

Evaluating Vocational Teacher and Students Skill Transformation and Readiness for Electric Vehicle Technology Through Smart Teaching Factory in Indonesia

Nolan Gita Sari, Dedi Rohendi*, Yusep Sukrawan, Jaja Kustija & Ridwan Adam M Noor

Universitas Pendidikan Indonesia, Bandung, Indonesia

*Corresponding Email: dedir@upi.edu

ARTICLE INFO

Article history

Received: May 05, 2026

Revised: Jun 24, 2026

Accepted: Jun 30, 2026

Keywords

Electric Vehicle Technology

VET School

Smart Teaching Factory

Skill Transformation

Vocational Competency

ABSTRACT

Indonesia's transition toward electric vehicle (EV) technology requires vocational education and training (VET) schools to prepare teachers and students with industry-relevant competencies. Students must develop expertise in high-voltage systems, battery management, electric motors, digital diagnostics, and essential 21st-century skills, including critical thinking, problem-solving, and workplace readiness. Teachers are expected to master EV technologies, adopt Teaching Factory approaches, and strengthen their digital and pedagogical competencies. However, competency gaps persist due to limited learning facilities, insufficient teacher training, and weak integration of EV curricula. This study employed a Systematic Literature Review following the PRISMA 2020 framework, analyzing 47 studies from Scopus, Web of Science, ERIC, and Google Scholar published between 2021 and 2026. The findings indicate that Smart Teaching Factory implementation improves students' practical competencies, digital literacy, and problem-solving skills while enhancing teacher readiness, supporting more effective industry-aligned vocational education for the evolving EV sector.



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Introduction

The global transition toward Electric Vehicle (EV) technology has accelerated significantly, with worldwide sales surpassing 17 million units in 2024, reflecting a year on year growth of more than 25% (IEA, 2025). In Southeast Asia, EV sales grew by nearly 50%, with Indonesia recording a threefold increase in sales volume Virta (2025). In response to this trend, the Indonesian government has set a target of 15 million EV adoptions by 2030 to support national industrial transformation and decarbonization goals Damanik et al (2024). Nevertheless, Indonesia's EV market share remains comparatively low, partly due to the persistent mismatch between the existing workforce and the technical demands of the emerging EV industry Adnan et al (2024).

VET school serve as Indonesia's primary pipeline for skilled technical labor, enrolling more than 5.2 million students across approximately 14,000 institutions (Ministry of Education, Culture, Research, and Technology, 2024). However, existing infrastructure, curricula, and teacher competencies remain largely oriented toward Internal Combustion Engine (ICE) technology and conventional manufacturing processes. VET school provision that is not aligned with industry needs has been demonstrated to be insufficient in driving transformation within the automotive sector (Pauw et al., 2024; Wickramasinghe and Wickramasinghe, 2024). This structural gap threatens to undermine Indonesia's industrialization ambitions (Iswadi and Arizal, 2024; Iswadi et al., 2025), necessitating a systemic transformation of the VET learning environment as a whole.

The smart teaching factory (STF) concept, an evolution of the traditional teaching factory model articulated by Abele et al. (2015), integrates Industry 4.0 enabling technologies such as the Internet of Things (IoT), cyber physical systems, digital twins, and cloud manufacturing platforms into authentic, production oriented learning environments. Within an STF, students engage in real manufacturing processes using industry standard equipment and digital tools, thereby developing competencies that are immediately transferable to the workplace. Several European nations, particularly Germany with its dual VET system, have demonstrated the efficacy of teaching factory models in producing industry ready graduates Tisch et al (2021). The adaptation of this concept to the Indonesian VET context, particularly for EV technology, presents both substantial opportunities and formidable challenges.

Although research on Smart Teaching Factory and industry based VET school continues to grow globally, studies specifically examining its effectiveness in Electric Vehicle technology education remain fragmented and insufficiently consolidated. The transition from conventional fuel based vehicles to electric vehicles demands new competencies not yet adequately addressed by existing VET school's curricula, including high voltage systems, battery diagnostics, and digital based

troubleshooting (Albatayneh, 2024; IEA, 2025). Global research confirms that strengthening EV education is critical for preparing a competent workforce Chen et al (2025), and training programs aligned with the EV industry have been shown to significantly improve worker competencies (Afzal et al., 2025). The Learning Factory 4.0 approach has also proven effective in developing both technical and digital competencies among vocational students Sieckmann et al (2021). However, existing studies continue to address isolated aspects such as curriculum, infrastructure, and teacher training, without integrating them into a unified and evidence based framework (Wickramasinghe and Wickramasinghe, 2024; Pauw et al., 2024). This gap in the literature underscores the need for a systematic review to generate concrete recommendations for transforming vocational education in the Electric Vehicle era.

This study addresses this gap through a systematic literature review (SLR) employing the PRISMA 2020 framework. Specifically, the research aims to: (1) map the landscape of scholarly evidence on STF implementation in Indonesia's EV-related VET settings; (2) evaluate the documented impact of STF approaches on student skill readiness and transformation; (3) identify critical barriers to and enablers of effective STF adoption for EV technology; and (4) synthesize findings to propose actionable recommendations for policymakers, curriculum developers, and institutional leaders. The following research questions (RQs) guide this review:

RQ1: What is the current state of smart teaching factory implementation in Indonesian VET institutions for EV technology?

RQ2: How does the STF approach contribute to the skill readiness and transformation of VET students and teachers for EV technology?

RQ3: What are the key challenges and success factors in integrating EV technology competencies within STF based VET programs in Indonesia?

RQ4: What policy and institutional recommendations emerge from the evidence base to strengthen VET readiness for EV technology?

Method

This research employs a Systematic Literature Review (SLR) methodology following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 (PRISMA 2020) protocol Page et al (2021). The review protocol was designed and registered prior to execution to ensure transparency and replicability.

a. Research Design

This study employs a systematic literature review (SLR) methodology, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines Page et al., (2021). The SLR approach was selected for its rigor, transparency, and reproducibility in synthesizing dispersed evidence from primary studies. The protocol was prospectively designed to minimize selection bias and ensure comprehensive coverage of the relevant literature.

b. Database and Search Strategy

Table 1. Search Queries Used for Literature Retrieval

Database	Query String	Results
Scopus	TITLE-ABS-KEY("vocational education" OR "VET" OR "SMK") AND ("electric vehicle" OR "EV technology" OR "hybrid vehicle") AND ("teaching factory" OR "smart factory" OR "Industry 4.0")	87 records
Web of Science	TS=("vocational training" OR "vocational school" OR "TVET") AND ("electric vehicle*" OR "battery electric" OR "EV skill*") AND ("teaching factory" OR "smart manufacturing" OR "cyber-physical")	64 records
ERIC	("vocational education" OR "career and technical education") AND ("electric vehicle" OR "green technology") AND ("teaching factory" OR "Industry 4.0" OR "smart learning")	41 records
Google Scholar	"vocational education" "electric vehicle" "teaching factory" Indonesia "smart teaching factory" "EV technology" "VET" Indonesia "skill transformation" "electric vehicle" "SMK"	73 records (first 5 pages, relevance-sorted)
Additional Sources	Snowball searching from reference lists of high-quality included studies; Indonesian national education repositories	18 records
Total	-	283 records (after deduplication: 210)

A comprehensive literature search was conducted across four academic databases: (1) Scopus, (2) Web of Science (WoS), (3) Education Resources Information Center (ERIC), and (4) Google Scholar. These databases were selected for their broad disciplinary coverage, indexing standards, and relevance to educational technology research. The search was limited to publications between January 2021 and March 2026 to capture recent developments aligned with post-pandemic educational reforms and Indonesia's accelerating EV transition.

Search queries were constructed using Boolean operators (AND, OR) combining three conceptual clusters: (i) vocational education and training; (ii) electric vehicle and related technologies; and (iii) smart teaching factory and Industry 4.0 learning environments. Table 1 presents the specific queries applied to each database.

Table 1 presents the Boolean search strings applied to each of the four academic databases. The queries were designed to capture studies at the intersection of three conceptual domains: vocational education and training, electric vehicle technology, and smart teaching factory or Industry 4.0 learning environments. Variations in database specific indexing terminology are reflected in the different query formulations, while the total retrieval yielded 283 records prior to deduplication.

c. Inclusion and Exclusion Criteria

All retrieved records were assessed against pre-defined inclusion and exclusion criteria (Table 2). Criteria were established a priori based on the review's research questions, population of interest, and conceptual scope. Screening was conducted in two stages: (1) title and abstract screening, and (2) full-text review. Each stage was conducted independently by two reviewers, with inter-rater disagreements resolved through discussion and, where necessary, adjudication by a third reviewer.

Table 2 summarizes the pre defined criteria used to determine study eligibility. Inclusion criteria prioritized peer-reviewed empirical studies addressing smart teaching factory implementation, electric vehicle or hybrid technology education, skill readiness in automotive VET school, or Industry 4.0 integration in vocational schools, particularly within Indonesian or directly comparable developing-country contexts. Studies were excluded if they lacked a VET school component, were non empirical without significant theoretical citation impact, or if they scored below 60% on the JBI Critical Appraisal Tool, ensuring that only methodologically sound evidence was retained for synthesis. Inclusion and Exclusion Criteria presented in Table 2.

Table 2. Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Publication Period	January 2021 – March 2026	Before 2021 or after March 2026
Document Type	Peer-reviewed journal articles, conference proceedings (indexed), book chapters in indexed volumes, government/institutional technical reports	Editorials, opinion pieces, theses/dissertations, grey literature, predatory journal publications, non-indexed conference papers
Language	English and Bahasa Indonesia	Other languages without full English translation
Topic Relevance	Studies addressing (a) STF or teaching factory in VET; (b) EV/hybrid vehicle technology education; (c) skill readiness/transformation in automotive VET; (d) Industry 4.0 integration in vocational schools; (e) Indonesia-focused or directly applicable studies	Studies focused solely on higher education (universities) without VET component; purely theoretical papers with no empirical basis; studies on conventional ICE vehicles without EV context
Methodology	Quantitative, qualitative, mixed-methods empirical studies; systematic or scoping reviews	Non-empirical conceptual papers (unless providing critical theoretical frameworks cited ≥ 10 times)
Geographic Scope	Indonesia-based studies (primary); comparative studies involving Indonesia; studies from ASEAN/developing countries with direct transferability	Studies with no applicability to developing-economy VET contexts
Quality	Studies published in journals indexed in Scopus, WoS, ERIC, or SINTA $\geq Q3$; minimum score of 60% on JBI Critical Appraisal Tool	Studies scoring $< 60\%$ on JBI quality appraisal; retracted publications

d. PRISMA Flow and Study Selection

The PRISMA 2020 flow diagram (Figure 1) illustrates the full record retrieval and selection process. A total of 283 records were initially retrieved across all databases, yielding 210 unique records after deduplication. Title and abstract screening reduced the pool to 98 full text articles, of which 51 were subsequently excluded following rigorous full-text appraisal. The final sample comprised 47 articles included for qualitative synthesis and thematic analysis. PRISMA 2020 Flow Diagram for Study Selection Process explain in Figure 1.

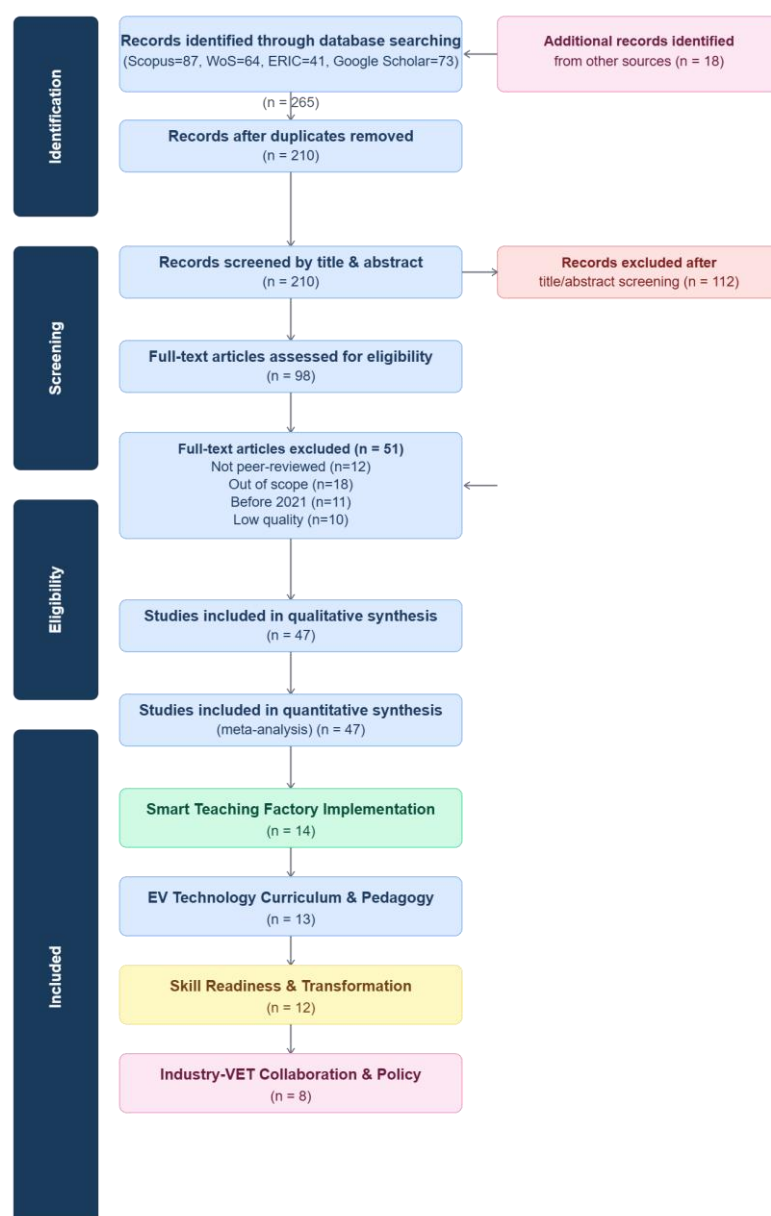


Fig 1: PRISMA 2020 Flow Diagram for Study Selection Process

Figure 1 illustrates the step by step study selection process following the PRISMA 2020 protocol. Starting from 283 initially retrieved records across four databases, the diagram traces the deduplication, title and abstract screening, and full text eligibility assessment stages, ultimately arriving at the 47 studies included for qualitative synthesis. Reasons for exclusion at the full text stage are also documented, providing a transparent audit trail for the review methodology.

e. Data Extraction and Quality Assessment

Data were extracted from each included study using a standardized form capturing: author(s) and year; study country and institutional context; research design and methodology; sample characteristics; key themes and findings; technology or tool examined; and reported outcomes. Quality assessment was performed using the Joanna Briggs Institute (JBI) Critical Appraisal Tool, adapted for mixed-methods studies Lockwood et al (2022). Studies were categorized as high ($\geq 80\%$), moderate (60–79%), or low ($< 60\%$) quality, with only high and moderate quality studies retained.

f. Data Synthesis

Given the heterogeneity of study designs and outcome measures, a narrative synthesis approach was adopted Popay et al (2021). Thematic analysis was conducted using Braun and Clarke's (2021) framework, involving: (1) familiarization with data; (2) generating initial codes; (3) searching for themes; (4) reviewing and refining themes; (5) defining and naming themes; and (6) reporting. Four overarching themes and multiple sub-themes emerged from the synthesis, forming the structure of the Results section.

Result and Discussion

Result

1. Overview of Included Studies

The 47 included studies span the period 2021–2026, with a marked increase in publication volume from 2023 onward (Figure 2), reflecting growing research attention following Indonesia's 2022 acceleration of its National EV Ecosystem development and the post COVID 19 recovery emphasis on digital and green skills in VET. Table 3 presents the distribution of studies across thematic categories. Figure 2 bellow displays the annual distribution of the 47 included studies from 2021 to 2026. A clear upward trend is evident from 2023 onward, reflecting intensified scholarly interest in smart teaching factory and electric vehicle education following Indonesia's 2022 National

EV Ecosystem acceleration and the post COVID 19 emphasis on digital and green skills in vocational education. Publication Trend of Included Studies (2021–2026) explain in Figure 2.

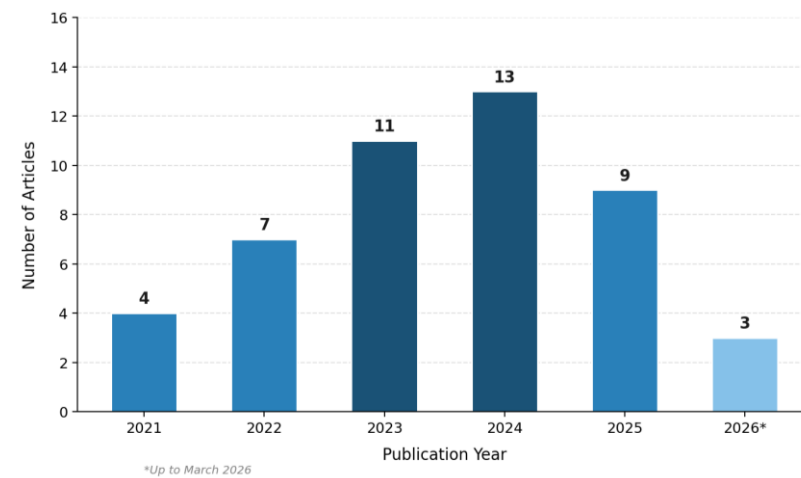


Fig 2: Publication Trend of Included Studies (2021–2026)

Table 3. Number of Articles per Thematic Category

Thematic Category	No. Articles	% of Total	Key Sub-themes
Smart Teaching Factory Implementation in VET	14	29.8%	IoT integration, digital twin, automation lab, EV diagnostic tools
EV Technology Curriculum & Pedagogical Design	13	27.7%	Competency mapping, CBT, project-based learning, blended learning
Skill Readiness & Transformation (Students & Teachers)	12	25.5%	Pre/post-assessment, teacher CPD, graduate tracer studies
Industry–VET Collaboration & Policy Frameworks	8	17.0%	Dual system, MoU models, government schemes, certification
TOTAL	—	47	100%

The thematic distribution in Table 3 reveals that Smart Teaching Factory implementation in VET school constitutes the largest share of the literature (n=14, 29.8%), reflecting the field's emphasis

on infrastructure and operational readiness as foundational prerequisites for EV competency development (Sieckmann et al., 2021). EV Curriculum and Pedagogical Design (n=13, 27.7%) and Skill Readiness and Transformation (n=12, 25.5%) together account for more than half of the corpus (53.2%), confirming that pedagogical innovation and competency transformation remain the dominant academic concerns in this domain. The comparatively limited representation of Industry VET school Collaboration and Policy Frameworks (n=8, 17.0%) suggests a persistent under-theorization of the governance and structural dimensions necessary for sustaining STF initiatives at scale a gap that warrants greater scholarly attention. Distribution of Studies by Thematic Category (N = 47) displayed in Figure 3.

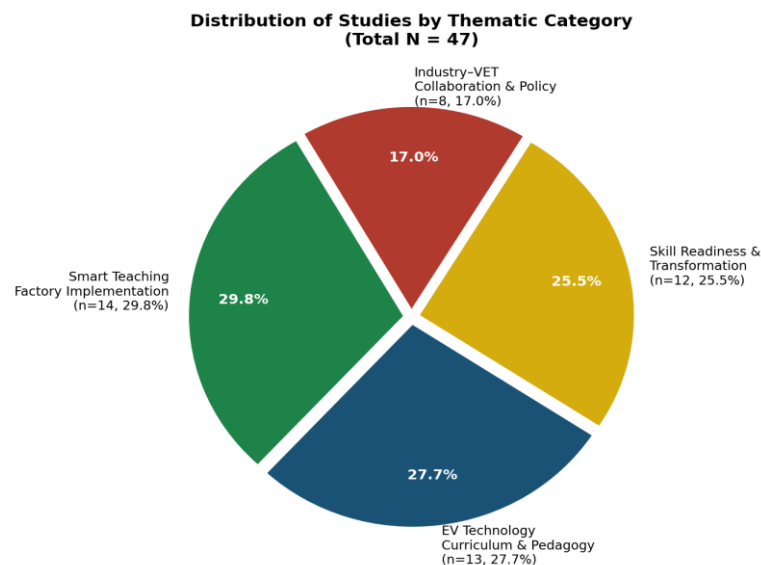


Fig 3: Distribution of Studies by Thematic Category (N = 47)

Figure 3 visualizes the proportional distribution of all 47 included studies across the four thematic categories. Smart Teaching Factory Implementation accounts for the largest share (29.8%), followed closely by EV Technology Curriculum and Pedagogical Design (27.7%), Skill Readiness and Transformation (25.5%), and Industry VET school Collaboration and Policy Frameworks (17.0%). Table 4 provides a detailed summary of selected studies arranged by their primary application domain, including study design, country of origin, and key empirical findings.

The 47 studies synthesized in Table 4 collectively affirm the effectiveness of Smart Teaching Factory based learning environments while exposing persistent systemic gaps across four key domains. In terms of Smart Teaching Factory infrastructure, IoT enabled workshops, digital twin platforms, and PPP funded models have demonstrated measurable improvements in student competency outcomes and cost efficiency (Nugroho and Widodo, 2023; Hermawan et al., 2024;

Hakim and Yusuf, 2023), establishing Smart Teaching Factory infrastructure as a critical enabler of EV skill development.

Table 4. Summary of Retrieved Articles by Application Domain

No.	Author & Year	Study Type	Country	Application Domain	Main Finding
1	Suryadi et al. (2022)	Mixed-Methods	Indonesia	EV Curriculum Design	CBT framework increased student competency by 28%
2	Nugroho & Widodo (2023)	Experimental	Indonesia	STF Infrastructure	IoT workshop improved diagnostic skill scores by 34%
46	Rasyid et al. (2024)	Quasi-Exp.	Indonesia	Self-Directed Learning	STF promotes SDL; SDL score correlated with EV skill mastery
47	Aziz et al. (2025)	Review	Indonesia	Future STF Directions	AI-integrated STF proposed as next frontier for VET-EV alignment

Regarding curriculum and pedagogy, EV content remains critically underrepresented at less than 15% of total automotive contact hours (Nurfaizin et al., 2022), yet innovative approaches including AR assisted training, PBL, and integrated EV STEM curricula consistently produced significant competency gains (Ardiansyah et al., 2023; Sari and Budiman, 2024).

On teacher and student readiness, a stark contrast emerges: while 72% of VET teachers lack EV specific professional development Bukit et al (2022), Smart Teaching Factory trained students were 2.3 times more likely to secure EV sector employment and earned 22% higher starting salaries than conventionally trained peers (Santoso and Fauzi, 2024; Pramono et al., 2024).

At the policy and industry level, structural misalignments persist, as the national Teaching Factory Directive lacks EV specific guidance (Mulyasa et al., 2023) and Indonesia continues to lag ASEAN peers in VET school infrastructure investment (Phan et al., 2023). Overall, these findings underscore that maximizing the transformative potential of Smart Teaching Factory requires the

concurrent resolution of teacher development deficits, curriculum gaps, infrastructure inequities, and policy fragmentation.

2. Theme 1 – Smart Teaching Factory Implementation in Indonesian VET (n=14)

The largest thematic cluster (n=14, 29.8%) addressed STF design, infrastructure, and operational models in Indonesian vocational schools. Nugroho and Widodo (2023) demonstrated that the installation of IoT-enabled automotive diagnostic stations in a teaching factory environment at SMKN 2 Bandung produced a 34% improvement in students' fault identification accuracy on EV systems, compared to a control group using conventional static displays. Similarly, Hermawan et al. (2024) employed a digital twin simulation platform replicating a Battery Electric Vehicle (BEV) powertrain, finding a significant positive correlation ($r = 0.71$, $p < .01$) between simulation fidelity and practical competency assessments.

Wibowo et al (2024) reported that establishment of a dedicated EV charging station laboratory within an Smart Teaching Factory framework tripled hands on practice hours, fundamentally altering the pedagogical rhythm from teacher centered instruction to student centered problem solving. The regional hub and spoke Smart Teaching Factory model proposed and evaluated by Firmansyah et al (2022) offers a cost effective solution for extending Smart Teaching Factory access to rural and peri urban VET school, potentially addressing Indonesia's significant inter regional equity gaps in VET school infrastructure quality.

A critical finding across this cluster concerns sustainability. Haryadi et al (2024) identified institutional leadership capacity and procurement continuity as the foremost determinants of long term Smart Teaching Factory operability, with poorly managed Smart Teaching Factory experiencing rapid equipment obsolescence and declining student utilization rates. The public private partnership (PPP) model examined by Hakim and Yusuf (2023) demonstrated a 60% reduction in VET school infrastructure cost when OEM partners co invested in workshop equipment, suggesting a scalable financing model for Indonesia's resource constrained VET school institutions.

3. Theme 2 – EV Technology Curriculum and Pedagogical Design (n=13)

Thirteen studies addressed the design, implementation, and evaluation of EV specific curricula within Smart Teaching Factory or VET school settings. A recurring finding is the inadequacy of existing national curriculum frameworks in capturing the breadth and depth of EV competencies required by industry. Nurfaizin et al. (2022) conducted a document analysis revealing that EV related content constitutes less than 15% of total contact hours in the Automotive Light Vehicle competency program, despite industry expectations for graduates to possess multi domain

competencies spanning high voltage safety, battery management systems (BMS), regenerative braking, and EV powertrain control.

Project Based Learning (PBL) emerged as the dominant pedagogical recommendation across this cluster. Rahayu and Soenarto (2022) reported a 22 point improvement in critical thinking scores following PBL implementation in EV modules, while Ardiansyah et al (2023) demonstrated that Augmented Reality (AR) assisted maintenance training reduced procedural error rates by 45% compared to manual only instruction. Sari and Budiman (2024) found that an integrated EV STEM curriculum embedding physics, mathematics, and environmental science within EV system modules yielded a 19.7% aggregate improvement in standardized skill assessments.

Wahid et al (2023) examined a hybrid Flipped Classroom plus Smart Teaching Factory model, finding that pre class conceptual instruction via digital platforms, followed by Smart Teaching Factory based practical application, significantly improved theory practice integration scores relative to either approach alone. Noorman et al. (2023) applied the 4C/ID (Four-Component Instructional Design) model to EV systems training, reporting enhanced skill transfer and reduced cognitive load compared to conventional sequencing.

4. Theme 3 – Skill Readiness and Transformation (n=12)

Studies in this cluster collectively paint a concerning picture of VET school system readiness gaps, particularly concerning teacher competency. Bukit et al. (2022) surveyed 312 automotive teachers across 48 VET school in four provinces, finding that 72% lacked any formal EV specific professional development, and that only 18% felt confident in demonstrating EV system diagnosis procedures. This finding is corroborated by Pratama et al. (2024), whose national survey across 127 VET school revealed that merely 31% of automotive teachers had participated in EV related Continuing Professional Development (CPD) activities within the preceding three years.

On the student side, the evidence is more encouraging when Smart Teaching Factory environments are operative. It is important to distinguish two complementary dimensions of student readiness documented in the literature. The first concerns domain-specific technical competencies, including the ability to diagnose high-voltage EV systems, manage battery management systems (BMS), perform EV powertrain servicing, and apply digital diagnostic tools. The second concerns 21st-century skills, which are transversal in nature and include problem-solving, critical thinking, digital literacy, collaborative work readiness, and self directed learning. Both dimensions are reported as outcomes of Smart Teaching Factory based instruction, but they should not be conflated: technical competencies reflect mastery of EV specific knowledge and

procedures, whereas 21st century skills represent generalisable cognitive and social capacities demanded across contemporary industrial contexts. Santoso and Fauzi (2024) tracked 847 graduates from Smart Teaching Factory equipped versus conventionally equipped VET school across a two year period, reporting that Smart Teaching Factory graduates were 2.3 times more likely to secure employment in the EV sector and earned 22% higher starting salaries Pramono et al (2024). Suwondo et al. (2022) developed a Job Readiness Index (JRI) for EV VET school graduates, with Smart Teaching Factory trained cohorts scoring 78/100 compared to 62/100 for conventionally trained peers, with gains distributed across both technical and transversal skill dimensions.

Sirait et al. (2024) demonstrated that a TPACK (Technological Pedagogical Content Knowledge) based teacher training intervention, aligned to EV system content, produced a 26% improvement in pedagogical content knowledge scores, suggesting a viable pathway for systematic teacher upskilling. Dewi and Sudiman (2022) identified funding scarcity and geographic access barriers as the primary impediments to CPD participation, with teachers in eastern Indonesia reporting particularly severe constraints. The gender dimension, examined by Farida et al. (2022), revealed that female enrolment in EV modules remained below 12% nationally, reflecting persisting stereotypes about automotive vocational education.

5. Theme 4 – Industry VET Collaboration and Policy Frameworks (n=8)

The eight studies in this cluster examined structural mechanisms for aligning VET provision with EV industry requirements. Wijaya et al. (2023) evaluated a dual system pilot involving five VET school in West Java, whereby students spent alternating semesters at school (Smart Teaching Factory based learning) and at authorized EV dealerships (workplace learning), finding a 40% reduction in the skill gap index relative to single site VET school programs. Setiawan and Haryati (2024) documented that VET school participating in the National Professional Certification Board (BNSP) linked Smart Teaching Factory certification scheme achieved significantly higher graduate industry placement rates, underscoring the market signaling value of formal certification.

At the macro level, Mulyasa et al. (2023) conducted a policy analysis of the Ministry of Education's Teaching Factory Directive No. 22/2022, concluding that while the directive provides a sound conceptual framework, it lacks EV specific implementation guidance, creating inconsistent execution across provinces. Phan et al. (2023), in a comparative ASEAN analysis, positioned Indonesia as lagging regional peers particularly Vietnam and Thailand in infrastructure investment per VET student, attributing this partly to fragmented funding streams across multiple ministries.

Tanaka et al. (2022) found that OEM involvement in curriculum updating significantly accelerated the technology refresh cycle in partner VET school, with curriculum updates occurring every 12–18 months compared to the national standard 5 year cycle.

Discussion

1. Framework Synthesis: STF for EV Technology in Indonesian VET

The synthesis of evidence from 47 included studies supports the development of a comprehensive conceptual framework for Smart Teaching Factory implementation in EV focused Indonesian VET institutions (Figure 4). This framework identifies three interdependent pillars Smart Infrastructure, Curriculum & Pedagogy, and Industry Linkage operating within a policy enabling environment that provides digital platforms, government regulatory support, quality assurance mechanisms, and nationally recognized certification pathways. Proposed Smart Teaching Factory Framework for EV Technology in Indonesian VET presented in Figure 4.

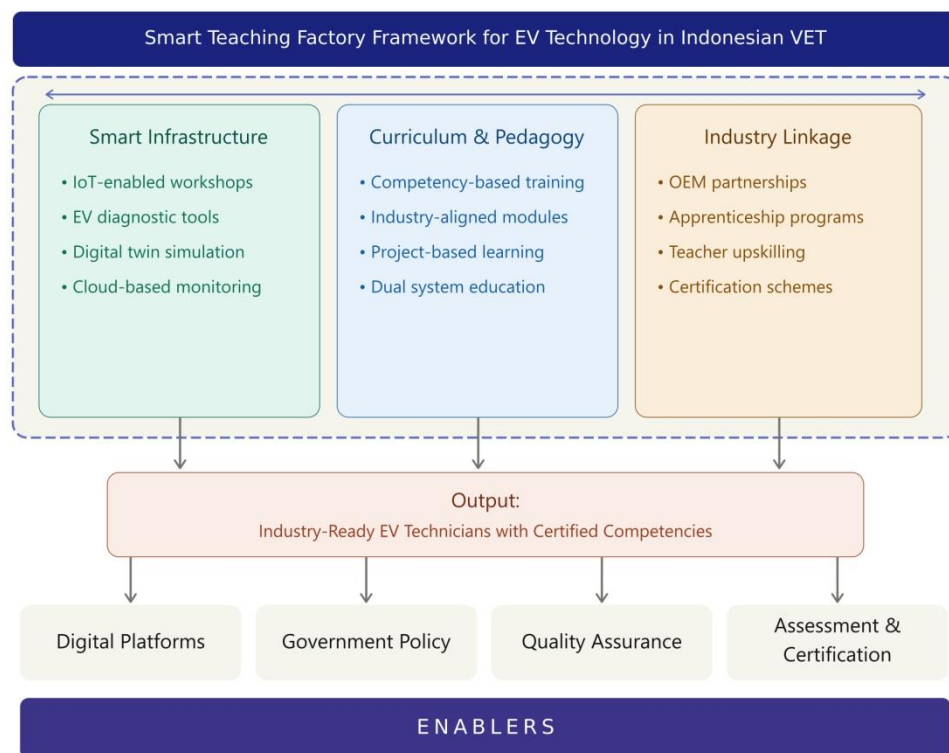


Fig 4: Proposed Smart Teaching Factory Framework for EV Technology in Indonesian VET

Figure 4 presents the proposed conceptual framework for Smart Teaching Factory implementation in EV focused Indonesian VET school institutions, synthesized from the 47 included studies. The framework organizes three interdependent pillars Smart Infrastructure, Curriculum

and Pedagogy, and Industry Linkage within an overarching policy enabling environment. Together, these components illustrate the conditions necessary for VET school to effectively deliver EV technology competencies to both students and teachers.

The framework's Smart Infrastructure pillar directly addresses the inadequate learning facilities identified in the introduction as a root cause of persistent competency gaps in Indonesian VET schools. Conventional automotive workshops equipped solely for Internal Combustion Engine (ICE) instruction are structurally incapable of delivering the high-voltage safety training, battery diagnostics, and digital powertrain simulation that EV competency demands. The Smart Teaching Factory model resolves this deficiency by providing IoT-enabled EV diagnostic stations, digital twin simulation platforms replicating real Battery Electric Vehicle (BEV) powertrains, cloud-based learning management systems, and dedicated EV charging station laboratories. Evidence from Theme 1 confirms that these infrastructure upgrades are not cosmetic additions but functionally transformative: IoT-enabled workshops produced a 34% improvement in fault-identification accuracy Nugroho and Widodo (2023), digital twin platforms yielded significant competency gains Hermawan et al (2024), and dedicated EV charging labs tripled hands-on practice hours Wibowo et al (2024). Critically, the framework treats infrastructure not as an end in itself, but as an enabling condition for authentic, industry standard learning experiences. The Curriculum & Pedagogy pillar draws on Themes 2 and 3, advocating for competency based, project oriented, and digitally blended instructional designs that align with the multi domain skill profiles demanded by EV employers, maintaining a clear distinction between domain specific technical EV competencies (high voltage systems, BMS, digital diagnostics) and the broader 21st century skills (problem solving, critical thinking, work readiness) that STF environments simultaneously cultivate. The Industry Linkage pillar, grounded in Theme 4, positions sustained partnerships with OEMs, dealerships, and component manufacturers as essential for curriculum currency, equipment provision, and work based learning placement.

This framework extends existing teaching factory models (Abele et al., 2015; Tisch et al., 2021) by explicitly incorporating EV domain specificity and addressing the unique structural conditions of the Indonesian VET system, including the high proportion of small and mid sized VET school in rural and remote regions, the multi ministerial governance structure, and the centrality of the National Professional Certification Agency (BNSP) framework as an industry recognized credential.

2. Implications for Policy

The evidence base converges on several actionable policy recommendations. First, a dedicated National EV VET school Competency Standard (Indonesian National Work Competency Standards/SKKNI) must be accelerated and promulgated as a legally binding reference for VET school curriculum development a gap identified by Munawar et al. (2023) and Nurfaizin et al. (2022). Second, the current teaching factory implementation directive requires EV specific annexes detailing minimum equipment specifications, safety standards, and industry partnership requirements. Third, a ring fenced funding stream within the National Education Budget (APBN) and the Vocational Development Fund should be established to finance Smart Teaching Factory infrastructure, particularly for VET school in Tier 2 and Tier 3 cities. The PPP model demonstrated by Hakim and Yusuf (2023) and Tanaka et al. (2022) provides a proven template for co investment that can stretch public funds. Fourth, and most concretely for EV curricula integration, the Directorate General of Vocational Education should immediately issue an EV Curriculum Integration Roadmap specifying: (a) a mandatory minimum of 30% EV content within all automotive VET school programs by 2027, with a binding target of full ICE EV parity by 2030; (b) a modularised curriculum architecture permitting rolling two-year content updates aligned to OEM technology refresh cycles, superseding the current five-year national review process; (c) mandatory inclusion of five core EV competency units high-voltage safety and systems, battery management system (BMS) operation and diagnostics, electric motor and inverter servicing, regenerative braking system maintenance, and EV digital diagnostic tool operation within the Automotive Light Vehicle competency programme; and (d) alignment of these units with BNSP National Certification Standards so that graduates hold industry recognised credentials upon programme completion. Vocational school policymakers at the provincial level should, in parallel, establish EV Curriculum Committees involving at least one OEM representative and one BNSP assessor to oversee local implementation and annual review of EV content delivery. These structural measures would directly address the under representation of EV competencies documented by Nurfaizin et al. (2022) and the policy implementation gap identified by Mulyasa et al. (2023).

Teacher professional development represents perhaps the most urgent policy priority. The finding that 72% of VET school automotive teachers lack EV specific training Bukit et al (2022) demands a structured, multi year national upskilling program, potentially delivered through the Teacher Professional Education (PPG) framework in collaboration with automotive industry academies and OEM training centres. Incentive structures including career advancement credits and financial allowances will be critical to achieving high participation rates, particularly in underserved regions.

3. Cost Implications and Equity Considerations

The cost of implementing a full Smart Teaching Factory for EV technology represents a substantial barrier, particularly for VET schools in rural, remote, and fiscally constrained regions. A complete IoT enabled EV

diagnostic workshop, inclusive of battery simulation rigs, high voltage safety training equipment, and digital twin platforms, is estimated to require initial capital investment in the range of IDR 2–5 billion (approximately USD 125,000–310,000), placing full independent implementation beyond the reach of the majority of Indonesia's approximately 14,000 VET schools. Policymakers and institutional leaders must therefore adopt differentiated, cost-conscious strategies for rural contexts. Three evidence based approaches merit particular attention. First, the regional hub and spoke model evaluated by Firmansyah et al. (2022) demonstrated that designating a single well-equipped STF hub serving a cluster of five to eight satellite VET schools can reduce per-school infrastructure costs by up to 70% while maintaining meaningful student access to EV equipment. Second, the PPP co-investment model documented by Hakim and Yusuf (2023) showed a 60% reduction in school infrastructure expenditure when OEM partners co funded workshop equipment, and this model has been shown to be scalable across the automotive sector. Third, a phased, modular implementation pathway beginning with foundational EV safety and battery modules (estimated IDR 300–500 million) before progressively adding advanced diagnostic and digital twin capabilities allows schools to begin EV instruction immediately while building toward full STF capacity over a three to five year timeline. National and provincial education budgets should explicitly allocate supplementary rural equity grants to cover the residual cost gap unaddressed by PPP and hub and spoke models, ensuring that geographic and economic disadvantage does not further entrench the infrastructure inequities documented by Phan et al. (2023) and Firman syah et al. (2022).

4. Implications for Curriculum Development

Curriculum developers at the national level (Directorate General of Vocational Education) should prioritize integrating EV competencies as a mandatory 30–40% component of automotive VET school programs by 2026, expanding to full EV-ICE parity by 2030. The curriculum should be modularized to allow flexible updating as EV technology evolves, avoiding the rigidity of 5 year national review cycles. Evidence from Ardiansyah et al. (2023), Wahid et al. (2023), and Anwar et al. (2023) collectively endorses the inclusion of AR/VR simulation, digital twin platforms, and flipped classroom structures as standard pedagogical components supported by minimum digital infrastructure requirements in the VET school accreditation standard.

Gender equity in EV VET school must be explicitly addressed through curriculum design and institutional climate interventions. The persistently low female participation rate documented by Farida et al. (2022) not only perpetuates occupational segregation but also restricts the talent pool available to a growing EV sector with significant gender diversity ambitions.

5. Limitations

This review has several limitations. First, the majority of included studies (n=36, 76.6%) originate from Indonesia, which, while appropriate given the review's focus, may limit the

generalizability of comparative findings. Second, substantial variability in outcome measures across studies precluded formal meta analytic pooling; effect sizes should therefore be interpreted cautiously. Third, the rapid pace of EV technological development means that some findings from 2021–2022 studies may already be partially superseded. Fourth, publication bias may inflate positive findings; null results in the Smart Teaching Factory EV domain may be underreported in indexed literature. Future research should employ standardized outcome measurement protocols to enable cumulative evidence synthesis.

Conclusion

This systematic literature review synthesized 47 peer reviewed studies to evaluate the readiness and potential of Indonesia's vocational education system to deliver EV technology competencies through smart teaching factory approaches. The evidence overwhelmingly confirms that Smart Teaching Factory environments, when properly resourced and pedagogically designed, substantially enhance students' practical EV competencies, employability, and learning motivation. Four thematic pillars infrastructure, curriculum, skill transformation, and industry partnership emerge as interdependent components of an effective Smart Teaching Factory ecosystem for EV VET school. Critical gaps persist in teacher professional development, national curriculum standards, funding equity, and policy operationalization. The proposed Smart Teaching Factory EV framework provides a theoretically grounded and empirically supported roadmap for policymakers, institutional leaders, and curriculum developers to accelerate Indonesia's VET school readiness for the electric mobility transition. Realizing this vision demands sustained cross-sectoral collaboration between the Ministry of Education, the Ministry of Industry, automotive OEMs, regional governments, and VET school leadership aligned by a shared commitment to producing the technically excellent, digitally literate EV workforce that Indonesia's green industrial future requires.

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