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ORIGINAL

Simulation-Based Diagnostic Learning with Diagnostic Trouble Box (DTB): Enhancing Analytical Thinking Skills in Vocational Automotive Education

Aprendizaje Diagnóstico Basado en Simulación con la Caja de Fallos Diagnósticos (DTB): Mejora de las Habilidades de Pensamiento Analítico en la Educación Vocacional Automotriz

Valiant Lukad Perdana Sutrisno[1,2], Pardjono[1], Wagiran[1], Muhammad Nurtanto[3], Dianna Ratnawati[4], Anna Marganingsih[5], Farid Mutohhari[6]

[1]Universitas Negeri Yogyakarta, Department of Technology and Vocational Education. Yogyakarta. Indonesia.
[2]Universitas Sebelas Maret, Department of Mechanical Engineering Education. Central Java. Indonesia.
[3]Universitas Negeri Jakarta, Department of Vocational and Technology Education. Jakarta. Indonesia.
[4]Universitas Negeri Malang, Department of Automotive Engineering Education. Malang. Indonesia.
[5]Sekolah Tinggi Ilmu Komunikasi Pembangunan Persada Khatulistiwa, Department of Economy Education. West Kalimantan. Indonesia.
[6]Universitas Sarjanawiyata Tamansiswa, Department of Mechanical Engineering Education. Yogyakarta. Indonesia.

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Corresponding author: Valiant Lukad Perdana Sutrisno

ABSTRACT

Introduction: teaching automotive electrical systems in vocational education presents several challenges, including the abstract nature of the concepts covered and the conventional, non-interactive teaching methods.
Objective: this study aims to describe analytical skills by introducing the Diagnostic Trouble Box (DTB). The research objective focuses on assessing the learning outcomes of the DTB in comparison to traditional methods.
Method: this study employed a quasi-experimental design with a pretest-posttest control group, involving 86 students in the 11th-grade automotive vocational class. Students were assigned to either an experimental group, which was taught using the DTB method, or a control group trained with conventional techniques. Data collection included analytical thinking tests, with data analyzed through paired and independent sample t-tests.
Results: learning with DTB significantly enhanced analytical thinking skills, especially off-set active electrical components based on diagnostics. The post-test mean score of the experimental group was 79,26 while the control group scored 68,41, resulting in a mean difference of 10,85 (p = 0,000). Improvement was most notable in the components of decision-making, systematic reasoning, and diagnostic accuracy. These findings demonstrate the reliability of DTBs for electrical diagnostics and suggest that the model may also be useful for developing other technical competencies based on data-driven problem-solving strategies.
Conclusion: the study highlights the vocational relevance of the DTB model for fostering critical and evaluative competencies in advanced automotive education. It enhances diagnostic preparedness by academically justifying the integration of simulation-based learning into vocational education.

Keywords: Automotive; Vocational Education; Simulation; Analytical Thinking; Diagnostic Trouble Box.

RESUMEN

Introducción: la enseñanza de los sistemas eléctricos automotrices en la educación vocacional presenta múltiples desafíos, entre ellos, la naturaleza abstracta de los conceptos abordados y el uso predominante de métodos tradicionales poco interactivos.
Objetivo: este estudio tiene como propósito fortalecer las habilidades de pensamiento analítico mediante la implementación del Diagnostic Trouble Box (DTB). El objetivo principal de la investigación es evaluar los resultados de aprendizaje obtenidos con el uso del DTB en comparación con los métodos convencionales.
Método: se empleó un diseño cuasi-experimental con grupo control y mediciones pretest y postest, en una muestra de 86 estudiantes de undécimo grado del programa vocacional automotriz. Los participantes fueron asignados a un grupo experimental instruido mediante la metodología DTB, o a un grupo control que recibió enseñanza tradicional. La recolección de datos incluyó pruebas de pensamiento analítico, las cuales fueron analizadas utilizando pruebas t para muestras relacionadas e independientes.
Resultados: el aprendizaje basado en DTB mejoró significativamente las habilidades de pensamiento analítico, en especial en la identificación de componentes eléctricos activos a partir del diagnóstico de fallos. La puntuación media del postest del grupo experimental fue de 79,26 frente a 68,41 en el grupo control, con una diferencia significativa de 10,85 puntos (p = 0,000). Las mejoras más destacadas se observaron en la toma de decisiones, el razonamiento sistemático y la precisión diagnóstica. Estos resultados confirman la eficacia del DTB como herramienta de diagnóstico eléctrico y sugieren su aplicabilidad en el desarrollo de otras competencias técnicas basadas en estrategias de resolución de problemas orientadas por datos.
Conclusión: el estudio resalta la relevancia del modelo DTB en la formación vocacional, al promover competencias críticas y evaluativas esenciales en la educación automotriz avanzada. Además, justifica académicamente la integración del aprendizaje basado en simulación como estrategia didáctica efectiva en el ámbito de la educación técnica y profesional.

Palabras clave: Automotriz; Educación Vocacional; Simulación; Pensamiento Analítico; Diagnostic Trouble Box.

INTRODUCTION

The teaching of electrical systems suffers significantly from a lack of interest among students worldwide, including in Indonesia. The unobservable nature of electricity, such as electric current and voltage, creates a conceptual gap that complicates understanding and hinders the ability to diagnose automotive systems.[1] Another major issue is the low exposure to practical work, which limits the development of students' analytical and diagnostic thinking skills, particularly in automotive systems.[2] An automotive electrical system is defined as an integrated network that includes the battery, starter motor, alternator, control units, wiring, and various loads such as lights, blowers, and infotainment systems. It functions to start, maintain, and optimize engine operation while also supporting safety and comfort systems.[3,4,5]

In recent years, electrical systems have become a baseline competency for vocational school graduates. According to UNESCO (2023), only 39 % of vocational students in Southeast Asia demonstrate adequate analytical competencies for employment in high-skill sectors.[6] In Indonesia, this is worsened by the limited number of certified teachers and practical tools in vocational schools. Many students in Indonesia face conceptual difficulties in grasping core principles of electrical engineering, particularly in power electronics and electric circuits. This stems partly from a general deficit in higher-order thinking skills (HOTS), which are crucial for understanding complex, multidisciplinary topics.[7,8] Additionally, students often develop misconceptions about electric circuits due to misleading everyday experiences and the abstract nature of electrical current flow, further complicating their learning process.[9] The lack of resources significantly affects the quality and effectiveness of teaching automotive electrical systems in Indonesia, particularly within vocational education institutions. This multidimensional challenge encompasses issues related to workforce availability, inadequate infrastructure, pedagogical limitations, and insufficient regulatory and technological support—all of which collectively hinder the development of industry-relevant competencies among students.

There is a need for innovative technology-based learning approaches, such as Flexible Project-Based Learning, interactive simulations, and other similar methods. Such techniques are known for improving both the comprehension and analytical skills of students in automotive electrical systems.[10,11] The instructional gap can be attributed to a deficiency in hands-on experience and an overreliance on classroom instruction and theatrical demonstrations. Automotive electrical diagnostics are hindered by rigid instructional schemes that lack real-world relevance. In practice, limited electrical trainers and narrow simulation scenarios impair learning outcomes. Instructors often avoid allowing students to explore circuits directly due to risks like short circuits or overheating.[12] Consequently, many students shift to more tangible competencies such, as engine or chassis systems, leaving their understanding of electricity fragmented and shallow.[13]

The lack of qualified educators further exacerbates the issue. For example, schools like SMKN 6 and SMKN 12 in Indonesia face shortages in automotive instructors due to low graduation rates in vocational teacher education.[14,15] Observations and interviews conducted in classrooms show that students tend to adopt passive learning roles, often relying on more active peers to explain core concepts. This leads to the reinforcement of misconceptions and memorization of wiring diagrams without grasping the underlying logic, as noted in studies on interactive multimedia.[16,17,18,19,20] Students also view wiring systems as more difficult than engine or chassis systems, citing the need for a systematic approach to fully understand circuit flow and connectivity.[21]

Vocational schools should encourage students to solve circuit problems independently and develop a strong interest in electrical systems. However, current teaching practices remain dominated by theory-heavy lectures with minimal interaction or practical application.[22] Collaborative learning, though widely used, often results in unequal participation, leaving some students disengaged and confused.[2,23,24] A lack of instructional variety and insufficient learning infrastructure further aggravate the problem.[25,26] While much research has focused on improving student achievement, few studies have emphasized the need for teaching innovation to stimulate motivation and engagement.[27,28] This suggests the urgency of applying experiential and project-based methods not only to improve outcomes but also to support student involvement and pedagogical efficiency.[29,30,31,32] Therefore, this study introduces a simulation-based learning approach using the Diagnostic Trouble Box (DTB), which simulates real-world automotive electrical faults and provides a platform for developing students' analytical and problem-solving skills.

This study aims to evaluate the effectiveness of the Diagnostic Trouble Box (DTB) in improving vocational students' analytical thinking skills in learning automotive electrical systems. The findings are expected to inform the development of interactive, problem-based instructional strategies that address limitations of conventional learning and align with industry demands. This study posits the following hypotheses:

Null Hypothesis (H_0): Using the Diagnostic Trouble Box (DTB), there is no notable disparity in the enhancement of analytical thinking skills amongst students when compared to their peers instructed through traditional methods in automotive electrical systems courses.

Alternative Hypothesis (H_1): Students using the Diagnostic Trouble Box (DTB) exhibit greater improvement in analytical thinking skills compared to their counterparts taught using conventional methods.

METHOD

Research Design

This study employs a quasi-experimental method with a pretest-posttest control group framework to assess the impact of the Diagnostic Trouble Box (DTB) on the analytical skills of vocational school students learning automotive electrical systems (table 1). Students in the experimental group will learn through DTB-based instruction while the control group will learn through traditional methods. The effectiveness of the intervention will be assessed empirically by measuring the change in results between the pretest and posttest for the two groups, ensuring internal validity through homogeneity tests and balanced initial group characteristics.[33]

This approach aligns with effectiveness in secondary vocational settings, where the practice is imperative, students need to understand the subject deeply.[34] The application of DTB enables students to engage with the vehicle's electrical systems realistically, fostering an analytical understanding that extends beyond rote memorization of diagrams.[35] Analyzing the improvements in pretest and posttest scores will clarify the extent to which DTB enhances students' critical thinking and problem-solving skills relative to conventional teaching.[36] The study outcomes aim to provide a foundational basis for developing innovations in technology-enhanced learning in vocational education, with a specific focus on automotive engineering.

Table 1. Research Design Pretest-Posttest Control Group Design

Samples	The Beginning Condition	The Treatment	The End Condition
The Experiment Class	O_1	X	O_2
The Control Class	O_3	Y	O_4

Respondens

The participants in this study were 86 students in the 11th grade of the Light Vehicle Engineering (TKR) program at SMK Negeri 1 Yogyakarta, comprising 42 students in the experimental group and 44 in the control group. The decision to focus on this specific cohort was based on two key considerations. One was that the students had some grounding knowledge of the automotive electrical systems from the previous year, which meant they could tackle more advanced topics associated with electrical diagnostics. The second reason was that, although the students were reasonably adept at performing tasks, they required considerable refinement in applying analytical and critical thinking skills in areas such as troubleshooting, which was a focal point of the study involving a Diagnostic Trouble Box (DTB). Participants were selected through purposive sampling, based on their alignment with the study's objectives. This selection was done in phases, starting with determining classes that included the automotive electrical systems subject and conducting a homogeneous test based on pretest score data to ensure students shared a common academic baseline. Thereafter, students were grouped using a random assignment with a matched pairs design, where students were paired based on their pre-test scores to balance the distribution of abilities. This approach aimed to enhance the rigor of the investigation by mitigating bias arising from differences in students' backgrounds, thereby ensuring that the outcome measures more accurately reflect the impact of DTB learning compared to traditional instruction.

Data Collection

This study uses a pretest-posttest control group design to maintain accuracy, objectivity, and validity in measurement outcomes.[13] In the first stage, a primary analytical thinking test instrument is developed, along with an evaluation framework. It is constructed on specified criteria and endorsed by three professionals in automotive education for learning assessment. After validation by experts, the instrument is pilot tested with a small sample, and its reliability is assessed using Cronbach's Alpha reliability test. An instrument is considered reliable if its coefficient of reliability is equal to or greater than 0,70.[37] The research instruments in this case include an analytical thinking test and an observation sheet. The analytical thinking test is administered in two stages (as a pre-test and a post-test), in which candidates respond to both multiple-choice questions and open-ended questions.

This study focuses on the critical analytical dimensions, which include: (1) classification of information, (2) cause-effect analysis, (3) decision-making, (4) evaluation and validation, and (5) systematic logical reasoning.[38,39] These five dimensions serve as the core variables for evaluating analytical thinking skills. The observation sheet is designed to measure student engagement within the DTB-based learning framework, as well as in a more traditional instructional context.

The pretest is administered to both groups to measure students' analytical thinking skills in problem analysis of electrical systems and fault diagnosis using given data, prior to any learning interventions.[40] Levene's Test performed on the pretest scores yields a significant value of 0,107 for the experimental group and 0,182 for the control group ($\alpha \geq 0,050$), indicating that both groups have comparable variance across the two populations.

In the intervention stage, the experimental group is trained using DTB-based learning, where students work through automotive electrical system problems with assistance from DTBs and the teacher serving as a facilitator. The instructor continues to use the control group more traditionally, employing lectures, discussions, and demonstrations.[12] This phase spans four weeks and comprises eight 90-minute sessions. Following the intervention, and in comparison with the control group, the students in the experimental group undergo a post-test aimed at measuring the improvement in analytical skills gained through the assessment intervention. Recall bias is also minimized by providing varying contexts for the questions asked in the pretest.[41] The analysis of the pretest and posttest score changes will assess the impact of DTB-based learning on students' analytical thinking skills.

This research was conducted with official permission from the participating school and adhered to the ethical standards of educational research. All participants were thoroughly informed about the study's objectives, procedures, and their rights, including the right to refuse participation or withdraw at any time without any academic penalty. Participation was voluntary, and all data were collected anonymously to ensure confidentiality. The activities were carried out during regular school hours under teacher supervision and posed no physical or psychological risk to the students.

Data Analysis

Utilizing SPSS as outlined by Bryce et al., aided in the checking of calculations for statistical accuracy.[42] The initial steps of the analysis involved testing for normal distribution using a Kolmogorov-Smirnov or Shapiro-Wilk test, as this is relevant in preliminary analysis. A normal distribution must be established before proceeding with further analysis.[43] Conducting a normality test verified that the pretest and posttest scores for both the experimental and control groups were normally distributed, thus permitting the application of parametric statistical methods.

Following this, Levene's Test was performed to check for homogeneity and test the assumption of equal variances between the two levels of the factor (control and experimental) and their corresponding groups.[44] In this analysis, Levene's Test was applied with the criterion that the data is homogeneous if the significance value (p-value) is greater than 0,050. The isolated test was performed to verify that the variation between the experimental group and the control group, in this case, a DTB pre-test and post-test assessment, was the same concerning homogeneity before DTB was administered, that is, treatment was performed on the

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experimental group alone. This step is necessary for any experimental research. Any observed difference in the final results can only be attributed to the defined treatment being given to all participants, and not to fundamental differences in the two groups that were randomly but deliberately selected.

The equivalence test was performed to check whether the experimental and control groups had comparable analytical thinking skills before the pre-test, sharp enough to be assigned to either side of the study before treatment DTB was given. This step must be taken to ensure that the differences observed after the test were not due to any reason other than DTB. The test was conducted using an independent sample t-test on the pretest scores of both samples. According to the rule, if the significance value (p-value) is greater than 0,05, the two groups are considered equivalent. After normal distribution and homogeneity were validated, a paired-sample t-test was performed to evaluate treatment efficacy by comparing within-group pre- and post-test scores.[45]

Furthermore, the assumption of no significant difference between the two groups (with and without the use of DTB) was tested using an independent samples t-test, analyzing post-scores to evaluate the impact of DTB on participants compared to conventional methods.[46] The outcomes of the analysis showed significance values (p-values) along with mean scores and standard deviations for each group. The findings confirmed that the differences were not random but rather attributable to the intervention that had been applied. The findings confirmed that the differences were not random but rather attributable to the intervention that had been applied.[47] Hence, the study effectively concluded that DTB enhanced students' analytical thinking skills in learning the automotive electrical systems.

RESULTS

Following the collection and analysis of data in SPSS, the results were reported in multiple steps aligned with the preset analysis framework. As part of the results, normality checks, homogeneity checks, balance assessments, within-group effectiveness assessments (using paired sample t-tests), and comparisons between groups (using independent sample t-tests) were all conducted.

Normality Test

The Kolmogorov-Smirnov and Shapiro-Wilk tests showed all significance values above 0,050, with 0,534 (experimental pretest), 0,206 (experimental posttest), 0,131 (control pretest), and 0,362 (control posttest) as shown in table 2. Hence, the normality assumption was satisfied, and parametric tests, including paired-sample t-tests and independent-sample t-tests, could be used to evaluate treatment effectiveness. The normal distribution ensured that any differences between pretest and posttest scores were not the result of chance or distribution bias, but rather actual changes that occurred as a result of the intervention. In addition, data normality reinforced the reliability of the study by enabling accurate evaluation of the Degree of impact of the Diagnostic Trouble Box (DTB) on the students' analytical thinking skills.

Table 2. Normality Test Results for Pretest and Posttest in Experimental and Control Groups

Class	Mean	Std. deviation	Kolmogorov-Smirnov (p)	Shapiro-Wilk (p)	Meaning
Experiment pretest	59,49	5,797	0,534	0,712	Normal
Control pretest	60,03	5,329	0,131	0,624	Normal
Experiment posttest	74,03	7,282	0,206	0,482	Normal
Control posttest	69,97	5,460	0,362	0,538	Normal

Homogeneity Test

The analysis results showed that the significance values of the pretest and posttest in both experimental and control groups were 0,107 and 0,182, respectively, and for the test values 0,221 and 0,144, respectively. As such, since all the significance values indicate that variance is homogeneous between the two groups at both pre- and post-test levels, as represented in table 3, we can safely conclude that variance is homogeneous between the groups. This means that the two groups had equal baseline metrics prior to the intervention, ensuring that any differences measured in the post-test could be confidently ascribed to administering the Diagnostic Trouble Box (DTB).

Equivalence Test

The analysis results returned a significance value of 0,681; hence, the conclusion of no difference between the experimental and control groups was validated at the pretest stage. The mean pretest score for the experimental group was 56,40, and for the control group, 58,20, which demonstrated a gap of only 1,80 points, as shown in table 4. This shows that both groups possessed the same level of analytical thinking skills prior to any intervention. Thus, the differences found in the results after the test suggest that DTB was effective in improving students' analytical thinking skills.

Table 3. Homogeneity Test Results for Pretest and Posttest in Experimental and Control Groups

Class	Levene stats	df	α	Desired level	Meaning
Keterampilan analitis (Pre-Eksperimen)	2,402	86	0,107	α≥ 0,050	Homogeneous
Keterampilan Analitis (Pre-Control)	2,816	86	0,182	α≥ 0,050	Homogeneous
Keterampilan analitis (Post-Eksperimen)	3,164	86	0,221	α≥ 0,050	Homogeneous
Keterampilan Analitis (Post-Control)	2,525	86	0,144	α≥ 0,050	Homogeneous

Table 4. Equivalence Test Results for Pretest in Experimental and Control Groups

Compared class	N	Mean	Mean Difference	Sig. (p)	Desired level	Meaning
Experiment pretest	42	56,40	1,80	0,681	α≥ .050	Balanced
Control pretest	44	58,20				

Evaluation of Treatment Effects and Pretest-Posttest Comparison (Paired Sample t-Test)

The findings indicated that the experimental group had a statistically significant increase in posttest scores relative to pretest scores, with a mean difference of 22,860 points and a significance value of 0,000. This suggests that DTBs do enhance students' analytical thinking skills. The control group did, however, improve with a mean difference of 10,210 points and a significance value of 0,000 (table 5). Although this improvement is indicative of some degree of effectiveness, it also suggests that the effectiveness of DTB-based learning greatly exceeded that of conventional teaching. It is therefore concluded that learning with DTBs significantly outperforms traditional methods in enhancing students' analytical thinking skills.

The most pronounced improvement in the scores attained by the experimental group indicates that DTB offers a more engaging method of learning, improves comprehension of the electrical concepts taught, and enhances the students' competencies in diagnosing problems related to automotive electrical systems.

Table 5. Treatment Effectiveness Test Results in Each Group (Paired Sample *t*-Test)

Class	Pair	Mean Difference	Sig. (p)	Desired level	Meaning
Experiment	Pretest - Posttest	22,860	0,000	α≤ 0,050	Significant
Control	Pretest - Posttest	10,210	0,000	α≥ 0,050	Significant

Based on the table above, both groups exhibited a significant increase in posttest scores compared to pretest scores. However, the experimental group demonstrated a larger score difference, indicating that the use of Diagnostic Trouble Box (DTB) was more effective than conventional methods in enhancing students' analytical thinking skills. This finding reinforces the notion that simulation-based learning technologies, such as DTB, can have a greater impact on improving students' analytical skills in automotive electrical systems.

Comparison of Test Results (Independent Sample T-Test)

To understand the differences in post-test scores between the experimental and control groups after the intervention, an independent sample t-test was conducted. It was found that the experimental group scored 79,26 while the control group's average score was 68,41. The mean difference was 10,850 with a significance value of 0,000 ($p \leq 0,050$), as shown in table 6. This finding reveals a significant difference between the two groups, particularly in the students taught with the Diagnostic Trouble Box (DTB), who showed greater improvement in their analytical thinking skills compared to those taught through conventional teaching methods. The study also concluded that learning through DTB provided better results in developing students' analytical skills in automotive electrical systems. Through active problem analysis and solution development, and by encouraging student participation, the DTB has demonstrated its effectiveness as an instructional tool, far surpassing traditional teaching approaches.

Table 6. Independent Sample T-Test Results for Posttest Comparison Between Groups

Class	N	Mean	Mean difference	Sig. (p)	Desired level	Meaning
Experiment	42	79,26	10,850	0,000	α≤ 0,050	Significant
Control	44	68,41				

DISCUSSION

The results of this research suggest that the development and application of the Diagnostic Trouble Box (DTB) enhances students' analytical thinking skills more than traditional methods.

Rather than relying solely on theoretical lectures and demonstrations, DTB-based instruction engages students in hands-on, diagnostic-oriented problem-solving, which fosters deeper analytical reasoning in interpreting automotive electrical systems. Students in the experimental group demonstrated stronger engagement in identifying faults and making decisions based on complex cause-and-effect relationships. The application of the Diagnostic Trouble Box (DTB) stimulated active problem solving by the students, which is consistent with the PBL philosophy. Problem-Based Learning, as noted in previous studies, significantly improves the analytical thinking competencies of learners.[48,49]

In contrast, students taught through conventional approaches tended to rely on memorization and passive reception of information, with limited opportunities to independently diagnose faults or apply reasoning strategies. This method inhibited the development of systematic thinking and made it difficult for students to build conceptual understanding of electric flow and circuit interactions.[50] Consequently, these students struggled to devise structured approaches when solving electrical problems, especially in unfamiliar scenarios. The findings reinforce prior arguments that simulation-based and interactive learning—such as the use of DTB—are more effective than conventional methods in promoting higher-order cognitive skills. In particular, the DTB facilitates experiential learning through repeated exposure to fault conditions, allowing students to apply logical reasoning in authentic contexts and correct misconceptions through trial and error.[51]

The findings confirm that using the Diagnostic Trouble Box (DTB) effectively cultivates students' analytical thinking, especially in dealing with complex diagnostic scenarios in automotive electrical systems. The active engagement fostered by DTB aligns with the core principles of Problem-Based Learning (PBL), which is known to significantly enhance learners' critical and analytical thinking competencies.[48,49] Unlike conventional teaching methods that emphasize memorization and teacher-led demonstrations, such as those applied in the control group, DTB encourages students to explore cause-and-effect relationships through diagnostic reasoning and iterative experimentation. These passive methods have been shown to hinder the development of systematic thinking and diagnostic independence in previous studies.[50] The implementation of interactive, simulation-based tools like DTB supports the pedagogical shift towards active learning environments, which consistently outperform traditional approaches in fostering higher-order thinking skills in vocational settings.[51]

This research supports prior studies contending that DTB-based diagnostic technology improves students' comprehension of automotive electrical system analysis more effectively than lectures.[52,53] Simulation-based learning, as a technique for developing problem-solving skills, has consistently yielded better results by providing an interactive experience that resembles real-world conditions.[54-56] The inadequacy of traditional practical tools in portraying electrical faults systematically narrows students' comprehensive diagnostic skills. With DTB incorporated into vocational training, students can thoroughly examine various types of vehicle malfunctions, which strengthen their conceptual understanding and sharpens their analytical abilities. Thus, vocational school graduates must go beyond mere theoretical understanding and acquire industry-sought competencies. The DTB integration into secondary vocational education shifts the focus towards actively equipping students for the increasingly competitive job market.

Incorporating DTB-based learning into vocational education helps to develop students' analytical capabilities for diagnosing problems with automotive electrical systems. Unlike traditional methods, DTB employs simulation-based learning and interactivity, which enables students to work on a variety of faults encountered in real-world industry settings.[57,58,59] Traditional practical teaching aids are not designed to offer a variety of electrical faults. Therefore, they are limited to complex diagnostic problems, which impedes the development of problem-solving skills.[60] Learning technology enables students to better understand concepts by facilitating the retention of information, thereby preparing them for professional environments where efficient data-driven decision-making is required.[61] Outside of automotive areas, DTB-based learning develops higher-order thinking skills necessary for mechanical engineering, mechatronics, and electronics, especially for accurate fault localization. This demonstrates that utilizing DTB in vocational education enables students to acquire the practical skills necessary for the rapidly evolving automotive industry.

The integration of DTB in automotive instruction is crucial in developing vocational students' advanced analytical and critical thinking skills in response to the modern industrial workforce's needs.[62] Employers not only value technical skills, but also problem-solving and decision-making abilities, which increase their value in the automotive and allied industries.[63,64,65] Research has shown that learners who use DTB-based instructions can acquire the necessary hands-on experiences that help them to tackle real-world diagnostic problems.[66] Furthermore, as the automotive sector advances, the need for data-driven troubleshooting capabilities will increase, not only for vehicle diagnostics but also in mechatronics and electronics. Innovative instructional methods and educational tools ensure that vocational graduates remain relevant and adaptable to the evolving demands of the industry and the economy's needs. It is, therefore, the responsibility of vocational education institutions to adopt and implement technology and instructional strategies that prepare learners for employment in a highly dynamic global workforce.

While this study demonstrates how the implementation of Diagnostic Trouble Boxes (DTBs) enhances students' analytical thinking skills, several limitations must be addressed. Firstly, the research was limited to only one school, focusing exclusively on the 11th-grade TKR students of SMK Negeri 1 Yogyakarta, which poses challenges for the generalizability of the findings to all vocational students with diverse background traits. Secondly, within the context of this study, a four-week intervention period may have inadequately captured the potential long-term impacts that DTB could have on students' analytical skills in more advanced industrial contexts. Thirdly, this study emphasized cognitive factors, neglecting the interplay of affective and motivational components in students' learning regarding diagnostic technologies, which is essential to understanding their effectiveness. Furthermore, this study did not address the impact of implementing DTBs in real industrial contexts on the work readiness of students. Thus, this study's scope should be expanded beyond a single school to include a prolonged duration, comprehensive analysis of motivational factors, and integration of real-world industrial contexts to strengthen the findings.

CONCLUSIONS

The Diagnostic Trouble Box (DTB) reinforces analytical thinking by fostering interactive, problem-oriented learning in vocational automotive education. Its use encourages students to engage in structured reasoning, systematic fault analysis, and independent decision-making. This approach aligns with the growing need for higher-order thinking skills and adaptive problem-solving in technical and engineering education. By integrating DTB into instructional practices, educators can bridge the gap between theoretical knowledge and practical application. The tool also promotes curriculum responsiveness to industrial change by embedding simulation-based diagnostics into learning environments. In doing so, DTB contributes to strengthening STEM-related competencies and supports the development of industry-relevant graduates. Overall, DTB represents a strategic pedagogical innovation that enhances the quality and relevance of vocational education in the face of increasingly complex automotive technologies.

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AUTHORSHIP CONTRIBUTION
Conceptualization: Valiant Lukad Perdana Sutrisno, Wagiran, Muhammad Nurtanto.
Data curation: Farid Mutohhari, Pardjono, Dianna Ratnawati.
Formal analysis: Valiant Lukad Perdana Sutrisno, Wagiran.
Research: Valiant Lukad Perdana Sutrisno, Farid Mutohhari.
Methodology: Muhammad Nurtanto, Farid Mutohhari.
Project management: Valiant Lukad Perdana Sutrisno.

Resources: Farid Mutohhari, Pardjono, Dianna Ratnawati.
Software: Muhammad Nurtanto, Farid Mutohhari.
Supervision: Valiant Lukad Perdana Sutrisno, Pardjono.
Validation: Valiant Lukad Perdana Sutrisno, Pardjono, Muhammad Nurtanto.
Display: Wagiran, Valiant Lukad Perdana Sutrisno, Dianna Ratnawati.
Drafting - original draft: Wagiran, Muhammad Nurtanto, Dianna Ratnawati.
Writing - proofreading and editing: Valiant Lukad Perdana Sutrisno, Pardjono, Wagiran, Muhammad Nurtanto, Dianna Ratnawati, Farid Mutohhari.