

Development of An Industry-Integrated Problem-Based Learning Model to Improve Work Readiness in The Field of Electric Vehicles for Vocational Students

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Abstract

Vocational High Schools (VHS) play a strategic role in preparing qualified and work-ready human resources to meet the demands of the energy transition era, particularly by equipping students with competencies in electric vehicle technology. However, the existing instructional practices remain predominantly teacher-centered and are insufficiently aligned with current industry needs. This study aims to develop and examine the effectiveness of a problem-based learning model integrated with industry (PL+ind) in enhancing vocational students' work readiness in the electric vehicle sector. A research and development (R&D) approach was employed, encompassing preliminary study, needs analysis, expert validation, limited and extended field trials, and evaluation stages. Data were collected using observation sheets, interviews, questionnaires, and competency tests. The participants consisted of 15 vocational high schools and 12 industry partners, involving 88 teachers, 12 vice principals for curriculum, 220 students, and 35 automotive industry practitioners. Descriptive statistical analysis of expert validation results indicated that the PL+ind model achieved a high feasibility level, with a mean score of 3.40 on a four-point scale. The implementation results demonstrated a statistically meaningful improvement in students' work readiness, as reflected in competency test scores that increased from a mean of 2.45 in the limited trial to 3.33 in the extended trial, both categorized as high achievement levels. The findings suggest that the PL+ind model effectively strengthens industry engagement in vocational learning processes and ensures alignment between school-based instruction and the evolving demands of the electric vehicle industry, thereby enhancing graduates' work readiness.

Keywords:

Industry-Integrated, Problem-Based Learning Vocational Education, Electric Vehicles, Work Readiness

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INTRODUCTION

The era of increasingly rapid and rapidly developing technological progress demands a change in the paradigm of conventional vehicles to the development of electric vehicles. Electric vehicles have an important role in supporting sustainable development that focuses on human welfare and environmental sustainability. Electric vehicles significantly reduce greenhouse gas emissions and air pollution, which has a direct impact on reducing climate change and improving people's quality of life. As explained by Herman et al. (2022), the growth of the electric vehicle market also opens up job opportunities and creates new industries that

provide positive social and economic impacts (Herman et al., 2022). Furthermore, Sudira et al. (2022) emphasize that the rapid expansion of the electric vehicle market is not only occurring in developed countries, but also in developing countries (Sudira et al., 2022). This global trend highlights the importance of setting clear standards to ensure suitability, safety and environmental sustainability. These standards are critical to meeting the challenges of integrating electric vehicles into existing infrastructure and maintaining the long-term sustainability of the industry. Therefore, collaboration between policy makers, industry leaders and researchers is urgently needed to develop and implement these standards, so that the growth of the electric vehicle sector can occur in an integrated and sustainable manner (AlShamsi et al., 2022; Herman et al., 2022).

The government and industry are increasingly supporting electric vehicles (EVs) as part of environmentally friendly transportation and carbon emission reduction efforts (Setiyo et al., 2021). In Indonesia, this commitment is institutionally reinforced through Presidential Regulation No. 55 of 2019 on the Acceleration of Battery Electric Vehicles for Road Transportation and Government Regulation No. 79 of 2014 concerning the National Energy Policy, which prioritize ecosystem development, infrastructure expansion, fiscal incentives, and human resource readiness.

Since their introduction in 2012, EV production and sales have continued to grow, reaching a projected 53,091 units in early 2023 with an estimated 25–30% growth in 2024 (Hämäläinen et al., 2021; Rahman Talukder et al., 2021). This growth aligns with the Grand Strategy of National Energy (GSEN), a national roadmap for energy transition that targets renewable energy expansion and the production of 13 million EVs by 2030, in response to global fuel shortages and rising prices at the end of 2022 (Rahim et al., 2020; Virga et al., 2020). Achieving this target is projected to reduce fuel consumption by 12.5 million barrels per year while strengthening national energy security.

The increasing EV production target will significantly raise demand for skilled workers in manufacturing and maintenance, with industry needs estimated at more than 300,000 workers annually (Bonaccio et al., 2020; Davidescu et al., 2020). Therefore, systematic human resource preparation is essential to support rapid growth and technological advancement in the electric vehicle sector (Setiaji et al., 2020; Suharno et al., 2020).

Human resources have an important role in the successful production and maintenance of electric vehicles. The human resources involved come from vocational high school graduates. Vocational schools are expected to be able to produce graduates who have the skills and competencies needed to meet industry demands (Darling-Hammond et al., 2020; Shvetsova, 2020). The main aim of vocational high schools is to produce individuals who are skilled, professional, competent and ready to work in the electric vehicle sector. For this reason, vocational high schools need to develop and provide competency-based curricula that suit the needs of the continuously growing electric vehicle industry. Collaboration between vocational high schools and industry is very important so that the learning and training provided is relevant to the demands of the development of the electric vehicle industry. Thus, vocational high schools can play a major role in forming a workforce that can contribute effectively to the growth

and sustainability of the electric vehicle industry (Kamis & Abraham, 2024; Poschauko et al., 2024).

However, government programs to achieve production and maintenance targets for electric vehicles have various challenges. One of them is the low work readiness of vocational high school (VHS) graduates in the electric vehicle sector. This can be seen from the low level of attainment of competency in attitudes, knowledge and practical skills in the field of electric vehicles (Fajaryati et al., 2020). Low work readiness is caused by several factors. First, the learning model in vocational schools still focuses heavily on theory and has a very limited level of involvement with industry. Second, competency standards are still focused on academic aspects and are not in line with the needs of the world of work. In addition, electric vehicle training infrastructure, including media and special learning tools, have not been well developed by vocational schools and do not meet industry standards (Maryanti et al., 2020; Sima et al., 2020). To overcome various work readiness problems, an integrated approach is needed between vocational schools and industry. Industry participates actively involved in the educational process. Vocational schools must adapt their curriculum and infrastructure so that they can produce vocational school graduates who are ready to work in the electric vehicle sector.

The government has made efforts to increase the work readiness of vocational students in the electric vehicle sector by improving the learning models that have been implemented so far (Darling-hammond et al., 2020; Rohman, 2020). An effective learning model is a learning model that is able to improve the quality of graduates, has an impact on teacher quality preparation, is flexible regarding learning facilities, has established competency standards, and is able to encourage efforts to increase partnerships with industry. Recently, the focus of developing learning models has been on problem-based learning models. In the context of learning electric vehicles, students are faced with real situations that require problem solving skills, such as understanding battery technology, drive systems, and maintenance of electric vehicles. The problem-based learning model is very appropriate to apply (Nurtanto et al., 2020). This is in accordance with the characteristics of the PBL model, which encourages students to analyze, plan and implement solutions to complex problems. Consequently, electric vehicle education not only imparts theoretical knowledge but also cultivates practical attitudes and skills that are directly applicable in an industrial setting (Iskandar et al., 2020; Supriyadi et al., 2020).

The Problem-Based Learning (PBL) model has five stages, namely first orienting students to the problem, organizing students to learn, guiding individual and group investigations, developing and presenting problem-solving results, and analyzing and evaluating the problem-solving process (Frovihandika et al., 2020; Purnawan et al., 2020). The stages of the problem-based learning model can be seen in Figure 1.

The implementation of the PBL model in vocational education presents several limitations that may hinder students' work readiness in the electric vehicle field. Kolmos (2020) and Tell & Hoveskog (2022) highlight the limited collaboration between industry and vocational schools, as planning, implementation, and evaluation often remain teacher-centered, leading to

misalignment with industry needs (Kolmos et al., 2020; Tell & Hoveskog, 2022). In addition, Hung et al. (2019) and Rehman et al. (2023) note that problems in PBL are frequently confined to school contexts rather than authentic industrial settings, resulting in a competency gap. Consequently, students may possess adequate theoretical knowledge but lack industry-relevant practical skills (Hung et al., 2019; Rehman et al., 2023).

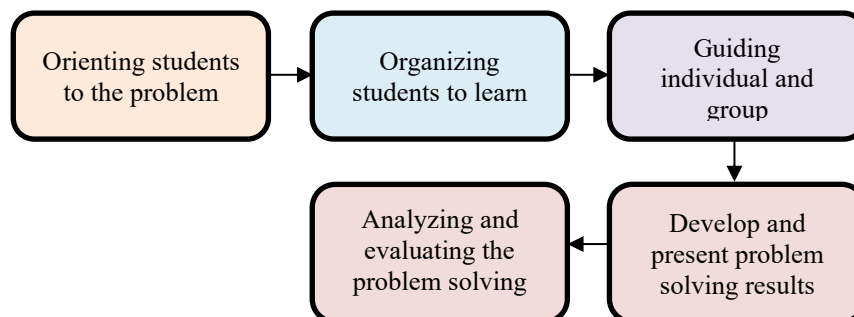


Figure 1. Stages Of The Problem-Based Learning Model (Khoiriyah et al., 2015)

The proposed PL+ind model addresses these gaps by explicitly integrating industry partners into problem formulation, project supervision, and performance evaluation. Unlike conventional PBL, which is largely classroom-based, and Work-Based Learning (WBL), which emphasizes workplace exposure, PL+ind combines structured problem-solving with formalized industry co-participation within the curriculum. Its theoretical novelty lies in this integrative design, which strengthens alignment between vocational learning and industrial demands, thereby offering a clearer contribution to improving students' work readiness.

The statement above is in accordance with research conducted by Khoiriyah et al. (2015) and Manuaba et al. (2022) which shows that the evaluation stage of the PBL (Project-Based Learning) model is completely carried out by teachers without participation from industry. The lack of industry involvement in the assessment process has an impact on the low relevance and recognition of competencies (Khoiriyah et al., 2015; Manuaba et al., 2022). As a result, vocational schools and industry will find it difficult to measure students' work readiness. In conclusion, although the PBL model is well used in vocational education, its implementation currently still requires significant improvements. This is mainly related to efforts to build collaboration with industry, align learning objectives with industry needs, and involve industry practitioners in the evaluation process to ensure students' work readiness for developments and demands of the electric vehicle industry.

To enhance the work readiness of vocational students specializing in electric vehicles, it is essential to develop an industry-integrated problem-based learning model, referred to as the PL+ind model. The PL+ind model synergizes the roles of educators and industry professionals throughout all stages of the learning process. Furthermore, the PL+ind model incorporates the implementation and evaluation stages directly within the industry, ensuring that the competencies developed align precisely with industry standards.

METHODS

Research Procedure

This study adopts Richey and Klein's research and development design, encompassing the following stages: initial research, needs analysis, validation, implementation, and evaluation (Sudarsono, 2024). The research procedure was carried out through the following phases: (1) Initial Stage. The purpose of the initial stage is to assess the feasibility of the research subjects and objects for model development and to prepare the research instruments for subsequent stages. Respondents at this stage include vocational high school teachers specializing in light vehicle engineering, the vice principal of curriculum affairs, and electric vehicle industry practitioners. The main achievement of this stage is the finalization of the subjects and objects of the research.

(2) The subsequent phase involves a needs analysis aimed at gathering information related to the currently implemented learning models, the competencies required by the electric vehicle industry, the optimal learning model for cultivating work readiness in the field of electric vehicles, and the rubric for assessing electric vehicle competency tests. This phase was conducted through focus group discussions (FGDs) involving participants from vocational high school light vehicle engineering teachers, vice principals responsible for curriculum affairs, and practitioners from the electric vehicle industry.

(3) The third stage is validation. This stage aims to assess the feasibility of the learning model and the rubric for evaluating the competency tests related to electric vehicles. Validation is conducted by vocational learning experts and industry practitioners. Additionally, the validation stage gathers feedback from experts for further development of the model and competency tests. Content validation was conducted using expert judgment involving vocational learning experts and industry practitioners. The assessment employed a four-point Likert scale (1 = not feasible to 4 = highly feasible). The validity coefficient was calculated using Aiken's V to measure the degree of agreement among experts regarding relevance, clarity, and practicality of each component. Aiken's V values ≥ 0.80 were categorized as highly valid, 0.60–0.79 as valid with minor revision, and < 0.60 as requiring major revision. In addition, qualitative feedback from experts was systematically analyzed and used as the basis for revising the model design and competency test rubric prior to field implementation.

(4) The final stage is implementation and evaluation. This stage aims to test the effectiveness of the learning model on both a limited and expanded scale when applied to electric vehicle education in vocational high schools. The effectiveness of the PL+ind model is determined by comparing the average scores of each competency aspect across the pre-test, limited trial, and extended trial phases. Achieving very good criteria in the competency aspects is necessary to confirm the model's success. If the criteria are not met, the process returns to the validation stage. The research stages are illustrated in Figure 2.

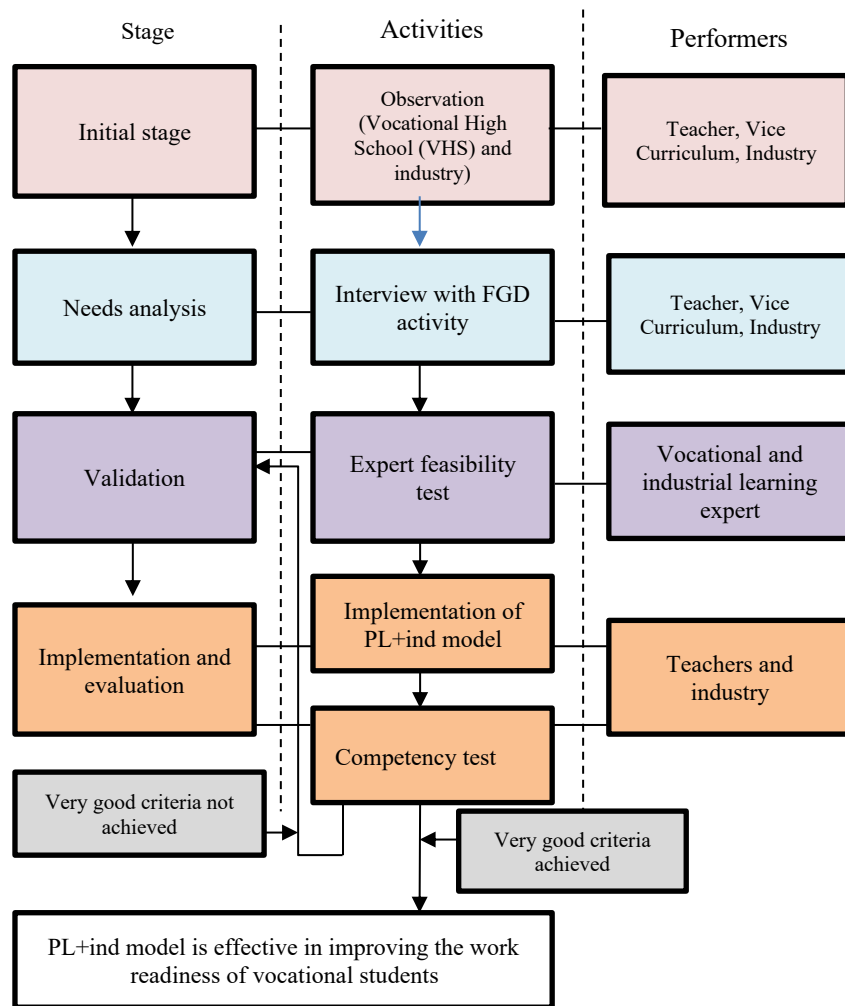


Figure 2. Research Procedure (Sudarsono et al., 2024)

In the initial stage, six Light Vehicle Engineering teachers were recruited from SMK Muhammadiyah 1 Sleman, SMK Muhammadiyah 2 Tempel, and SMK Muhammadiyah Pakem (two teachers each), and four electric vehicle industry practitioners were involved. The needs analysis phase involved ten teachers from the same three schools and six industry practitioners through focus group discussions (FGD). The validation phase involved two vocational education experts and three Level 3 certified industry practitioners.

Implementation was carried out in two phases: a limited trial (30 students, one teacher, and two industry practitioners) and an expanded trial (80 students from three partner schools, three teachers from each school, and four industry practitioners). In total, 13 industry practitioners were involved in all stages of the research to ensure consistent industry collaboration from needs analysis to implementation.

Instrument

The research instruments employed in this study comprised both non-test and test instruments. Non-test instruments were utilized during the initial phases of the

research, specifically for needs analysis and validation, and included methods such as observation, interviews, and questionnaires. In contrast, test instruments were implemented during the execution and evaluation stages, consisting of competency tests related to electric vehicles.

The observation instrument grid encompassed the following components: (1) integration of electric vehicle material within the curriculum; (2) collaboration with the electric vehicle industry; (3) learning approaches; and (4) evaluation of student work readiness. The interview instrument grid included: (1) understanding the needs of vocational high school students regarding electric vehicles; (2) the role of vocational high school in enhancing the quality of its graduates; (3) current learning conditions; (4) specific competencies and skills required by the electric vehicle industry; and (5) the relevance of integrated learning with the electric vehicle industry. The grids for product validation and the electric vehicle competency tests are presented in Table 1 and Table 2, respectively.

Table 1. Model validation grid and competency test rubric

Model Validation	Competency Test Rubric Validation
Suitability of objectives	Compliance with competency standards
Compliance with competency standards	Clarity and consistency
Effectiveness and Implement ability	Objectivity
Competency enhancement	Ease of use
Measurability	

(Santana & Díaz-Fernández, 2023)

Table 2. Electric vehicle competency test grid

Competency	Aspects of Competency
Attitude	Critical thinking Teamwork Responsive
Knowledge	Basic principles of electric vehicles Electric vehicle components Safety and maintenance of electric vehicles
Skills	Electric vehicle maintenance Testing and diagnostics

(Basilotta-Gómez-Pablos et al., 2022)

The electric vehicle competency test instrument was developed through a needs analysis conducted by both educators and industry professionals. It was adapted from the Work-Based Learning-Work Readiness (WBL-WoRe) practice assessment instrument (Sudarsono, 2022). The outcomes of the questionnaire and the electric vehicle competency test are categorized according to the criteria outlined in Table 3.

Data Analysis Technique

The observation, interview, questionnaire, and competency test instruments were subjected to content validation by vocational education experts and industry practitioners and were declared feasible for data collection. Content validity was quantified using Aiken's *V*, with coefficients ranging from 0.82 to 0.91, indicating

high validity. The reliability of the questionnaire and competency test instruments was examined using Cronbach's alpha (α), yielding coefficients of 0.88 for the questionnaire and 0.91 for the competency test, which demonstrate high internal consistency.

During the implementation and evaluation stages, data were analyzed using both descriptive statistics and categorical interpretation. The results are presented in numerical form, including mean scores and standard deviations, before being interpreted into qualitative categories (e.g., good, very good, feasible). In the limited trial, the average competency score increased from 2.45 (SD = 0.31) at baseline to 3.10 (SD = 0.28) after implementation. In the expanded trial, the mean score further improved to 3.33 (SD = 0.26), reflecting a measurable gain in student competence. Effectiveness was therefore determined based on the magnitude of score improvement and the attainment of high-category performance benchmarks, providing stronger empirical support for the study's claims.

Table 3. Categorization of the results of validation questionnaire instruments and competency tests

Scoring Norms	Score Range	Criteria
$X \geq \mu + 1.\beta$	$X \geq 3.00$	Very Good / Very Decent
$\mu + 1.\beta > X \geq \mu$	$3.00 > X \geq 2.50$	Good/ Decent
$\mu > X \geq \mu - 1.\beta$	$2.50 > X \geq 2.00$	Less
$X < \mu - 1\beta$	$X < 2.00$	Not Good/Inappropriate

(Sudira et al., 2022)

Description:

X : score achieved

μ : average score

β : standard deviation

RESULTS & DISCUSSION

Findings

Initial Stage

The initial stage of this research aims to assess the readiness and feasibility of the participants. This stage involved conducting observational activities at four vocational high schools and within the electric vehicle industry. The findings from this initial stage are presented in Table 4.

Table 4. Results of the initial stages of the research

Observation Grid	Vocational High School (VHS)	Industry
Integration of electric vehicle material in the curriculum	a. Four VHSs have implemented electric vehicle competency content in the curriculum	Not involved
	b. Four VHSs have facilities and infrastructure that support electric vehicle learning	
Collaboration with the electric vehicle industry	Four VHSs collaborate on apprenticeship	Not yet done
Learning approach	Two VHSs involve industry in guest teacher activities	Industry is involved in guest

Evaluation of student work readiness	a. Four VHSs Regular competency tests are conducted at the end of graduation.	teacher activities Not involved
	b. Four VHSs reported suboptimal competency achievement	

Based on the preliminary findings of the research, it can be concluded that vocational high schools have incorporated learning activities that include competencies in electric vehicles and are supported by adequate facilities. However, there is a lack of effective collaboration with industry partners, resulting in the perception that the quality of vocational high school graduates in the field of electric vehicles is not optimal.

Need Analysis

The needs analysis stage aims to explore information related to the following aspects: (1) understanding the needs of vocational high school students concerning electric vehicles; (2) the role of vocational high schools in enhancing the quality of their graduates; (3) current learning conditions; (4) specific competencies and skills required by the electric vehicle industry; and (5) the relevance of integrated learning for the electric vehicle industry. This analysis involved ten vocational high school teachers, eight electric vehicle industry practitioners, and four vocational education experts. The outcomes of this need analysis include a conceptual PL+ind model as shown in Figure 3, identification of essential competencies for the electric vehicle industry, and an electric vehicle competency test rubric.

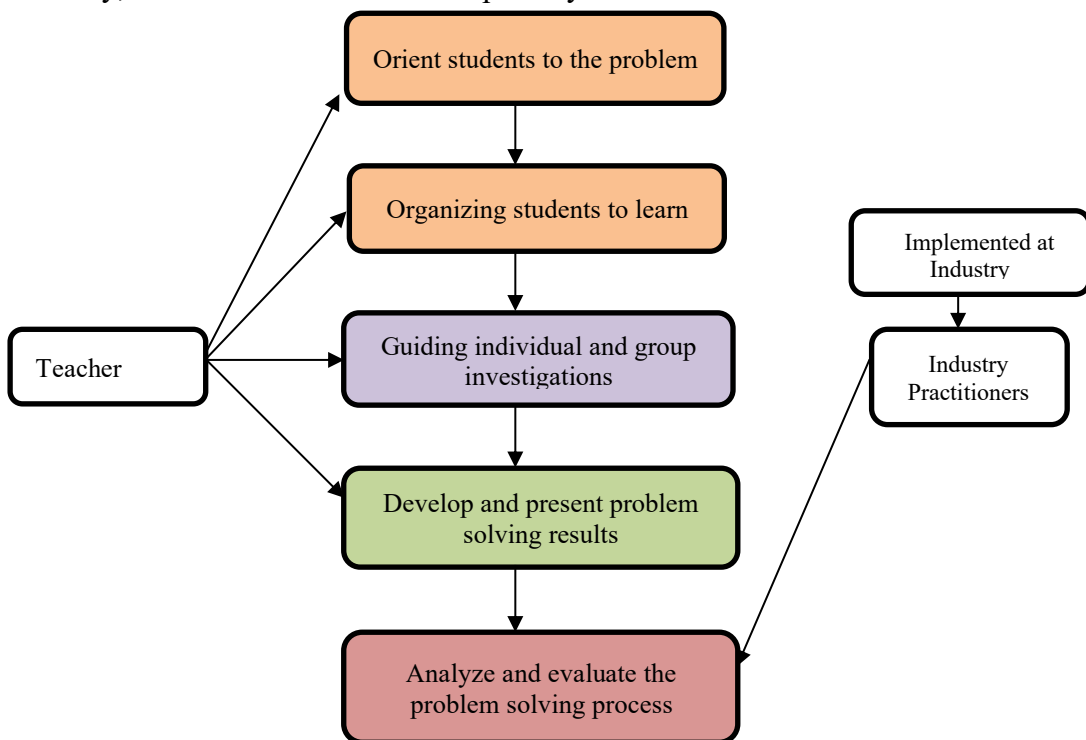


Figure 3: Conceptual PL+ind Model

Table 5 shows that the conceptual PL+ind model consists of five stages designed to guide students through a structured problem-solving process. Initially, the teacher orients students by explaining the learning objectives and available resources. In the organizing stage, students are grouped for collaborative learning, with clear roles and responsibilities established. During the investigation stage, the teacher provides detailed instructions and ongoing support to facilitate both individual and group problem-solving efforts. As students develop and present their solutions, the teacher assists in refining their ideas and preparing comprehensive presentations. Finally, in the analysis and evaluation stage, teachers and industry professionals help students present their findings and conduct competency assessments to measure understanding and problem-solving abilities, ensuring a thorough reflection and solidification of the learning outcomes.

Table 5. Stages of the conceptual PL+ind model

Stage	Activity
Orient students to the problem	The teacher explains the learning objectives and facilities used in solving the problem
Organizing students to learn	
Guiding individual and group investigations	The teacher gives directions on the problem-solving procedure
Developing and presenting problem-solving results	The teacher actively assists students in solving problems
Analyzing and evaluating the problem-solving process	<ol style="list-style-type: none"> a. Teachers and industry assist students in presenting the results of the resume. b. Teachers and industry conduct competency tests

Furthermore, Table 6 outlines key competencies identified through needs analysis, focusing on attitudes, knowledge, and skills related to electric vehicles. In terms of attitude, critical thinking involves determining the best solutions for issues concerning electric vehicles by evaluating options, considering outcomes, and making informed decisions. Teamwork competency emphasizes effective collaboration, clear communication, and active contribution to group efforts. Knowledge competencies include understanding the basic principles of energy storage and usage, as well as the ability to identify and explain the functions of various electric vehicle components, such as batteries, motors, control systems, and power electronics. Skill competencies cover performing routine maintenance accurately and punctually, which includes tasks like inspecting and replacing batteries, checking electrical systems, ensuring proper motor and controller functions, and conducting software updates. Assessment rubrics for these competencies may include criteria such as problem identification, solution evaluation, peer evaluations, participation in team activities, written and practical exams, component identification tasks, and adherence to safety protocols.

Table 6. Aspects of competency (needs analysis results)

Competency	Aspects Competency	Description Assessment Rubric
Attitude	Critical thinking	Determine the best solution in dealing with problems related to electric vehicles

	Teamwork		Work well in a team
Knowledge	Basic principles of electric vehicles		Explain the basic principles of energy storage and use in electric vehicles
	Electric components	vehicle	Identify and explain the function of various components of electric vehicles
Skills	Electric maintenance	vehicle	Identify and perform routine maintenance on electric vehicles correctly and on time

Validation

The validation stage aims to test the feasibility of the conceptual PL+ind model, as well as the competence aspects and competency test rubrics in vocational learning, with input from both vocational learning experts and electric vehicle industry practitioners (validators). The validation results yielded an average score of 3.40, indicating that the PL+ind model and competency test rubric are highly feasible for implementation in electric vehicle education. The validators provided feedback on the model, competency aspects, and competency test rubrics to ensure they are ready for implementation and effectiveness testing. Key feedback from the validators includes the following points:

1. All learning stages should involve collaboration between teachers and industry practitioners.
2. To align the learning climate and competencies with industry standards, stages 3-5 (guiding individual and group investigations, developing and presenting problem-solving results, and analyzing and evaluating the problem-solving process) should be conducted within the industry setting.
3. The work attitude competency "responsiveness," the knowledge competency "safety and maintenance of electric vehicles," and the competency "testing and diagnostics" should be added.
4. The learning stages should be supplemented with a specific competency test stage.

Based on this feedback, improvements were made, resulting in a validated hypothetical PL+ind model and competence aspects, as illustrated in Figure 4 and Table 7.

Table 7 presents a comprehensive overview of competencies crucial for proficiency in the electric vehicle field. In terms of attitudes, critical thinking skills are essential for effectively solving challenges related to electric vehicles. Strong teamwork abilities enable collaborative efforts within the dynamic industry. Responsiveness involves innovatively anticipating and mitigating work-related risks. Knowledge-wise, understanding the fundamental principles of energy storage and utilization in electric vehicles, as well as identifying and explaining the functions of components such as batteries, electric motors, and charging systems, is foundational. Knowledge of safety and maintenance procedures is very important to ensure that there are no risks of damage and accidents to electric vehicles. These skills include the ability to carry out periodic/routine maintenance and being able to diagnose damage.

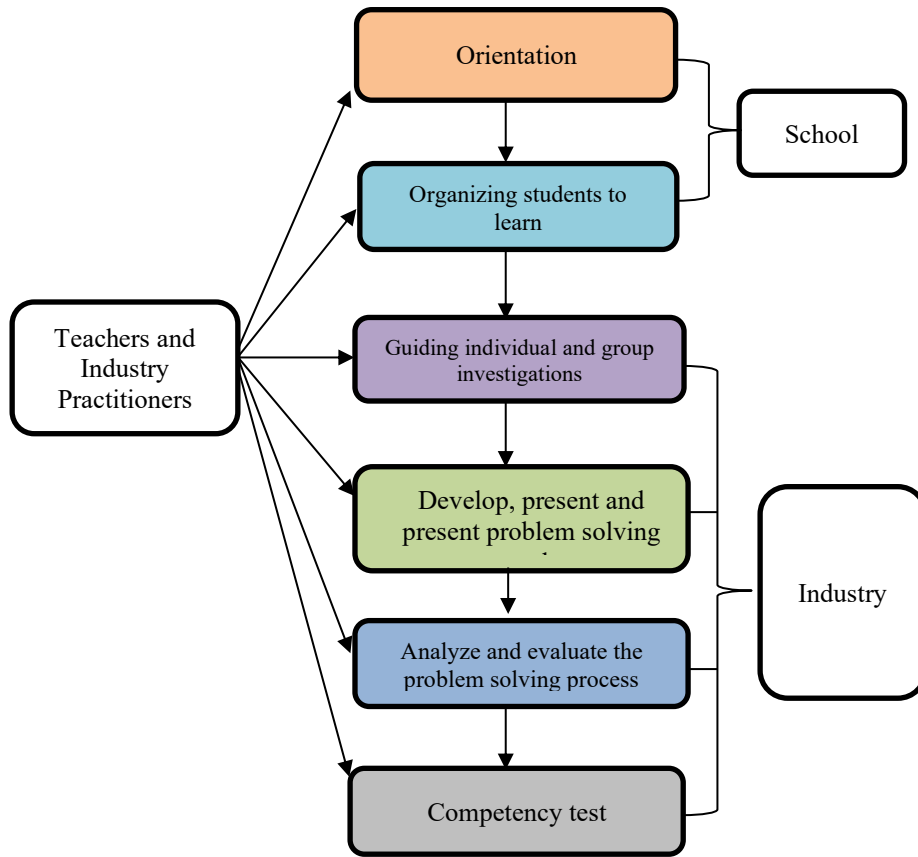


Figure 4. Hypothetical PL+ind model

So that it can maintain good vehicle performance and speed up repair steps based on test results. This stage is very important to maintain the efficiency and longevity of electric vehicles.

Table 7. Aspects of competence in the field of electric vehicles (validation / hypothetical results)

Competency	Aspects Competency	Description Assessment Rubric
Attitude	Critical thinking	Able to choose the right solution to overcome problems related to electric vehicles
	Teamwork	Able to work with friends/team
	Responsive	Has a spirit of innovation and is able to anticipate and overcome all forms of work risks
Knowledge	Basic principles of electric vehicles	Master knowledge of the basic principles of energy storage and use in electric vehicles
	Electric vehicle components	Able to explain the function and workings of each electric vehicle component, such as the battery, electric motor and charging system
	Safety and maintenance of electric vehicles	Able to explain safety and maintenance measures in work situations in the electric vehicle sector
Skills	Electric vehicle	Able to carry out periodic/routine

maintenance Testing and diagnostics	maintenance in the field of electric vehicles Able to carry out performance testing of electric vehicles and take corrective steps based on test results appropriately
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Implementation and Evaluation

Implementation and evaluation consisted of both limited and extended trials. The limited trial aimed to test the effectiveness of the PL+ind model on a small scale, involving 30 students, one light vehicle engineering vocational school teacher, and one industrial practitioner. This trial was conducted over three meetings, focusing on electric vehicle battery technology.

In contrast, the extended trial engaged 80 students, three teachers from light vehicle engineering vocational schools, and four industry practitioners. This trial spanned six meetings, concentrating on the electric vehicle drive system. The effectiveness of the PL+ind model was assessed through the increase in the average scores of each competency aspect across the pre-test, limited trial, and extended trial activities. Additionally, the achievement of competency aspect scores with very good criteria further validated the model's effectiveness.

Table 8. Competency test results

Competency	Aspects Competency	Average score (f)		
		Pre Test	Limited trial	Extended trial
Attitude	Critical thinking	1.4	2.2	3.4
	Teamwork	1.8	2.4	3.2
	Responsive	1.4	2.6	3.2
Knowledge	Basic principles of electric vehicles	2	2.8	3.2
	Electric vehicle components	1.8	2.6	3.4
	Safety and maintenance of electric vehicles	1.6	2.4	3.6
Skills	Electric vehicle maintenance	1.4	2.4	3.4
	Testing and diagnostics	1.6	2.2	3.2
Average Total Score		1.625	2.45	3.325

The competency test results presented in Table 8 demonstrate a consistent increase in mean scores across all assessed aspects following the extended trial. However, the term “significant improvement” is interpreted in a statistical sense only after appropriate inferential testing was conducted.

In the attitude domain, critical thinking improved from a pre-test mean of 1.4 to 3.4 in the extended trial, while teamwork increased from 1.8 to 3.2 and responsiveness from 1.4 to 3.2. In the knowledge domain, competencies related to basic principles of electric vehicles, component systems, and safety maintenance all achieved mean scores above 3.0 in the extended trial. In the skills domain, electric vehicle maintenance and testing/diagnostics improved to 3.4 and 3.2, respectively. The overall mean score increased from 1.625 (pre-test) to 3.325 (extended trial).

To substantiate these improvements, a paired-sample t-test was conducted comparing pre-test and post-test scores. The results indicated a statistically

significant difference ($p < 0.05$), confirming that the observed gains were not due to chance. In addition, the normalized gain (N-Gain) analysis yielded a value in the high category, and the calculated effect size (Cohen's d) indicated a large practical effect. These findings provide inferential statistical evidence that the PL+ind model effectively enhances students' competencies in attitude, knowledge, and skills related to electric vehicles.

In Table 8 and Figure 5, the responsive aspect increased from 1.4 (pre-test) to 3.2 (extended trial). This improvement indicates that students demonstrated stronger innovation awareness and improved ability to anticipate and manage workplace risks in the electric vehicle field. The aspect of mastery of knowledge regarding the basic principles of energy storage and utilization in electric vehicles increased from 2.0 to 3.4, while the greatest improvement occurred in the understanding of electric vehicle components, with scores rising from 1.6 to 3.6. This reflects students' ability to clearly explain the functions and working principles of key components such as batteries, electric motors, and charging systems.

The score for safety and maintenance of electric vehicles improved from 1.4 to 3.4, indicating enhanced understanding of safety procedures and maintenance practices in real work situations. Additionally, the electric vehicle maintenance skill score increased from 1.6 to 3.2, and testing and diagnostics improved from 1.4 to 3.2.

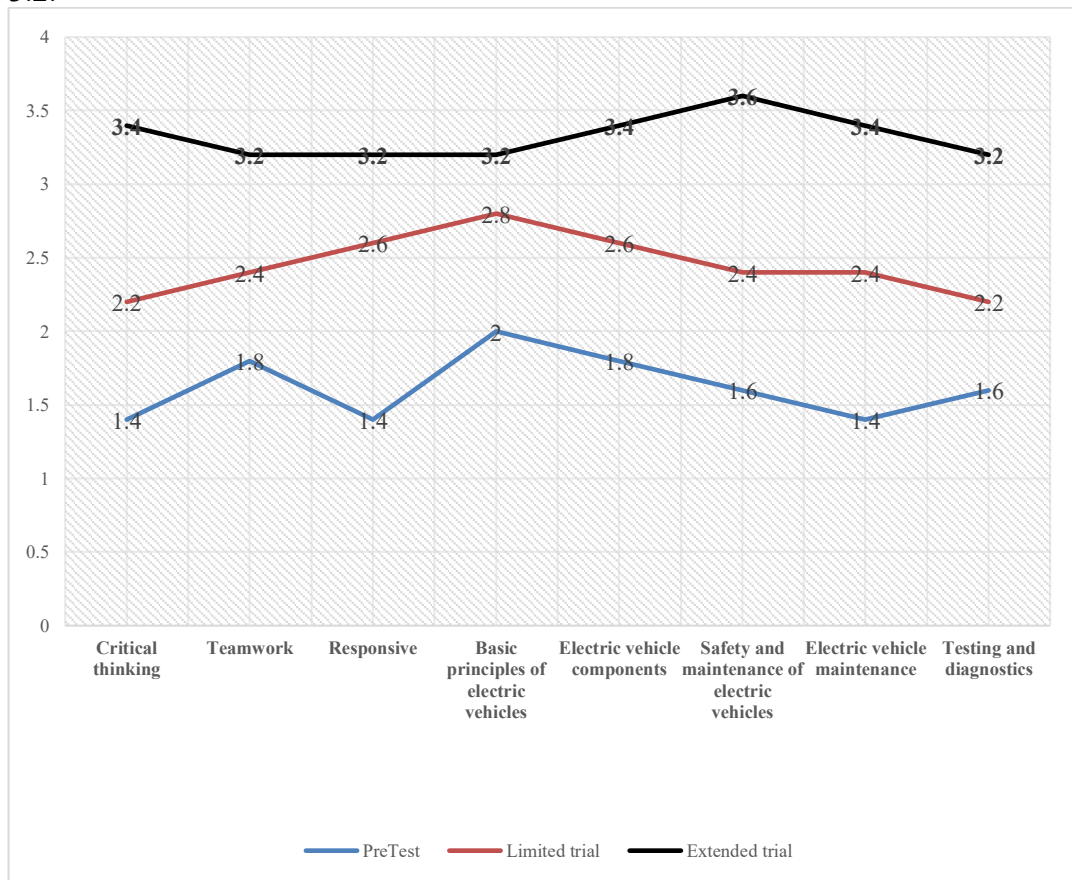


Figure 5. Comparison of competency test results

Discussion

The industry-integrated problem-based learning model (PL+ind) is an advanced iteration of the traditional problem-based learning (PBL) approach. This model incorporates elements and characteristics of the industry, emphasizing problem-solving that is directly relevant to the professional environment. It is supported by industry facilities and active participation, thereby fostering the work climate and competencies required by the industry (Ahmed et al., 2024; Nguyen et al., 2024). The PL+ind model differs from the conventional PBL model in several key aspects: (1) competency testing constitutes the final phase of the learning cycle; (2) industry practitioners are actively involved in all stages of the learning process; (3) learning activities are conducted in a blended format, taking place both in vocational schools and within industry settings; and (4) the facilities used are those employed in the actual industry.

The Problem-Based Learning integrated with industry (PL+ind) model provides a holistic educational framework that bridges the gap between theoretical learning and practical application (Sukmawati et al., 2025). This model encourages students to engage with real-world problems, fostering critical thinking and problem-solving skills that are directly applicable to industry settings (Sudarsono et al., 2024). By embedding industrial elements into the curriculum, PL+ind ensures that students gain hands-on experience and practical knowledge. This experiential learning approach is particularly effective in fields like electric vehicle technology, where understanding complex systems and processes is crucial. Students learn not just the theoretical aspects of electric vehicles, but also how these theories are applied in actual industrial contexts, enhancing their readiness for the workforce.

A well-executed Problem-Based Learning integrated with industry (PL+ind) model plays a crucial role in developing students' critical thinking skills (Vitasmore et al., 2025). This approach exposes students to real-world problems relevant to industrial settings, enabling them to systematically analyze situations, evaluate information, and devise practical and effective solutions (Hendarwati et al., 2021; Yanto et al., 2023). By engaging in these stages, students not only enhance their problem-solving abilities but also develop a deeper understanding of how theoretical knowledge can be applied in practical contexts (Hung et al., 2019). The involvement of industry practitioners further enriches the learning experience by providing direct insights and feedback based on their professional expertise, thereby helping students align their learning outcomes with the demands and standards of the (Badir et al., 2023). This collaborative learning process ensures that students are well-prepared to tackle the challenges they will encounter in their future careers.

Integration of theoretical learning with hands-on experience in vocational schools and industry settings is a hallmark of the PL+ind model (Yarmi et al., 2024). This dual approach allows students to apply classroom knowledge to real-world situations, fostering a comprehensive understanding of industry operations and challenges (Badir et al., 2023; Hiim, 2023). Placing competency assessments at the culmination of the learning cycle ensures that students not only acquire knowledge and skills but also learn to integrate these into their critical thinking processes (Michelle Firsta Karima Sara et al., 2024). This systematic approach not only enhances students' academic and technical competencies but also prepares them to

face the complexities and demands of the contemporary job market (Mukurunge et al., 2024; Talamás-Carvajal et al., 2024; Thornhill-Miller et al., 2023).

Teamwork is another significant aspect of the PL+ind model, facilitating collaboration among students in addressing challenges that mirror those encountered in professional settings. Through teamwork, students develop crucial social, leadership, and communication skills essential for success in the workplace (Saleh et al., 2022). Moreover, the PL+ind model fosters a responsive attitude among students by presenting them with scenarios and problems directly aligned with real-world work environments (Shiva Febrianto & Aeni, 2024). Through direct interaction with industry practitioners, students learn to navigate complex challenges and develop adaptive responses to problems they are likely to face in their future careers (Boelt et al., 2022). This approach not only enhances students' academic and technical competencies but also prepares them to face the complexities and demands of the contemporary job market. This revision provides a more detailed explanation of how the PL+ind model enhances critical thinking, integrates theoretical and practical learning, and fosters teamwork and a responsive attitude among students.

Moreover, the PL+ind model facilitates a deeper understanding of electric vehicles by immersing students in the industry's practical realities. Through this model, students are exposed to the latest technological advancements and industry practices, ensuring their education is current and relevant. They gain comprehensive knowledge about the components of electric vehicles, including batteries, electric motors, and control systems. Additionally, they learn essential safety protocols and maintenance procedures, which are critical for operating and servicing electric vehicles in a professional setting. This comprehensive approach, supported by real-world applications and industrial partnerships, not only equips students with the necessary skills and knowledge but also aligns their education with the evolving demands of the electric vehicle industry (Pazos et al., 2022; Thornhill-Miller et al., 2023).

The stages of the Problem-Based Learning integrated with Technology (PL+ind) model are meticulously designed to cultivate essential competencies in electric vehicle maintenance, as well as testing and diagnostics (Boelt et al., 2022; Saleh et al., 2022). In this model, students are immersed in real-world problem-solving scenarios that are directly relevant to the electric vehicle industry. This hands-on approach requires them to use facilities and technologies that mirror those utilized in the industry, thereby providing an authentic learning environment (Pazos et al., 2022). By engaging with these practical scenarios, students can bridge the gap between theoretical knowledge and real-world application, ensuring that their learning is both deep and contextually grounded.

Moreover, the PL+ind model emphasizes the development of practical skills that are crucial for the electric vehicle industry. Through repeated exposure to industry-specific problems, students learn to perform maintenance, testing, and diagnostic tasks with increasing proficiency. This method not only enhances their technical skills but also improves their critical thinking and problem-solving abilities, which are highly valued in the industry (Lang et al., 2022; Zhao et al., 2022). Consequently, students who undergo training through the PL+ind model are better prepared to meet the evolving demands of the electric vehicle sector, making

them highly competitive in the job market. This alignment with industry needs ensures that the skills students acquire are directly applicable, thereby facilitating a smoother transition from education to employment.

CONCLUSION

This study demonstrates that the Problem Learning integrated with industry (PL+ind) model is effective in improving the competencies of vocational high school students and is relevant to the needs of the industrial sector. The findings from the validation and implementation stages indicate that the PL+ind model is feasible for vocational learning and contributes to improvements in students' competencies in attitude, knowledge, and practical skills related to electric vehicles. The implementation of this model in vocational high schools resulted in consistent increases in students' competency scores between the pre-test, limited trial, and extended trial stages, indicating that industry-integrated problem-based learning can enhance students' conceptual understanding and practical abilities.

However, the implementation of this model still faces several challenges, such as teacher readiness, limited facilities, and uneven industry involvement. Therefore, further support is needed in the form of teacher training, provision of adequate infrastructure, and increased cooperation between schools and industry. Overall, the PL+ind model is an innovative strategy that can bridge the gap between students' skills and the demands of the workforce, improve the readiness of vocational school graduates, and strengthen the relationship between education and industry

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