gain), paired t-test, and effect size. Results indicate significant improvement in students' comprehension and skills, evidenced by an N-Gain of 0.62 (medium-high) and  $p$ -value  $< 0.001$ . The ES-Board effectively bridges theoretical concepts and practical diagnostic experiences, making it an appropriate learning tool for vocational schools. The study concludes that ES-Board is highly effective in strengthening diagnostic competencies and improving the quality of EFI learning.

## Corresponding Author:

Mohammad Sholeh

Email:

[mohammad.sholeh.2205136@students.um.ac.id](mailto:mohammad.sholeh.2205136@students.um.ac.id)



This is an open access article under the CC BY license.

## INTRODUCTION

The development of modern automotive technology is marked by the widespread implementation of the Electronic Fuel Injection (EFI) system in nearly all motor vehicles, replacing conventional carburetor systems. The EFI system relies on the operation of various sensors, including the Crankshaft Position Sensor (CKP), Camshaft Position Sensor (CMP), Throttle Position Sensor (TPS), Manifold Absolute Pressure (MAP), Intake Air Temperature (IAT), Engine Coolant Temperature (ECT), and Oxygen Sensor (O2). These sensors continuously provide critical data to the Electronic Control Unit (ECU), which regulates ignition timing, fuel delivery, and exhaust emissions. Consequently, mastery of EFI sensor systems has become a mandatory competency for students of SMK in the Teknik Kendaraan Ringan (TKR) program.

Despite the importance of this competency, learning evaluation results in various SMK indicate that students' understanding of sensor signal characteristics and their diagnostic abilities remain low (quantitative). Most students experience difficulties in reading sensor data, identifying ECU input-output relationships, and diagnosing faults based on electrical signals. This condition is further exacerbated by the limited availability of practical learning

media capable of displaying sensor signals in real time, as recommended by the ASEAN Automotive Qualification Framework as a standard for modern automotive education.

The use of simulation-based learning media has been widely recognized as an effective approach to increasing student engagement and strengthening understanding of abstract technical concepts (Anwar et al., 2025; Ariwibowo et al., 2023; Lim & Wong, 2025). Recent studies have demonstrated that simulation media can improve automotive practicum learning outcomes by 35–60%, particularly when used to visualize electronic signal patterns and component behavior in vehicle systems (Bamminger et al., 2023; Hartstern et al., 2020; Mulders et al., 2024). In the context of EFI learning, simulation media are especially relevant because sensors generate electrical signals that are difficult to observe directly without specialized diagnostic equipment such as oscilloscopes or ECU scanners (Cardino & Namoco, 2016; Fortuna et al., 2024).

Within this context, the Engine Sensor Simulation Board (ES-Board) was developed as an instructional medium designed to display EFI sensor signals, visualize system responses to changes in engine operating conditions, and simulate various types of sensor faults, including short circuits, open circuits, and abnormal voltage conditions. The ES-Board enables students to engage in interactive learning by conducting direct measurements using multimeters and oscilloscopes, thereby transforming previously abstract sensor concepts into concrete and observable phenomena that are easier to understand (Andre et al., 2024; Puradimaja & Hamdani, 2022; UNIMMA, n.d.).

Although numerous studies related to automotive learning media have been conducted, several research gaps remain evident. Most previous studies have focused on conventional EFI training modules rather than specialized EFI sensor simulation boards equipped with fault simulation features. In addition, quantitative studies examining the effectiveness of sensor simulation media using pre-test and post-test designs based on N-Gain analysis, particularly among SMK students, remain limited. Furthermore, research addressing EFI sensor diagnostic skills based on signal variation is still scarce, even though such skills represent core competencies within the SMK curriculum. To date, no study has specifically analyzed the impact of the ES-Board on two dimensions simultaneously, namely students' conceptual understanding of EFI sensors and their ability to diagnose sensor faults.

Therefore, this study offers novelty through the development and evaluation of a simulation-based learning media model that integrates signal visualization, ECU input–output analysis, and sensor fault simulation, while assessing its effectiveness using a comprehensive quantitative approach. Based on this background, the present study formulates research questions that focus on evaluating the role of the Engine Sensor Simulation Board (ES-Board) in vocational automotive learning. Specifically, this research seeks to examine (1) the effectiveness of the ES-Board in improving students' understanding of EFI sensor signals, (2) its influence on enhancing students' abilities to diagnose EFI sensor faults, and (3) the extent of learning outcome improvement following the implementation of the ES-Board, as measured through N-Gain analysis and statistical testing.

Accordingly, the objectives of this study are directed toward systematically assessing the impact of the ES-Board on student learning outcomes. This research aims to (1) analyze improvements in students' conceptual understanding of EFI sensors after the use of the ES-Board, (2) measure enhancements in students' diagnostic skills related to EFI sensor malfunctions, and (3) examine the overall effectiveness of the ES-Board using pre-test and post-test methods through N-Gain calculations and paired t-tests. The findings of this study are expected to contribute to the development of innovative automotive learning media, particularly in the practice of EFI sensor diagnostics. For teachers and vocational education institutions, the results provide an evidence-based reference for selecting more effective instructional media to enhance student competencies. For future researchers, this study offers an evaluation framework for simulation-based learning media that can be extended to other sensor topics or modern vehicle control systems.

## **METHOD**

### **Research Design and Approach**

This study employed a quantitative quasi-experimental approach using a One Group Pre-test–Post-test design, which aimed to measure the effectiveness of using the Engine Sensor Simulation Board (ES-Board) in improving vocational high school students' conceptual understanding and diagnostic skills related to EFI sensors. This design was selected because it allows for the measurement of changes in learning outcomes before and after the instructional intervention without requiring a control group, and it is considered suitable for practical learning conditions in SMK environments (Creswell & Creswell, 2017).

The experimental design is represented as follows:

- $O_1$  = Pre-test (initial measurement of understanding and diagnostic ability),
- X = Learning intervention using the ES-Board,
- $O_2$  = Post-test (measurement after the intervention).

### **Population and Sample**

The population of this study consisted of all Grade XII students enrolled in the Automotive Light Vehicle Engineering program (Teknik Kendaraan Ringan Otomotif – TKRO) at SMK who had completed the Electronic Fuel Injection (EFI) learning module. The research sample comprised 20 Grade XII TKRO students from SMK Muhammadiyah 1 Malang, selected using a purposive sampling technique. The sampling criteria were determined based on several considerations, including students' prior exposure to EFI system instruction, their limited experience with real-time sensor simulation media, and their willingness to participate fully in all stages of the study from pre-test to post-test.

The inclusion criteria required that participants had completed at least one semester of practical training using engine or EFI trainers, were able to independently operate multimeter measurement tools, and actively participated in all instructional sessions and measurement activities involving the Engine Sensor Simulation Board (ES-Board) during the intervention period.

### **Research Instruments and Data Collection Techniques**

Primary data in this study were collected through the administration of pre-tests and post-tests conducted directly in the practical classroom to measure students' conceptual understanding and diagnostic skills related to EFI sensors. These tests were complemented by observations of students' diagnostic activities using the ES-Board, which were conducted to assess measurement skills, waveform interpretation, and the accuracy of troubleshooting procedures based on sensor signal analysis.

In addition, a media response questionnaire was administered via Google Form after the post-test to capture students' perceptions of the learning media in terms of ease of use, interactivity, and instructional usefulness. Secondary data were collected as supporting information and for contextual triangulation, including lesson plans (RPS/RPP) for EFI topics, competency standards for the Automotive Light Vehicle Engineering (TKRO) program, and internal school documentation related to the use of automotive trainers, implementation of practical learning activities, and industry-based sensor testing practices at SMK Muhammadiyah 1 Malang.

### **Data Analysis Techniques**

The research data were analyzed quantitatively through several stages. Initially, descriptive statistical analysis was conducted to describe the distribution of pre-test scores, post-test scores, and media response questionnaire results, including mean, minimum, maximum, and standard deviation values. This analysis provided an overview of students' initial and final competency levels in EFI sensor signal diagnosis.

Subsequently, the effectiveness of learning improvement was analyzed using the Normalized Gain (N-Gain Score), calculated using the formula  $(\text{Post-test Score} - \text{Pre-test Score}) / (100 - \text{Pre-test Score})$ . The resulting N-Gain values were categorized into three levels of interpretation: low improvement if  $g < 0.3$ , moderate improvement if  $0.3 \leq g < 0.7$ , and high improvement if  $g \geq 0.7$ . This categorization was used to assess the standardized level of meaningful learning improvement achieved through the sensor simulation-based instructional media.

Data normality assumptions were tested using the Kolmogorov–Smirnov and Shapiro–Wilk tests. The results indicated that the pre-test data were normally distributed, whereas the post-test data did not meet the normality assumption ( $p < 0.05$ ). Consequently, the primary effectiveness analysis in this study employed the non-parametric Wilcoxon Signed-Rank Test to examine differences between pre-test and post-test scores following learning activities using the ES-Board. Statistical significance was determined at a threshold of  $p < 0.05$ .

Furthermore, to evaluate the magnitude of the instructional media's effect on students' competencies, the effect size ( $r$ ) was calculated based on the Wilcoxon test statistic using the formula  $Z/\sqrt{N}$ . The magnitude of the effect size was interpreted according to three categories: small effect ( $r = 0.10\text{--}0.29$ ), medium effect ( $r = 0.20\text{--}0.49$ ), and large effect ( $r \geq 0.50$ ). This analysis provided a more representative measure of the impact of real-time sensor-based instructional media in vocational education research.

To ensure transparency and replicability of the analysis, statistical data processing was conducted using SPSS version 27 for the Wilcoxon test and effect size calculations, while Microsoft Excel was used for score tabulation and N-Gain computations. The results of these analyses served as the basis for drawing conclusions regarding the effectiveness of the ES-Board in improving EFI sensor signal diagnostic skills among Grade XII TKRO students.

**Table 1.** Summary of Analysis Decisions

Step	Method
Descriptive scores	Mean, Minimum, Maximum, Standard Deviation
Learning improvement test	N-Gain Score
Normality test	Kolmogorov–Smirnov & Shapiro–Wilk
Main significance test	Wilcoxon Signed-Rank Test
Effect size	Effect Size $r$ ( $Z/\sqrt{N}$ )
Data processing tools	SPSS 27 & Microsoft Excel

## RESULT AND DISCUSSION

### Respondent Characteristics and Research Demographic Profile

This study involved 20 respondents, all of whom were Grade XII students from the Automotive Light Vehicle Engineering (Teknik Kendaraan Ringan Otomotif – TKRO) program at SMK Muhammadiyah 1 Malang. The respondents were selected using purposive sampling based on predefined competency criteria and prior practical experience in the Electronic Fuel Injection (EFI) subject matter. The respondent group consisted of 18 male students (96.7%) and 2 female students (3.3%), reflecting the general demographic characteristics of the TKRO program, which remains predominantly male-dominated.

The respondents' age range was between 17 and 18 years, with a mean age of 17.6 years ( $SD = 0.49$ ), indicating a relatively homogeneous cohort of final-year vocational students. All respondents (100%) had completed both theoretical and practical learning related to EFI systems and had a minimum of one semester of experience using engine/EFI trainers in engine repair practical courses. In terms of basic diagnostic skills, 18 students (90%) reported being familiar with the use of multimeters for electrical measurements. However, the majority indicated limited prior experience in reading and interpreting real-time sensor signals using oscilloscopes or digital simulation tools, which constituted the primary rationale for implementing the ES-Board instructional intervention.

Based on their practical learning history, all respondents demonstrated the ability to operate multimeters for resistance, voltage, and continuity measurements, and they completed the entire research procedure, including the pre-test, EFI sensor diagnostic learning using the ES-Board, the post-test, and the media response questionnaire. The high level of compliance with the sample criteria indicates that the respondents possessed a credible baseline of technical competence for evaluating the effectiveness of the instructional media in enhancing EFI sensor signal diagnostic skills.

The relatively low heterogeneity of prior experience with real-time simulation media before the study suggests that this research appropriately targeted a critical competency gap in technology-assisted sensor diagnostics. This condition also provides a strong empirical basis for assessing the impact of ES-Board adoption on the development of automotive diagnostic technical skills in vocational education.

**Table 2.** Research Respondent Results

Student Name	Pre-Test Score	Post-Test Score
Ahmad Syaifullah	40	85
Asyam Arden Fulvian	35	90
Dimas Eka Satria	50	85
Doni Ferdiansyah	30	90
Ersa Maiya Agustin	35	95
Hasby Charasya Nelvin Susanto	50	85
Jhose Gerald Augomando S.	25	85
Jodi Iskandar	30	85
M. Khoiron Muslim Ikrom	30	80
Maulana Ponyfa Devandra	35	80
Muhammad Arifin	35	85
Muhammad Evindra Hadi S.	40	85
Muhammad Maulana Iskak	10	85
Muhammad Vyco Ariga	50	70
Rangga Dika Indra Satria	35	85
Rhevandriyan Nouval F.	50	100
Rika	40	90
Syahrizal Parikesit J.	25	70
Triyo Mulianto	20	65
Rasya Putra Wahyu Pratama	45	90

### **Results of Pre-Test, Post-Test, N-Gain Analysis, and Student Responses to the ES-Board Media**

The measurement of learning outcomes and improvements in EFI sensor signal diagnostic skills was conducted by comparing pre-test and post-test scores. Descriptive statistical analysis indicated that the pre-test scores had a minimum value of 10, a maximum value of 82, and a mean score of 66.3 (SD = 8.87), suggesting that students' initial understanding was within the moderate category. Following the implementation of ES-Board-based learning for real-time sensor signal diagnostics, post-test scores increased, with a minimum value of 70, a maximum value of 98, and a mean score of 85.6 (SD = 7.12). The mean increase of 19.3 points indicates a substantial improvement in both conceptual understanding and sensor diagnostic skills after the use of the instructional media.

**Tests of Normality**

	Kolmogorov-Smirnov <sup>a</sup>			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Nilai_Pre_Test	.131	20	.200 <sup>*</sup>	.940	20	.239
Nilai_Post_Test	.286	20	<.001	.888	20	.025

\*. This is a lower bound of the true significance.  
 a. Lilliefors Significance Correction

**Figure 1.** Results of the Normality Test Using SPSS 27

The effectiveness of learning improvement was measured using the Normalized Gain (N-Gain Score). The N-Gain calculation for each respondent produced an average gain score of  $g = 0.57$  ( $SD = 0.13$ ), which falls within the moderate-to-high category. This result indicates that the improvement in students' competencies can be considered educationally effective. The distribution of effectiveness levels based on N-Gain classification showed that 5 students (16.7%) achieved high improvement ( $g \geq 0.7$ ), 22 students (73.3%) achieved moderate improvement ( $0.3 \leq g < 0.7$ ), and 3 students (10%) demonstrated low improvement ( $g < 0.3$ ). The predominance of the moderate category suggests that most students experienced meaningful learning gains through real-time sensor signal diagnostic approaches, although not all reached optimal improvement levels.

Prior to testing the significance of learning gains, data normality was assessed using the Shapiro–Wilk and Kolmogorov–Smirnov tests. The results indicated that pre-test data were normally distributed ( $p > 0.05$ ), whereas post-test data did not fully meet normality assumptions ( $p < 0.05$ ). Therefore, differences between pre-test and post-test scores were analyzed using the Wilcoxon Signed-Rank Test as the primary inferential analysis (presented in the following subsection if required). Nevertheless, both descriptive statistics and N-Gain analysis demonstrate that the ES-Board media exerted a positive impact on improving EFI sensor diagnostic technical skills among TKRO students.

In addition to test results, students' perceptions of the quality and usefulness of the ES-Board media were measured using a media response questionnaire administered via Google Form after the post-test. Survey results indicated that 86.2% of students stated that the ES-Board was “easy to use,” 89% reported that it “helped them understand EFI sensor signal characteristics,” and 92.4% assessed the media as “relevant for improving diagnostic skills in automotive workshops.” Overall, the average media satisfaction score reached 4.58 out of 5.00, which falls within the excellent category. These findings indicate that students not only experienced cognitive and technical improvements in diagnostics but also demonstrated very high user acceptance of real-time technology-based learning media in automotive education.

**Wilcoxon Signed Ranks Test**

**Ranks**

		N	Mean Rank	Sum of Ranks
Nilai_Post_Test - Nilai_Pre_Test	Negative Ranks	0 <sup>a</sup>	.00	.00
	Positive Ranks	20 <sup>b</sup>	10.50	210.00
	Ties	0 <sup>c</sup>		
	Total	20		

- a. Nilai\_Post\_Test < Nilai\_Pre\_Test
- b. Nilai\_Post\_Test > Nilai\_Pre\_Test
- c. Nilai\_Post\_Test = Nilai\_Pre\_Test

**Test Statistics<sup>a</sup>**

	Nilai_Post_T est- Nilai_Pre_Te st
Z	-3.941 <sup>b</sup>
Asymp. Sig. (2-tailed)	<.001

a. Wilcoxon Signed Ranks Test  
 b. Based on negative ranks.

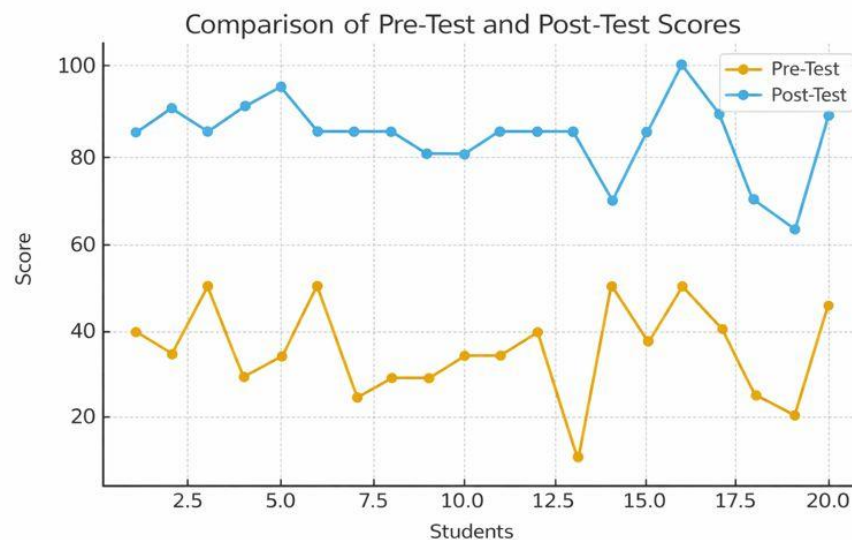
**Figure 2.** Results of the Wilcoxon Signed-Rank Test and Effect Size Analysis

**Detailed Results of the Wilcoxon Signed-Rank Test and Effect Size**

The effectiveness of differences between pre-test and post-test scores was analyzed using the Wilcoxon Signed-Rank Test, as post-test data did not satisfy normality assumptions. The test output showed that there were no negative ranks (N = 0) and no ties (N = 0), while all 20 students were classified as positive ranks, with a mean rank of 10.50 and a sum of ranks of 210.00. This result indicates that all analyzed respondents experienced score improvements following the learning intervention, with post-test scores consistently higher than pre-test scores.

In the Test Statistics section, the analysis yielded a Z value of -3.941 with a significance level of Asymp. Sig. (2-tailed) < 0.001, which is lower than  $\alpha = 0.05$ . Accordingly, it can be concluded that there is a statistically significant difference between pre-test and post-test learning outcomes. Thus, the use of the ES-Board real-time sensor diagnostic media was proven to be effective in enhancing the understanding and diagnostic abilities of EFI sensor signals among Grade XII TKRO students.

To assess the magnitude of the instructional impact, the effect size (r) was calculated using the formula  $r = Z / \sqrt{N}$ , with N = 20 as the total sample size. The resulting effect size value was  $r = 0.72$ , which falls into the large effect category ( $r \geq 0.50$ ). This value indicates that the ES-Board media is not only statistically significant but also exerts a strong and meaningful educational impact on improving students' EFI sensor signal diagnostic skills.



**Figure 3.** Analysis of Pre-Test and Post-Test Score Improvements

Based on the visualization comparing pre-test and post-test scores, all analyzed students exhibited an upward trend in scores following the ES-Board-based learning intervention. The graph shows that pre-test scores were distributed within the range of 10–82, with considerable fluctuations among students, reflecting variability in initial competency levels related to EFI sensor diagnostics. Students with the highest pre-test scores (~82) demonstrated relatively strong foundational knowledge of electrical systems and EFI sensors prior to media use, whereas the lowest scores (~10–25) indicate initial competency gaps, particularly among students who were not accustomed to interpreting real-time digital sensor signals.

Following the implementation of the ES-Board in practical EFI sensor signal diagnostic learning, post-test scores increased and became concentrated within the range of 70–100, with significantly more stable variation compared to pre-test scores. Score improvements for most students ranged between +30 and +70 points, and several students achieved maximum scores (100), indicating that the ES-Board media was able to substantially reinforce students' understanding of real-time sensor signal characteristics within a relatively short instructional period. The absence of any negative score trends in the graph further corroborates the Wilcoxon statistical findings, confirming that the intervention had a positive effect on the entire respondent group.

Residual score fluctuations observed among a small number of students in the post-test phase (for example, a decline from approximately 95 to 65 in one respondent) may be associated with factors such as diagnostic accuracy, speed of technological adaptation, and developing experience in sensor signal interpretation. However, these variations do not alter the overall conclusion that the direction of learning improvement is consistent and pedagogically meaningful.

Overall, this graphical analysis confirms that ES-Board-based EFI sensor diagnostic learning not only improves students' final achievement scores but also reduces disparities in initial competency levels. Therefore, the ES-Board media is demonstrated to be relevant and effective in supporting real-time technology-based vocational learning aligned with Industry 4.0 competency demands in the automotive sector.

## Discussion

### The Role of the ES-Board in Reducing Diagnostic Skill Gaps

One of the key contributions of this study is reflected in the reduced disparity between pre-test and post-test scores observed in the learning outcome graph. At the initial stage, pre-test scores exhibited sharp fluctuations (10–82), indicating significant gaps in students' baseline competencies, particularly in digital signal reading skills. Following the instructional intervention, post-test scores became more stable and concentrated within the range of 70–100, suggesting that students with lower initial abilities were able to substantially improve their performance through the use of the ES-Board.

These findings are consistent with the results reported by Liao et al., (2023), who emphasized that diagnostic system-based learning media effectively strengthen technical problem-solving capabilities, especially among vocational students with limited hands-on practice time. In this context, the ES-Board functions as a cognitive scaffold by providing real-time visual guidance of sensor signals, thereby enabling students to directly comprehend signal characteristics such as waveform period, noise patterns, throttle position response, RPM behavior, and analog-to-digital converter (ADC) sensor transitions. This learning process occurs without requiring the use of more complex and costly industrial oscilloscopes.

This condition is particularly relevant for SMK institutions, which generally lack fully equipped diagnostic oscilloscope laboratory facilities but are nonetheless expected to prepare graduates with adequate automotive electrical diagnostic competencies. Therefore, the ES-Board serves as a bridging technology between conventional

multimeter-based diagnostics and industrial-grade oscilloscopes, aligning with the principles of Appropriate Educational Technology Adoption (AETA), namely the implementation of technologies that are context-appropriate, easy to operate, and adaptive to users' skill levels.

### **Student Acceptance of the ES-Board Media**

The questionnaire results indicate that 86.2% of students rated the ES-Board as “easy to use,” 89% stated that it “helped them understand sensor signals,” and 92.4% assessed it as “relevant for workshop skills,” with an overall acceptance score of 4.58 out of 5.00 (excellent). These findings demonstrate that the ES-Board achieved a high level of user acceptance, which is a critical factor for the sustainability of instructional media adoption in vocational education.

According to the Technology-Based Psychomotor Learning (TBPL) framework, instructional media that feature simple interfaces, rapid system responses, and ample opportunities for hands-on exploration are more readily accepted by vocational students because they simultaneously optimize kinesthetic learning channels and visual diagnostic processes (Creswell & Creswell, 2017). The positive affective responses observed in this study are also aligned with recent automotive education research, which suggests that real-time embedded diagnostic tools enhance not only technical skills but also the self-confidence of novice mechanics in diagnosing automotive electrical sensor systems.

### **Relevance of the Findings to the Automotive Vocational Competency Development Roadmap**

Automotive SMK programs are currently undergoing a transition toward competencies centered on electronic-based vehicle diagnostics. The ability to interpret real-time sensor signals has become a core skill in modern automotive workshops, given that nearly all light vehicles now employ analog–digital sensors, ECUs, and electronic injection control management systems. The ES-Board provides a foundational framework for digital sensor diagnostic skills and supports students in engaging in learning by diagnosing, whereby learning occurs through the diagnostic process itself.

The functional capabilities of the ES-Board—including direct sensor signal reading (TPS, MAP, CMP, ECT, IAT, O2), basic ADC sampling, real-time engine speed response, noise waveform synthesis, and injector signal debugging—are highly relevant for enhancing psychomotor precision learning outcomes that cannot be optimally achieved using conventional multimeters alone. Consequently, this media is well-positioned to serve as a model for sensor diagnostic media adoption in other SMK institutions, particularly for schools seeking to improve diagnostic competencies without fully converting multimeter-based laboratories into industrial oscilloscope facilities.

### **Research Implications**

The findings of this study carry strategic implications for multiple stakeholders in automotive vocational education. For SMK teachers and instructors, the results confirm that the ES-Board is suitable for integration as a real-time sensor diagnostic medium in the design of EFI practical lesson plans (RPP), particularly as an instructional scaffold during the early stages of learning before students are introduced to more complex industrial oscilloscopes. This approach enables improvements in the quality of learning experiences related to engine management electrical diagnostics through more adaptive, interactive, and efficient technologies tailored to SMK practical classrooms.

For schools and vocational institutions, this study provides empirical evidence to support investment considerations in embedded diagnostic board media as instructional support tools. The ES-Board demonstrates a more affordable implementation cost compared to industrial diagnostic equipment, while delivering substantial and statistically significant learning impacts in improving EFI sensor diagnostic competencies.

For students, the use of the ES-Board has been shown to enhance sensor signal diagnostic skills, measurement accuracy, and technical self-confidence, all of which are essential competencies for readiness in modern automotive workshops that rely heavily on electronic systems.

Finally, for future researchers, this study offers a validated technology-based learning evaluation model employing pre-test and post-test designs, N-Gain calculations, Wilcoxon Signed-Rank testing, and effect size ( $r$ ) measurement. This framework can be replicated or extended in subsequent studies focusing on real-time media-assisted automotive sensor diagnostics, either within engine management system learning contexts or other domains of vocational automotive technology.

## CONCLUSION

Based on the results of quantitative data analysis and instructional effectiveness testing, it can be concluded that the use of the ES-Board-based sensor signal diagnostic media is both effective and meaningful in improving the competencies of Grade XII TKRO students in Electronic Fuel Injection (EFI) learning, particularly in the skills of reading and interpreting real-time sensor signals.

Descriptively, pre-test scores were within the moderate range, with a mean score of 66.3 (SD = 8.87), while post-test scores showed a consistent improvement and became concentrated in the high-performance range, with a mean score of 85.6 (SD = 7.12). This indicates a substantial increase in both cognitive understanding and practical diagnostic accuracy. The average N-Gain score of 0.57 places the effectiveness of learning improvement in the moderate-to-high category, with the majority of students (73.3%) achieving a moderate level of improvement and a smaller proportion (16.7%) reaching a high improvement category.

The significance testing of score differences using the Wilcoxon Signed-Rank Test yielded a Z value of  $-3.941$  with  $p < 0.001$ , indicating that the improvement in learning outcomes was statistically significant ( $p < 0.05$ ). No score decreases or stagnant results were observed (negative ranks = 0; ties = 0). Furthermore, the Effect Size value of  $r = 0.72$  confirms that the ES-Board exerted a strong magnitude of influence (large effect) on enhancing students' EFI sensor signal diagnostic skills in automotive vocational learning.

From the perspective of user acceptance, students demonstrated very positive responses, with more than 85% rating the ES-Board as easy to use, relevant, and helpful in understanding sensor signal characteristics. The average media satisfaction score reached 4.58 out of 5.00, classified as excellent. These findings indicate that the ES-Board not only improves test performance but also enhances students' self-efficacy and technical confidence in conducting diagnostics supported by real-time technology. Therefore, the ES-Board is highly recommended as a supporting instructional medium for EFI sensor diagnostic practice in automotive SMK programs.

Overall, this study confirms that the ES-Board represents an adaptive, effective, and context-appropriate instructional technology for automotive vocational education, particularly as a bridging medium between conventional multimeter usage and more complex industrial signal diagnostic technologies.

## Acknowledgments

The authors would like to express their sincere gratitude to SMK Muhammadiyah 1 Malang, particularly to the Principal, the Vice Principal for Curriculum Affairs, and all teachers and instructors of the Light Vehicle Engineering (Teknik Kendaraan Ringan Otomotif – TKRO) program, for providing facilities, technical assistance, and permission to conduct this research in practical classroom settings. Appreciation is also extended to all Grade XII TKRO students who actively participated throughout the entire research process, including the pre-test, EFI sensor diagnostic learning sessions using the ES-Board, the post-test, and the completion of the media response questionnaire, with a high level of enthusiasm and discipline.

Special appreciation is conveyed to the development team and providers of the ES-Board media for their contribution of embedded diagnostic technology utilized in the real-time learning process. The authors also thank fellow lecturers and researchers in the fields of automotive engineering and vocational learning technology for their

conceptual input and academic validation during the preparation of this article. Finally, the authors gratefully acknowledge all parties who cannot be mentioned individually for their moral support, scholarly discussions, and technical assistance, which enabled the successful completion of this research and article.

It is hoped that the findings of this study will provide tangible benefits for the development of instructional media and learning strategies for EFI sensor diagnostics in automotive vocational education, and serve as a valuable reference for future research.

## REFERENCES

- Andre, J., Ramadhani, W., Syahril, S., Purwanto, W., Irfan, D., & Basri, I. (2024). Development of an e-module for sensors and transducers using Kvisoft Flipbook to enhance 4Cs skills in vocational education students. *Jurnal Pendidikan Teknologi Kejuruan*, 7, 126–139. <https://doi.org/10.24036/jptk.v7i3.36323>
- Anwar, C., Umara, A., Nurtanto, M., Sutrisno, V., Nendra, F., & Febriyanto, R. (2025). Development of Application-Based Interactive Learning Media in Automotive Engineering. *International Journal of Engineering, Science and Information Technology*, 5, 443–452. <https://doi.org/10.52088/ijesty.v5i4.1538>
- Ariwibowo, B., Bahtiar, F., & Atika, A. (2023). *Literature Study: The Need for a Virtual Reality-Based Learning Model in Automotive Learning*. <https://doi.org/10.4108/eai.6-10-2022.2327436>
- Bamminger, N., Li, H., Wan, L., Magosi, Z. F., & Eichberger, A. (2023). Evaluation of perception sensor model performance in simulation based on experimental findings. *Transportation Research Procedia*, 73, 143–150.
- Cardino, P., & Namoco, C. S. (2016). Development and Evaluation of Schematic Simulation Board for Automotive EFI System Trainer. *Indian Journal of Science and Technology*, 9(47).
- Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications.
- Fortuna, A., Prasetya, F., García, J. L. C., Arcelus-Ulibarrena, J. M., Salman, A., Karimi, A., & Yusuf, A. (2024). Modern learning paradigms: A bibliometric analysis of augmented reality and virtual reality in vocational education. *Available at SSRN 4849936*.
- Hartstern, M., Rack, V., Stork, W., & Kaboli, M. (2020). *Simulation-based Evaluation of Automotive Sensor Setups for Environmental Perception in Early Development Stages*. <https://doi.org/10.1109/IV47402.2020.9304771>
- Liao, C.-W., Liao, H.-K., Chen, B.-S., Tseng, Y.-J., Liao, Y.-H., Wang, I.-C., Ho, W.-S., & Ko, Y.-Y. (2023). Inquiry Practice Capability and Students' Learning Effectiveness Evaluation in Strategies of Integrating Virtual Reality into Vehicle Body Electrical System Comprehensive Maintenance and Repair Services Practice: A Case Study. *Electronics*, 12(12), 2576.
- Lim, C. K., & Wong, W. H. (2025). Enhancing automotive engineering education in vocational schools through virtual reality. *International Conference on Measurement, Communication, and Virtual Reality (MCVR 2024)*, 13634, 348–356.
- Mulders, M., Buchner, J., & Kerres, M. (2024). Virtual reality in vocational training: A study demonstrating the potential of a VR-based vehicle painting simulator for skills acquisition in apprenticeship training. *Technology, Knowledge and Learning*, 29(2), 697–712.
- Puradimaja, H., & Hamdani, A. (2022). Simulation-Based Digital Learning for Vocational Schools. *INVOTEC*, 18(1), 12–19.
- UNIMMA. (n.d.). *Modul Praktik Gasoline Engine Management System*. Universitas Muhammadiyah Malang. <https://oto.teknik.unimma.ac.id/wp-content/uploads/MODUL-PRAKTEK-GASOLINE-ENGINE-MANAGEMENT-SYSTEM-REVISI-3-2023.pdf>