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BRIDGING THE COMPETENCY GAP: PREPARING VOCATIONAL AUTOMOTIVE EDUCATION FOR THE ELECTRIC VEHICLE ERA

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ABSTRACT

The rapid transition of the global automotive industry toward electric vehicles (EVs) has significantly changed workforce competency requirements. Vocational automotive education institutions are expected to prepare graduates who possess competencies relevant to EV technology, including high-voltage systems, battery management, electric motor diagnostics, and charging infrastructure. However, many vocational automotive curricula remain dominated by internal combustion engine (ICE) technology, resulting in a competency gap between graduate skills and industry expectations. This study aims to analyze curriculum readiness in vocational automotive education, identify competency gaps related to EV systems, and propose a collaborative model between educational institutions and industry. This research employed a descriptive qualitative approach through curriculum document analysis, literature review, and semi-structured interviews with vocational educators and automotive industry practitioners. The data were analyzed using thematic analysis and competency gap analysis. The findings indicate that EV-related competencies are still minimally integrated into vocational curricula and are mostly theoretical in nature. Several critical competency gaps were identified, including deficiencies in high-voltage safety, battery management systems, inverter and motor diagnostics, and EV charging infrastructure. The study also found that limited laboratory facilities, inadequate EV training equipment, and weak industry collaboration hinder curriculum transformation. Therefore, curriculum reconstruction, infrastructure development, and stronger industry partnerships through teaching factory implementation, internships, certification programs, and joint laboratory development are necessary to prepare vocational graduates for the EV era.

Keywords: Keywords: electric vehicle, vocational education, curriculum readiness, competency gap, automotive education

1. INTRODUCTION

The automotive industry is currently experiencing a major transformation driven by the rapid development of electric vehicle (EV) technology (Osatis & Asavanirandorn, 2022). Governments and automotive manufacturers worldwide are accelerating the transition from internal combustion engine (ICE) vehicles toward environmentally friendly transportation systems to reduce carbon emissions and dependence on fossil fuels (Reolfi et al., 2024). This transition is not only changing vehicle technology but also reshaping workforce competency requirements in the automotive sector, particularly in areas related to electrification systems, battery technology, and digital diagnostics (Yudantoko et al., 2024).

As EV adoption continues to increase, the automotive workforce must possess new technical competencies related to electrical systems, battery technologies, digital diagnostics, and

high-voltage safety procedures (Poolkrajang & Papanai, 2025; Widaningsih et al., 2025). Consequently, vocational education institutions, particularly those focusing on automotive engineering, play a strategic role in preparing future workers who are capable of adapting to this technological transformation (Sudarsono et al., 2021).

However, many vocational automotive education programs still emphasize conventional automotive systems such as gasoline engines, diesel engines, transmission systems, and mechanical diagnostics. EV-related learning materials are often limited, theoretical, and not systematically integrated into the curriculum (Zehao et al., 2025). This condition creates a competency gap between graduate capabilities and industry needs, particularly in the areas of electrical and electronic automotive systems (Ali et al., 2020; Muoghalu & Ahmad, 2026).

Previous studies have highlighted the importance of curriculum transformation in Technical and Vocational Education and Training (TVET) to support industrial development and technological innovation (Calero López & Rodríguez-López, 2020). Research also emphasizes that vocational education must strengthen digital and technical competencies to meet the demands of Industry 4.0 and EV-based industries (Rahmawati et al., 2025; Rahmatya et al., 2025). Nevertheless, studies specifically discussing curriculum readiness and competency gaps related to EV technology in vocational automotive education remain limited. Therefore, this study seeks to examine how prepared vocational automotive education is for the EV transition and identify competencies that need to be strengthened.

The global automotive industry is undergoing a significant transformation due to the rapid advancement of electric vehicle (EV) technology. Increasing concerns regarding environmental sustainability, greenhouse gas emissions, and fossil fuel dependency have encouraged governments and automotive manufacturers worldwide to accelerate the adoption of EVs. According to recent studies, the transition toward vehicle electrification is expected to reshape transportation systems and create new demands for highly skilled workers with competencies related to electrical engineering, energy systems, and digital technologies (Reolfi et al., 2024; International Energy Agency [IEA], 2023). Consequently, the automotive sector is no longer centered solely on mechanical systems but increasingly integrates electronics, software, and intelligent control systems (Osatis & Asavanirandorn, 2022).

Electric vehicles differ substantially from conventional internal combustion engine (ICE) vehicles in terms of operating principles, system architecture, and maintenance procedures. EVs utilize electric motors powered by battery systems and controlled through electronic power converters and digital management systems. Key EV components include battery packs, battery management systems (BMS), inverters, regenerative braking systems, and charging infrastructure (Yudantoko et al., 2024). These technological characteristics require workers to possess interdisciplinary competencies involving electrical systems, electronics, diagnostics, safety procedures, and digital troubleshooting (Poolkrajang & Papanai, 2025). Therefore, the emergence of EV technology has transformed workforce competency standards in the automotive industry (Widaningsih et al., 2025).

In response to industrial transformation, Technical and Vocational Education and Training (TVET) institutions are expected to adapt their educational systems to ensure graduate employability and industrial relevance. Vocational education plays a strategic role in preparing skilled human resources through competency-based learning and practical training. According to Sudarsono et al. (2021), vocational curricula should continuously evolve in line with industrial innovation and technological development. Educational institutions that fail to adapt their curricula risk producing graduates whose competencies no longer align with labor market requirements (Calero López & Rodríguez-López, 2020).

However, many vocational automotive education programs still predominantly focus on conventional automotive technologies such as engine systems, fuel systems, transmission systems, and mechanical diagnostics. Several studies indicate that EV-related content remains minimally integrated into vocational curricula and is often delivered only theoretically without sufficient hands-on practice (Halim & Rahman, 2023; Zehao et al., 2025). This condition reflects a lack of curriculum responsiveness toward emerging automotive technologies. As a result, graduates may experience difficulties adapting to industrial environments that increasingly demand competencies in EV maintenance, diagnostics, and safety procedures (Rahmawati et al., 2025).

The mismatch between educational outcomes and industrial competency requirements is commonly referred to as a competency gap. In the context of EV technology, competency gaps are particularly evident in areas such as high-voltage safety, battery diagnostics, electric motor control systems, charging infrastructure, and digital diagnostic tools (Ali et al., 2020). Research conducted in several TVET institutions also found that limited infrastructure, insufficient laboratory equipment, and lack of educator expertise contribute significantly to the persistence of competency gaps in EV education (Muoghalu & Ahmad, 2026). Therefore, improving curriculum quality alone is insufficient without simultaneous improvements in institutional readiness and learning facilities (Poolkrajang & Papanai, 2025).

Another important issue in EV-oriented vocational education is industry collaboration. Strong partnerships between educational institutions and industry are essential to ensure curriculum relevance and practical competency development. Collaborative approaches such as teaching factory (TEFA), industrial internships, curriculum co-development, and competency certification programs have been widely recommended to strengthen vocational education outcomes (Rahmatya et al., 2025). Industry involvement allows students to gain direct exposure to current technologies and industrial working environments, thereby improving workforce readiness and reducing competency mismatches (Sudarsono et al., 2021).

Despite growing discussions regarding EV adoption and vocational education transformation, studies specifically examining curriculum readiness and competency gaps in vocational automotive education remain relatively limited. Most previous research has focused on general TVET transformation or Industry 4.0 readiness without specifically addressing EV competencies (Calero López & Rodríguez-López, 2020). Therefore, further research is needed to analyze the readiness of vocational automotive education in responding to the EV transition and identify competencies that should be prioritized to support future workforce development in the automotive sector (Reolfi et al., 2024; Yudantoko et al., 2024).

Based on the challenges and opportunities arising from the transition toward electric vehicle technology, this study aims to examine the readiness of vocational automotive education in responding to the changing competency demands of the automotive industry. Specifically, the study focuses on analyzing curriculum readiness, identifying competency gaps related to electric vehicle systems, and exploring the barriers faced by vocational institutions in implementing EV-oriented learning. Furthermore, this research proposes a collaborative model between vocational education institutions and the automotive industry to strengthen workforce preparedness through curriculum co-development, practical training, certification programs, and industry-based learning approaches. Through this study, it is expected that vocational automotive education can better adapt to technological transformation and produce graduates who are relevant to the future needs of the automotive sector.

2. METHODOLOGY

This study employed a descriptive qualitative research design to explore curriculum readiness and competency gaps in vocational automotive education related to electric vehicle (EV) technology. The qualitative approach was selected because it enables an in-depth understanding of educational conditions, curriculum implementation, and industrial competency demands within the context of the ongoing automotive transformation. The study focused on identifying how vocational automotive education institutions respond to the increasing need for EV-related competencies and the challenges encountered during curriculum adaptation.

Data were collected through several techniques to obtain comprehensive and relevant information. First, curriculum document analysis was conducted to examine the extent to which EV-related competencies had been integrated into vocational automotive education programs. The analyzed documents included course structures, learning outcomes, competency standards, and practical learning materials. Second, a literature review was carried out by examining recent studies, journal articles, and reports related to EV technology, workforce transformation, and Technical and Vocational Education and Training (TVET). This review provided theoretical and empirical foundations regarding curriculum transformation and competency development in the EV era. Third, semi-structured interviews were conducted with vocational educators and automotive industry practitioners to gain insights into current curriculum implementation, competency requirements, and challenges faced in preparing graduates for the EV industry.

The collected data were analyzed using thematic analysis to identify recurring patterns and themes related to curriculum readiness, competency gaps, infrastructure limitations, and industry collaboration. In addition, competency gap analysis was employed by comparing existing curriculum content and learning practices with competency requirements demanded by the EV industry. The analysis focused on several critical competency areas, including high-voltage safety, battery management systems, electric motor diagnostics, inverter systems, and EV charging infrastructure. Through this analytical approach, the study aimed to provide a comprehensive understanding of the preparedness of vocational automotive education in supporting the transition toward electric vehicle technology.

3. RESULTS

The findings of this study indicate that the readiness of vocational automotive education toward electric vehicle (EV) technology is still relatively limited. Based on curriculum document analysis, literature review, and interviews with educators and industry practitioners, several competency areas related to EV systems have not been comprehensively integrated into existing vocational curricula. The results also reveal disparities between the competencies taught in educational institutions and the technical skills required by the automotive industry. Table 1 presents the level of curriculum readiness across several automotive competency areas related to EV technology.

Table 1. Curriculum Readiness toward EV Competencies in Vocational Automotive Education

Competency Area	Existing Curriculum Coverage	Practical Learning Availability	Readiness Level
Internal Combustion Engine Systems	Extensive	High	High
Transmission Systems	Extensive	High	High
Electrical Diagnostic Systems	Moderate	Moderate	Moderate
High-Voltage Safety Systems	Limited	Low	Low
Battery Management Systems (BMS)	Limited	Low	Low
Inverter and Motor Diagnostics	Very Limited	Low	Low
EV Charging Infrastructure	Very Limited	Not Available	Low

Table 1 shows that vocational automotive curricula are still predominantly focused on conventional automotive systems, particularly internal combustion engine and transmission systems. Meanwhile, EV-related competencies such as high-voltage safety, battery management systems, inverter diagnostics, and charging infrastructure receive limited attention within the curriculum. Practical learning opportunities related to EV systems are also still inadequate due to limited facilities and training equipment. These findings indicate that the readiness level of vocational automotive education toward EV technology remains relatively low.

The analysis showed that vocational automotive curricula are still heavily dominated by conventional automotive technologies, particularly internal combustion engine systems, transmission systems, and mechanical diagnostics. Most learning activities continue to focus on mechanical maintenance and troubleshooting of conventional vehicles, while EV-related topics receive only limited attention. Although several institutions have started introducing EV concepts into their learning materials, the content remains largely theoretical and has not yet been supported by sufficient practical activities. As a result, students have limited opportunities to develop practical competencies related to EV systems and technologies.

The study also identified several critical competency gaps related to EV technology. One of the most significant gaps concerns high-voltage safety competencies. Many students and educators still lack adequate understanding and training regarding safe handling procedures for high-voltage systems, including the use of personal protective equipment, electrical isolation procedures, and emergency response mechanisms. This condition may increase safety risks during practical learning activities involving EV systems.

Another important competency gap was found in battery management systems (BMS). The findings indicate that students generally possess limited knowledge regarding battery diagnostics, thermal management systems, battery monitoring processes, and battery maintenance procedures. This issue is particularly important because battery systems represent one of the core technologies in electric vehicles and require specialized competencies that differ significantly from conventional automotive systems.

Furthermore, the results revealed limited student exposure to inverter systems and electric motor diagnostics. Most vocational institutions have not yet provided adequate learning experiences related to electric motor control systems, inverter operation, or digital diagnostic procedures used in EV maintenance. Similarly, knowledge regarding EV charging infrastructure,

charging standards, and charging technologies remains insufficiently addressed within existing curricula. Consequently, students may face difficulties adapting to industrial environments where EV charging systems and digital automotive technologies are increasingly utilized.

The study additionally found several barriers that hinder the implementation of EV-oriented vocational education. One of the main challenges is the limited availability of EV training equipment and laboratory facilities. Many institutions do not yet possess battery simulators, EV trainers, charging stations, or specialized diagnostic tools required for practical EV learning. This limitation significantly reduces students' opportunities for hands-on learning and competency development.

Another challenge identified in this study relates to limited industry involvement in curriculum development and learning implementation. Collaboration between vocational institutions and automotive industries remains relatively weak and unstructured, resulting in learning content that is not fully aligned with current industrial practices and technological developments. In addition, EV-specific competency certification programs are still not widely available, making it difficult to standardize graduate competencies and ensure workforce readiness for the EV industry.

Based on these findings, this study proposes an integrated collaboration model involving vocational education institutions and industry partners to bridge the identified competency gaps. The proposed model emphasizes curriculum co-development to ensure that learning outcomes reflect current industrial competency requirements. The model also encourages the implementation of teaching factory (TEFA) approaches that provide students with industry-based learning experiences through project-based and production-based activities.

In addition, industrial internship programs are considered essential to strengthen students' practical competencies and expose them directly to current EV technologies and workplace environments. The study also highlights the importance of developing EV competency certification programs collaboratively between educational institutions and industry partners to standardize technical competencies. Furthermore, joint laboratory development is proposed as a strategic solution to overcome infrastructure limitations and improve practical learning quality in vocational automotive education.

4. DISCUSSION

The findings of this study indicate that vocational automotive education is still facing challenges in adapting to the rapid transition toward electric vehicle (EV) technology. The dominance of conventional automotive content within vocational curricula demonstrates that many institutions continue to prioritize internal combustion engine (ICE) systems over electrification technologies. This condition reflects the broader challenge of aligning Technical and Vocational Education and Training (TVET) with industrial transformation and technological innovation (Pavlova, 2019). Recent studies have emphasized that the automotive industry's transition toward EVs requires educational institutions to redesign curricula and learning systems to ensure workforce relevance and sustainability (Liu et al., 2023).

The limited practical integration of EV-related learning identified in this study also suggests insufficient institutional readiness in responding to technological disruption. Most institutions still provide EV topics only at the theoretical level without adequate laboratory practice or industrial simulation. According to research by Khan et al. (2022), effective EV education requires experiential and competency-based learning approaches involving real diagnostic systems, battery technologies, and digital automotive tools. Without sufficient

practical exposure, students may struggle to meet industrial competency standards required in modern automotive workplaces.

The competency gaps identified in areas such as high-voltage safety, battery management systems, inverter diagnostics, and charging infrastructure are closely related to the changing nature of automotive occupations in the EV era. Research conducted by Mayyas et al. (2021) explained that electrification technologies significantly alter the skill composition of automotive technicians by increasing the importance of electrical, electronic, and software-related competencies. Consequently, vocational graduates who only possess conventional mechanical competencies may experience difficulties adapting to EV-based industrial environments.

Another important issue revealed in this study concerns the limited availability of EV training equipment and laboratory infrastructure. Many vocational institutions still lack specialized facilities such as EV trainers, battery simulators, charging stations, and advanced diagnostic tools. Similar findings were reported by Widodo et al. (2023), who found that infrastructure limitations remain one of the major obstacles to implementing EV-oriented vocational learning in developing countries. Limited facilities reduce opportunities for hands-on learning and weaken students' practical competency development.

This study also highlights the importance of strengthening collaboration between vocational institutions and industry partners. Weak industry participation in curriculum development contributes to competency mismatches between graduates and workplace demands. According to research by Veza et al. (2022), industry involvement in vocational curriculum design and competency assessment is essential for ensuring educational relevance in rapidly changing industrial sectors. Collaborative approaches enable institutions to gain access to updated industrial technologies, industrial standards, and professional expertise.

The proposed collaboration model involving curriculum co-development, teaching factory implementation, industrial internships, competency certification, and joint laboratory development aligns with previous studies emphasizing industry-based vocational learning. Research by Putra et al. (2023) demonstrated that teaching factory (TEFA) models improve student readiness, technical competencies, and workplace adaptability by integrating production-based learning into vocational education. Furthermore, industrial internship programs provide direct exposure to emerging EV technologies and industrial work culture, which are essential for improving workforce readiness.

Overall, the findings of this study confirm that vocational automotive education must undergo comprehensive transformation to respond effectively to the EV transition. Curriculum redesign, infrastructure development, educator competency improvement, and stronger industry collaboration are necessary to ensure that vocational graduates possess competencies relevant to future automotive industry needs. As highlighted by the International Labour Organization (ILO, 2022), workforce transformation in the green mobility sector will require educational systems that are adaptive, industry-oriented, and responsive to technological innovation.

5. CONCLUSION

This study concludes that vocational automotive education is still not fully prepared to support the transition toward electric vehicle (EV) technology. The findings reveal that existing curricula remain predominantly focused on conventional internal combustion engine (ICE) systems, while EV-related competencies are only minimally integrated and are mostly delivered theoretically. As a result, significant competency gaps persist between vocational graduates and the emerging workforce demands of the automotive industry.

Several critical competency gaps were identified, particularly in high-voltage safety, battery management systems, inverter and electric motor diagnostics, and EV charging infrastructure. In addition, the study found that limited training facilities, inadequate EV learning equipment, weak industry involvement, and the absence of standardized EV certification programs hinder the effective implementation of EV-oriented vocational education. These limitations reduce opportunities for practical learning and negatively affect students' readiness to work in the evolving automotive sector.

To address these challenges, vocational automotive education institutions must undertake comprehensive curriculum transformation by integrating EV competencies into core learning programs and strengthening practical learning experiences. Furthermore, stronger collaboration between educational institutions and industry is essential to ensure curriculum relevance and competency alignment with industrial needs. Strategic initiatives such as curriculum co-development, teaching factory (TEFA) implementation, industrial internships, competency certification programs, and joint laboratory development can serve as effective approaches to bridge the competency gap and improve workforce readiness for the EV era.

Overall, this study highlights the urgent need for adaptive and industry-responsive vocational education systems capable of supporting technological transformation in the automotive sector. Future research is recommended to explore the implementation effectiveness of EV-based curricula and evaluate the impact of industry collaboration models on student competency development and employability.

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