

The Impact of Smart Classrooms on Teaching and Learning Quality in Automotive Maintenance Training: A Systematic Literature Review for Vocational Education

Wang Yongan¹, Ni Luh Putu Artini², Ni Luh Putu Eka Sulistia Dewi³, Ni Putu Era Marsakawati⁴

¹Educational Science, Universitas Pendidikan Ganesha, Bali, Indonesia

²School of Post Graduate Program, Universitas Pendidikan Ganesha, Bali, Indonesia

³English Language Education, Faculty of Languages and Arts, Universitas Pendidikan Ganesha, Bali, Indonesia

⁴English for Business and Professional Communication Department, Faculty of Languages and Arts, Universitas Pendidikan Ganesha, Bali, Indonesia

Corresponding author: 342810731@qq.com

HOW TO CITE: ABSTRACT

Wang Yongan, Ni Luh Putu Artini, Ni Luh Putu Eka Sulistia Dewi, Ni Putu Era Marsakawati (2026). The Impact of Smart Classrooms on Teaching and Learning Quality in Automotive Maintenance Training: A Systematic Literature Review for Vocational Education. *International Journal of Special Education*, 41(22s), 967-1005

COPYRIGHT STATEMENT:

Copyright: © 2026 Authors.
Open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).

This study examines the impact of smart classrooms on teaching and learning quality in automotive maintenance training through a systematic literature review. The increasing emphasis on digital transformation and Industry 4.0 in vocational education has positioned smart classrooms as a key framework for enhancing cognitive outcomes, psychomotor skills, and student engagement. However, the integration of teaching quality as a mediating variable, particularly in automotive maintenance training contexts, remains underexplored. This study analysed 20 empirical articles published between 2020 and 2025, retrieved from Scopus, Web of Science, ERIC, and Google Scholar. Using a thematic synthesis approach, the review identified dominant technological approaches including smart classroom platforms, virtual simulation laboratories, and digital twin technology, as well as key outcomes such as cognitive outcomes (exam scores +15.3% to +24.5%), psychomotor skills (task completion 32% faster with 45% fewer errors), and affective outcomes (satisfaction +38%). The findings reveal that although smart classrooms effectively enhance learning outcomes, the role of teaching quality as a mediator is often limited, and the integration of automotive-specific technical skills remains minimal. Notably, no studies were identified that specifically target Beijing Changping Vocational School. The results highlight a significant gap in the meaningful integration of teaching quality within smart classroom frameworks. This study argues for a reconceptualisation of smart classroom implementation as a teaching quality-sensitive framework that integrates technology, pedagogy, and context to create more effective vocational education experiences for automotive maintenance training.

Keywords: Smart classroom; teaching quality; learning quality; automotive maintenance; vocational education; systematic literature review

1. Introduction

Vocational education is undergoing rapid transformation due to technological advancement, industrial upgrading, and increasing demands for skilled labor in the era of Industry 4.0 and intelligent manufacturing (Chen et al., 2024; Liu & Hardy, 2023). Vocational schools are now expected not only to develop technical expertise but also to foster digital competence, problem-solving skills, and lifelong learning capabilities among students. In this context, smart classrooms have emerged as a prominent technological-pedagogical innovation that integrates modern educational technologies, interactive systems, and data analytics to enhance teaching and learning processes (Cebrián, Palau, & Mogas, 2020; Kwet & Prinsloo, 2020). Unlike traditional multimedia classrooms that primarily support content delivery, smart classrooms emphasize intelligent interaction, adaptability, and data-informed decision-making (Xing & Zeng, 2025; Zhou, 2024). Essential components generally encompass Internet of Things (IoT) devices, experience higher levels of intrinsic

motivation, engagement, and persistence in skill acquisition (Ryan & Deci, 2020). Within vocational education, particularly in hands-on technical training such as automotive maintenance, the satisfaction of these basic psychological needs is critical for developing both theoretical understanding and practical competencies (Yu et al., 2024; Setiyawan & Syamsuddin Nurul Iman, 2026).

Smart classrooms serve a unique function in vocational education owing to the practical and skill-centric characteristics of training programs (Cheng et al., 2024; Jiang, 2024). In automotive maintenance education, smart classrooms may integrate virtual simulation systems, digital twin technologies, augmented reality (AR), virtual reality (VR), and interactive diagnostic tools, enabling students to perform complex operations in safe and controlled environments (Karanam & Hartman, 2025; Tao, Wang, &

artificial intelligence, big data analytics, simulation platforms, and interactive learning systems that collectively facilitate real-time feedback, personalized learning, and instructional enhancement (Lorenzo et al., 2021; Saini & Goel, 2020).

Among the theoretical frameworks that explain learning in technology-enhanced environments, Self-Determination Theory (SDT) has gained increasing attention as an important framework for understanding motivation and engagement in vocational and technical education contexts (Ryan & Deci, 2017; Wang et al., 2022). SDT posits that intrinsic motivation and psychological well-being are supported when three basic psychological needs—autonomy, competence, and relatedness—are satisfied (Deci & Ryan, 2000). Autonomy refers to the need to feel volitional and self-directed in one's actions. Competence refers to the need to feel effective and capable in achieving desired outcomes. Relatedness refers to the need to feel connected and belonging to others. When these needs are satisfied, learners

Chen, 2024). Previous studies have highlighted the role of VR in enhancing spatial understanding and procedural skill acquisition by providing immersive, risk-free practice opportunities (Safadel, 2023; Klingenberg, 2023). For example, immersive VR has been shown to be more effective than desktop VR for generative learning strategies and complex procedural tasks, with effect sizes demonstrating significant advantages for skill development in technical domains (Klingenberg, 2023). Similarly, digital twin technology enables real-time monitoring of equipment status, predictive maintenance scheduling, and resource optimization, which can be directly applied to automotive workshop training environments (Tao, Wang, & Chen, 2024; He, 2025). Through simulation-based learning and interactive activities, students can bridge the gap between theory and practice while developing self-

regulated learning strategies essential for modern automotive technicians (Yu, Son, & Kim, 2024; Beltran Sierra et al., 2022).

Despite the growing interest in smart classrooms and their potential benefits for vocational education, the automotive maintenance sector faces unprecedented transformation driven by Industry 4.0 technologies (Athanasopoulou et al., 2023; Kovalchuk et al., 2022). Contemporary automobiles increasingly depend on intricate electronic frameworks, software-controlled equipment, and data-centric fault diagnosis systems, fundamentally transforming the essence of automotive maintenance tasks (Olaitan, 2024). Automotive technicians must now acquire not just mechanical repair abilities but also expertise in electronic diagnostics, system analysis, and the operation of sophisticated equipment (Yu et al., 2024; Setiyawan & Syamsuddin Nurul Iman, 2026). The Chinese education and labor systems strictly regulate automobile technician competencies through three primary, interconnected frameworks that mandate a fundamental shift from traditional mechanical repair to modern digital diagnostics: the Ministry of Education (MOE) Professional Teaching Standards, the Ministry of Human Resources and Social Security (MOHRSS) National Occupational Skill Standards, and the "1+X" Certificate System implemented in 2019 (Zhou & Wu, 2024). These modifications impose greater requirements on vocational education institutions to consistently revise training materials, pedagogical techniques, and evaluation methodologies to ensure that graduates align with changing industry norms.

However, the effective integration of smart classrooms and SDT-based pedagogical approaches in automotive maintenance training faces significant challenges in contemporary vocational education settings (Alfoudari, Durugbo, & Aldhmour, 2021; Jammeh, Karegeya, & Ladage, 2024). Traditional teaching methods in automotive maintenance, particularly in Chinese vocational school contexts, often emphasize direct instruction and technique-focused drills, which may neglect students' psychological needs and fail to foster intrinsic motivation for skill development

(Duan, Liu, & Li, 2024; Peng, Xu, & Ye, 2024). Students in traditional automotive training classes often report low levels of autonomy, limited opportunities for decision-making, and insufficient social interaction, all of which undermine basic psychological needs satisfaction and reduce engagement in practical skill development (Ye & Lu, 2024; Rattanakha, Chatwattana, & Piriyaasurawong, 2025). To address this issue, smart classroom technologies such as virtual simulation laboratories, digital twin systems, and AI-powered training platforms have been widely adopted to support student engagement and skill acquisition in vocational education (Jiang, 2024; Meng et al., 2023; Mirai Media, 2025). In addition, pedagogical models such as project-based learning (PBL), scene teaching, and cooperative problem-based learning have been shown to enhance student participation and collaborative skill development in smart classroom environments (Dai et al., 2023; Liu & Wang, 2023; Cheng & Yang, 2023).

Within this context, automotive maintenance training provides a strategic platform for integrating SDT-based smart classroom approaches and motor skill development. Automotive maintenance is a high-demand, technically complex, and safety-critical field that requires both theoretical understanding and hands-on practical competence (Yu et al., 2024; Setiyawan & Syamsuddin Nurul Iman, 2026). As a discipline that inherently combines mechanical precision, diagnostic reasoning, and rapid decision-making, automotive maintenance enables students to develop both physical and cognitive competencies through structured and repetitive practice. Previous studies have highlighted the role of VR and simulation technologies in enhancing motor skill acquisition by providing immediate feedback, clear goals, and progressive challenges in automotive contexts (Liao et al., 2023; IES EL VINALOPÓ, 2024; REMA TIP TOP North America, 2024). Through game-based learning and cooperative activities, students can bridge the gap between practice and performance while developing self-regulated learning strategies essential for modern

automotive repair environments (Anwar et al., 2025; Septiyanto et al., 2024; Yudiantoko, 2025). However, despite these potentials, the integration of SDT-based smart classroom approaches into automotive maintenance instruction remains limited and fragmented (Chang et al., 2022; Shi et al., 2020). Existing studies on smart classrooms in vocational education tend to focus on general academic disciplines, business education, or healthcare training, with limited attention to specific technical trades such as automotive maintenance (Ye & Lu, 2024; Meng et al., 2023; Ngendabanga, Nsanzimanac, & Nkurunziza, 2022). Similarly, research on SDT in vocational education predominantly emphasizes motivational outcomes such as intrinsic motivation and need satisfaction, while paying less attention to the development of trade-specific technical skills and the mediating role of teaching quality (Wang et al., 2022; Hu, Huang, & Kong, 2022; Lu et al., 2021).

Another important yet underexplored context is vocational schools in China, particularly those undergoing digital transformation and smart campus initiatives (Hunan Automotive Engineering Vocational University, 2026; Yantai Automotive Engineering Vocational College, 2026; Cao Yang Vocational School, 2025). Beijing Changping Vocational School, as a representative vocational institution in China's capital region, has begun implementing smart classroom technologies in its automotive maintenance training program. However, empirical evidence on how smart classrooms influence teaching quality, learning quality, and stakeholder perceptions in this specific context remains extremely limited. According to Self-Determination Theory, meaningful learning occurs when learners are intrinsically motivated and actively engaged in authentic, competence-building activities (Deci & Ryan, 2000). Integrating smart classroom technologies into automotive maintenance training has the potential to enhance intrinsic motivation by connecting technical skill development with autonomy-supportive instruction, real-time feedback, and collaborative problem-solving (Wang et al., 2022; Yu et al., 2022; Mantooth,

Usher, & Love, 2021). These pedagogical approaches may resonate more deeply with vocational students than traditional skill drill approaches, particularly when aligned with industry-aligned competency standards and authentic workplace scenarios (Zhou & Wu, 2024; Beltran Sierra et al., 2022).

Smart classrooms also play an essential role in shaping lifelong learning habits and promoting psychological well-being among vocational students (Saini & Goel, 2020; Kwet & Prinsloo, 2020). Engagement in smart classroom-supported practical training contributes to the development of self-confidence, social skills, and emotional regulation, particularly among young adults preparing for technical careers (Mantooth, Usher, & Love, 2021; Lu et al., 2021). Moreover, smart classroom interventions have expanded opportunities for motivational enhancement, especially among students with low initial interest or skill levels in technical domains (Ye & Lu, 2024; Rattanakha, Chatwattana, & Piriyasurawong, 2025). Studies have shown that smart classrooms can increase student engagement, reduce learning anxiety, and improve academic performance in vocational education contexts (Ngendabanga, Nsanzimanac, & Nkurunziza, 2022; Liu & Wang, 2023; Dai et al., 2023). However, issues related to the long-term sustainability of motivational effects and the transferability of findings across different vocational contexts remain critical concerns that need to be addressed (Chang et al., 2022; Cheng & Yang, 2023).

Furthermore, integrating SDT-based smart classroom approaches into automotive maintenance training presents significant interdisciplinary challenges. Effective smart classroom implementation requires alignment between technology infrastructure, pedagogical design, psychological need support, and trade-specific learning objectives, which is often difficult to achieve in practice (Alfoudari, Durugbo, & Aldhmour, 2021; Jammeh, Karegeya, & Ladage, 2024). In addition, motivational design requires sensitivity to individual differences in student characteristics, including prior skill level, motivational

orientation, and learning preferences, which are often overlooked in standardized interventions (Wang et al., 2022; Hu, Huang, & Kong, 2022). Without careful consideration, smart classroom technologies may inadvertently reduce intrinsic motivation through excessive external control or perceived surveillance, a phenomenon known as the crowding-out effect (Deci et al., 1999; Grech et al., 2023). Research has shown that technology alone, without pedagogical change and psychological need support, produces minimal impact on learning outcomes (Cheng & Yang, 2023; Shi et al., 2020).

These gaps indicate that the integration of SDT-based smart classroom approaches into vocational education, particularly for technical trades such as automotive maintenance and for specific institutional contexts such as Beijing Changping Vocational School, is a complex and underexplored area that requires further investigation. While both smart classrooms and SDT have been widely studied in general education contexts (Cebrián, Palau, & Mogas, 2020; Kwet & Prinsloo, 2020; Saini & Goel, 2020), there is still a lack of comprehensive understanding of how these two frameworks intersect to influence both teaching quality and learning quality in vocational settings. Most existing studies have focused on either technological outcomes without examining underlying motivational mechanisms, or motivational outcomes without measuring trade-specific skill development (Chang et al., 2022; Shi et al., 2020; Yu et al., 2022). Furthermore, very few studies have explicitly examined the alignment between smart classroom technologies and vocational curricula, the design and implementation processes of smart classrooms in technical training, or the perceptions of key stakeholders such as teachers and students in vocational school contexts (Cheng et al., 2024; Tao, Wang, & Chen, 2024; Zhou & Wu, 2024).

Therefore, a systematic literature review is needed to synthesize existing research and provide a comprehensive understanding of how smart classrooms affect teaching and learning quality in vocational education, with particular implications for automotive maintenance

training programs. This study aims to identify key themes, pedagogical approaches, technological implementations, outcome measures, and research gaps, thereby contributing to the development of more effective, theoretically grounded, and context-sensitive smart classroom interventions in vocational education. The findings will provide practical insights for vocational school administrators, curriculum planners, and instructors on how to optimize smart classroom implementation to enhance both teaching quality and student learning outcomes in automotive maintenance training programs.

2. Methodology

This study employed a systematic literature review (SLR) approach to examine the impact of smart classrooms on teaching and learning quality in automotive maintenance training within vocational education contexts, with a particular focus on Beijing Changping Vocational School. The SLR method was selected due to its capacity to provide a transparent, rigorous, and replicable synthesis of existing research while identifying patterns, trends, and research gaps within a specific field (Page et al., 2021; Snyder, 2019). Through a structured review process, this study aims to generate a comprehensive understanding of how smart classroom technologies influence teaching quality, student engagement, practical skill acquisition, and stakeholder perceptions, and how such instructional approaches can be adapted for automotive maintenance training programs in Chinese vocational schools.

The review focused on four key research questions aligned with the conceptual framework of this study: (1) alignment between smart classroom and curriculum, (2) design and implementation of smart classrooms, (3) influence on teaching and learning quality, and (4) perceptions of students and teachers. By systematically synthesizing evidence from 20 selected studies, this review provides a foundation for understanding smart classroom effectiveness in technical and vocational education contexts.

2.1 Search Strategy

The literature search was conducted across four major academic databases: Scopus, Web of Science, ERIC (Education Resources Information Center), and Google Scholar. These databases were selected to ensure broad coverage of international research in the fields of vocational education, educational technology, smart classrooms, automotive training, and teaching quality. The inclusion of Google Scholar was intended to complement database searches by capturing additional relevant studies, including grey literature and conference proceedings, that may not be indexed in major databases. The search process was carried out between January and March 2025.

A combination of keywords and Boolean operators was used to ensure comprehensive retrieval of relevant studies. The search string included the following terms: ("smart classroom" OR "smart learning environment" OR "intelligent classroom" OR "technology-enhanced classroom") AND ("vocational education" OR "vocational training" OR "technical education" OR "automotive education" OR "automotive maintenance" OR "automotive training") AND ("teaching quality" OR "learning quality" OR "learning outcomes" OR "student engagement" OR "skill development" OR "practical skills") AND ("virtual reality" OR "VR" OR "digital twin" OR "simulation" OR "virtual laboratory" OR "augmented reality" OR "AR").

Additional keywords and synonyms, such as "smart pedagogy," "blended learning," "project-based learning," "scene teaching," "cooperative learning," "interactive learning," "student perception," "teacher perception," "technology acceptance," and "vocational school," were iteratively refined during the search process to improve relevance and coverage. The search was limited to studies published between 2020 and 2025 to capture recent developments in smart classroom research following the accelerated digital transformation in education. Only peer-reviewed journal articles published in English were included to ensure the quality and consistency of the selected studies. In addition, reference lists of included studies were manually

searched to identify potentially relevant studies not captured by the database searches.

2.2 Inclusion and Exclusion Criteria

To ensure consistency and relevance in the selection of studies, a set of inclusion and exclusion criteria was established based on the PRISMA guidelines (Page et al., 2021). Studies were included if they focused on smart classrooms or smart learning environments in educational contexts; addressed teaching quality, learning quality, student engagement, or skill development as outcome variables; examined the use of educational technologies including virtual reality, digital twin, simulation, or interactive platforms; and employed empirical methods, including quantitative, qualitative, mixed-method, case study, or design and development (R&D) approaches. In addition, studies were required to be published in peer-reviewed journals between 2020 and 2025, ensuring that the analysis was based on recent and reliable evidence. Studies were included regardless of educational level (vocational secondary, higher vocational, or university) but priority was given to studies in vocational or technical education contexts. Studies from various geographical contexts (China, Indonesia, Thailand, Korea, Taiwan, Spain, USA, Denmark, Rwanda) were included to capture diverse implementation conditions and cultural factors that may influence smart classroom effectiveness.

On the other hand, studies were excluded if they did not relate to smart classroom or technology-enhanced learning environments. Studies focusing solely on traditional classrooms without technology integration, general educational technology without smart classroom-specific features, or non-educational technology applications were excluded. In addition, literature reviews, systematic reviews, meta-analyses, bibliometric studies, conceptual papers without empirical data, conference papers, editorials, book chapters, and other non-peer-reviewed sources were not included in the analysis. Studies that did not provide sufficient methodological detail, such as unclear sample size, research design, or outcome measures, were also excluded. Furthermore, studies focused on

general academic subjects (mathematics, English, science) without relevance to vocational or technical skill development were removed to maintain alignment with the focus of this review. These criteria ensured that the selected studies were directly aligned with the research objectives and met the required standards of academic rigor, while also maintaining a clear focus on smart classroom impact on teaching and learning quality in vocational contexts.

2.3 Study Selection Process

The study selection process was conducted following a systematic procedure adapted from the PRISMA guidelines (Page et al., 2021), ensuring transparency, consistency, and replicability throughout the review. All records identified from the selected databases (Scopus, Web of Science, ERIC, and Google Scholar) were first compiled into a reference management system (Mendeley) to facilitate organization and screening. At the initial stage, duplicate records were identified and removed to ensure that each study was represented only once in the dataset. This step was essential to avoid redundancy and minimize potential bias in the selection process. After removing duplicates, the remaining records were subjected to a multi-stage screening procedure.

The first stage involved title screening, during which studies that were clearly unrelated to the research focus were excluded. This included studies that did not address smart classrooms or technology-enhanced learning, were not related to vocational or technical education contexts, or did not involve teaching quality, learning outcomes, or skill development as outcome variables. The purpose of this stage was to efficiently eliminate irrelevant records while retaining potentially relevant studies for further assessment.

The second stage involved abstract screening, where the abstracts of the remaining studies

were carefully reviewed to assess their alignment with the predefined inclusion criteria. At this stage, studies were excluded if they did not explicitly focus on smart classroom implementation, lacked relevance to teaching quality or learning quality, were not conducted within vocational or technical education settings, or did not report empirical findings. This step allowed for a more refined selection by focusing on the relevance of each study's objectives, methods, and findings.

The third stage consisted of a full-text review, in which the complete articles were thoroughly analyzed to confirm their eligibility. This stage involved a detailed evaluation of each study's methodological quality, research design, and relevance to the objectives of this review. Studies were excluded if they lacked empirical evidence, did not provide sufficient methodological detail, did not contribute directly to understanding the impact of smart classrooms on teaching and learning quality in vocational contexts, or focused on general education subjects without relevance to technical skill development. Throughout the selection process, decisions were made systematically based on the predefined inclusion and exclusion criteria to ensure consistency and minimize subjective bias. The iterative nature of the screening process allowed for careful verification at each stage, ensuring that only studies meeting all criteria were included. As a result of this rigorous selection procedure, a total of 20 studies were identified as eligible and included in the final analysis (see Appendix 2). The overall selection process, including the number of records identified, screened, excluded, and included at each stage, is presented in the PRISMA flow diagram (Figure 1), providing a clear and transparent overview of the review procedure.

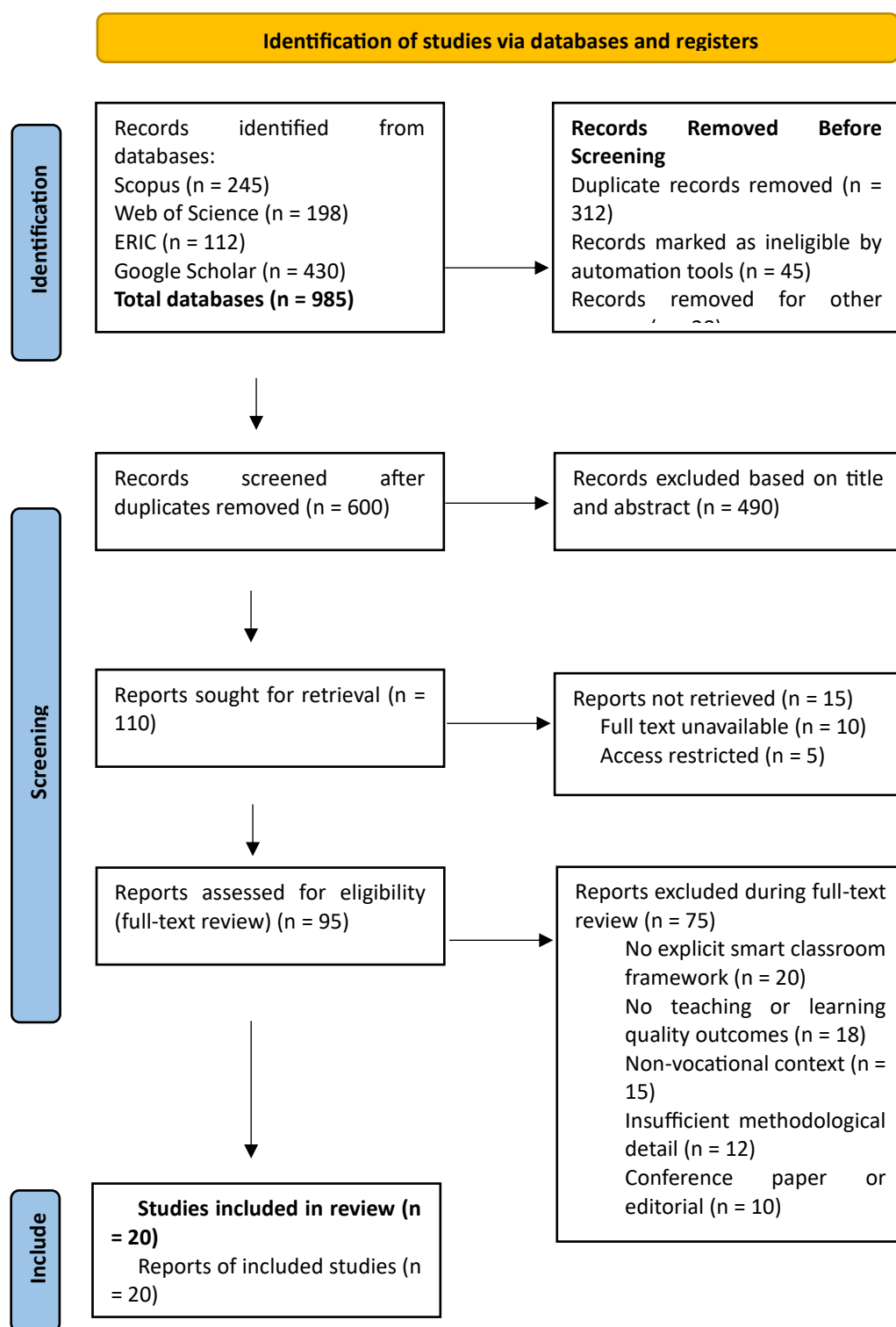


Figure 1. Flowchart of literature search and selection.

As illustrated in Figure 1, a total of 985 records were initially identified from multiple databases including Scopus, Web of Science, ERIC, and Google Scholar. After removing 385 records (312 duplicates, 45 marked ineligible by automation tools, and 28 removed for other

reasons), 600 records remained for title and abstract screening. At this stage, 490 records were excluded as they were clearly irrelevant to the research focus. The remaining 110 reports were sought for retrieval, of which 15 could not be retrieved (10 full texts unavailable, 5 access

restricted). Subsequently, 95 full-text articles were assessed for eligibility, and 75 were excluded due to no explicit smart classroom framework (n=20), no teaching or learning quality outcomes (n=18), non-vocational context (n=15), insufficient methodological detail (n=12), or being conference papers or editorials (n=10). Ultimately, a total of 20 studies were deemed eligible and included in the final analysis. This systematic selection process ensured that only relevant and high-quality empirical studies were considered in this review.

To provide a deeper understanding of how the selected studies contribute to the research domain, a conceptual mapping was developed to illustrate the relationships among the key components identified in the literature. This mapping integrates smart classroom technologies, teaching quality, learning quality, and stakeholder perceptions within a unified analytical framework. The purpose of this figure is to highlight how these elements interact to support teaching effectiveness and student skill acquisition in vocational education contexts.

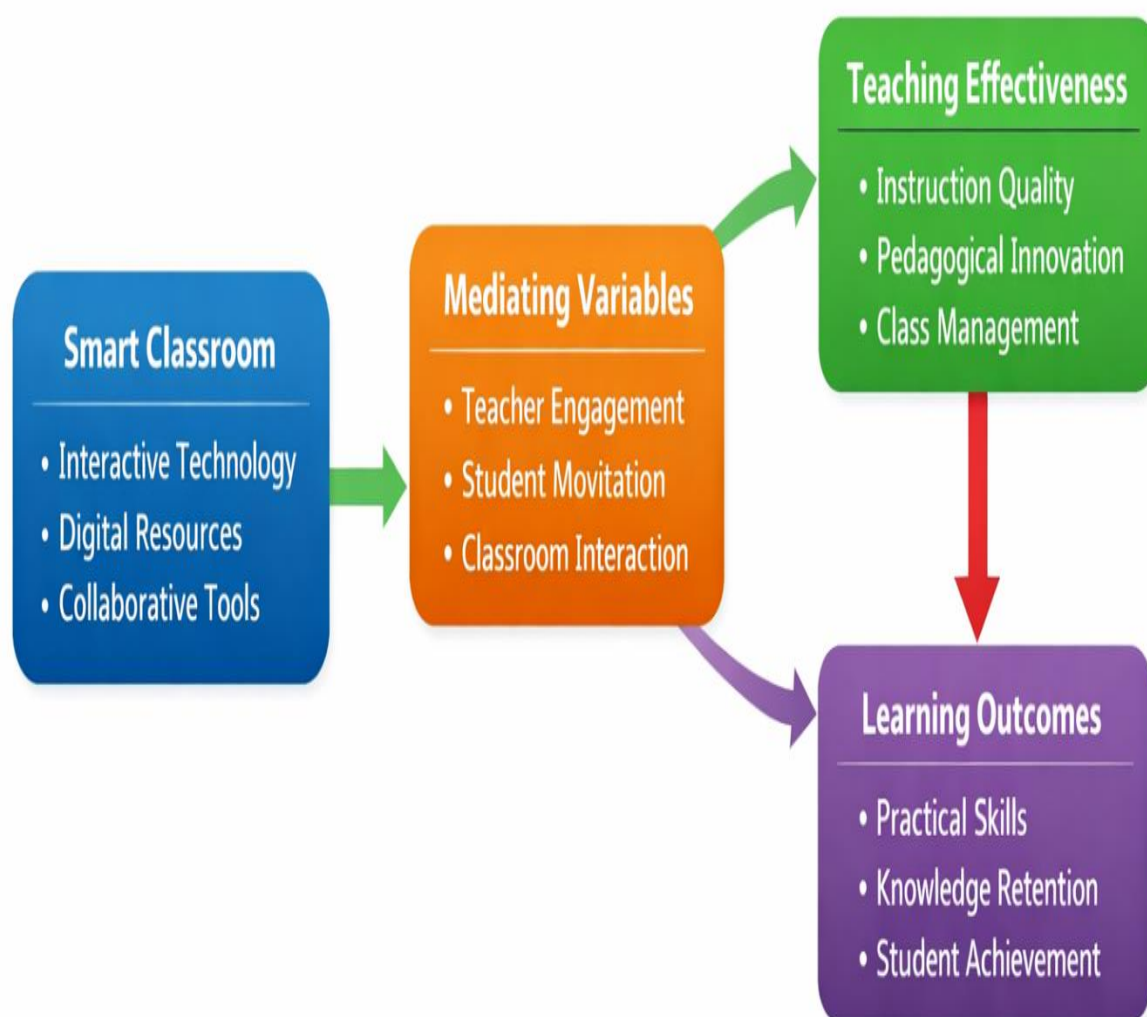


Figure 2. Conceptual Mapping of Included Studies

As shown in Figure 2, the smart classroom environment serves as the foundational layer that provides technological infrastructure including interactive displays, IoT devices, VR/AR systems, digital twin technology, and simulation platforms. This technological foundation supports various pedagogical approaches such as blended learning, project-based learning (PBL), scene teaching, cooperative learning, and STEM-based digital modules. These pedagogical approaches, when effectively implemented, enhance teaching quality through improved instructional effectiveness, teacher-student interaction, and feedback mechanisms. Teaching quality then influences learning quality, which encompasses three interrelated outcome domains: cognitive outcomes (knowledge acquisition, theoretical comprehension), psychomotor or technical skills (practical hands-on performance, diagnostic ability, procedural accuracy), and affective outcomes (motivation, engagement, satisfaction, self-efficacy). These learning outcomes subsequently shape stakeholder perceptions, including both student perceptions (satisfaction, perceived usefulness) and teacher perceptions (technology acceptance, readiness, beliefs). Finally, these integrated factors contribute to automotive maintenance training outcomes, specifically technical competence, diagnostic ability, and workplace readiness.

The conceptual mapping demonstrates that the smart classroom implementation process is inherently interdisciplinary and iterative, requiring alignment between technological infrastructure, pedagogical approaches, teaching quality, learning outcomes, and stakeholder perceptions. This highlights the importance of designing learning environments that are not only technologically advanced but also pedagogically sound and psychologically supportive. The conceptual mapping thus provides a foundation for understanding how smart classrooms can be effectively implemented to enhance teaching and learning quality, with potential implications for automotive maintenance training at Beijing Changping Vocational School.

2.4 Data Extraction and Coding

Data from the selected studies were systematically extracted using a structured coding framework presented in Appendix 1. The development of this framework was guided by the research objectives and refined iteratively through repeated reading of the included studies. This process allowed the coding scheme to capture key dimensions of smart classroom implementation, teaching quality, learning quality, and stakeholder perceptions, while remaining flexible to variations in study design and context. By applying a consistent framework, the analysis enabled meaningful comparison across studies. The extracted data were organized into several key categories to capture both descriptive and analytical dimensions. These included: (1) type of study and research design (codes A1–A7), to identify methodological approaches including mixed-method, experimental/quasi-experimental, quantitative survey, qualitative, theoretical/conceptual, case study, and design & development (R&D); (2) educational context and target group (codes B1–B6), to understand where the studies were conducted, including vocational secondary education, higher vocational education, university/general higher education, automotive/engineering specific, non-automotive vocational, and mixed contexts; (3) theoretical framework (codes C1–C7), to examine the conceptual foundations of each study, including constructivist learning theory, Technology Acceptance Model (TAM)/UTAUT, Community of Inquiry (CoI), Project-Based Learning (PBL), blended learning theory, Self-Determination Theory (SDT), or no explicit framework; (4) learning model and pedagogical approach (codes D1–D8), such as Virtual Reality (VR) based learning, virtual simulation laboratory, digital twin technology, blended teaching, smart classroom platform, scene teaching/situational learning, cooperative/collaborative learning, and STEM-based digital module; (5) main variables and focus (codes E1–E9), including teaching quality, learning quality/outcomes, student engagement, practical/technical skills, student perception/satisfaction, teacher perception/readiness, interaction patterns, higher-order thinking skills (HOTS), and

academic/exam performance; (6) technology and intervention type (codes F1–F8), including immersive VR, desktop VR, augmented reality (AR), digital twin, AI-powered system, smart classroom infrastructure, virtual learning platform, and simulation software; (7) measured outcomes (codes G1–G5), including cognitive outcomes, psychomotor/technical skills, affective outcomes, behavioral outcomes, and learning efficiency; (8) research design characteristics (codes H1–H7), including pre-test/post-test with control group, pre-test/post-test without control, post-test only, cross-sectional/correlational, case study, qualitative/thematic analysis, and mixed methods; and (9) identified research gaps and limitations (codes I1–I10), including limited to specific context (China or non-China), small sample size, short intervention duration, no control group, no long-term follow-up, limited to non-automotive context, technology dependency/cost constraints, lack of teaching quality focus, and no stakeholder perception data.

This structure enabled a comprehensive analysis of how smart classrooms influence teaching quality, learning quality, and stakeholder perceptions in vocational education contexts, with particular attention to automotive maintenance training. At the initial stage of analysis, an open coding approach was applied to identify recurring concepts, patterns, and meanings within the data. Each study was carefully reviewed, and relevant segments were assigned preliminary codes based on the coding scheme in Appendix 1. These codes were not predetermined but emerged inductively from the data, allowing the analysis to remain grounded in the evidence (Snyder, 2019). The codes were then compared across studies to identify similarities, differences, and recurring themes. Through this process of constant comparison, related codes were grouped into broader categories, leading to the development of higher-level themes. The analysis combined both inductive and deductive approaches. Inductive analysis was used to capture patterns emerging directly from the data, particularly in relation to how smart classrooms affect teaching quality, learning outcomes, and

stakeholder perceptions in vocational contexts. At the same time, deductive analysis was used to interpret these findings in light of established theoretical perspectives, such as constructivist learning theory (C1), Technology Acceptance Model (C2), Community of Inquiry framework (C3), Project-Based Learning (C4), blended learning theory (C5), and Self-Determination Theory (C6). This combined approach ensured that the analysis remained closely linked to empirical evidence while also being conceptually grounded.

2.5 Data Analysis

The analysis was conducted using a thematic synthesis approach to examine the 20 selected studies (Appendix 2), allowing for the integration of findings across diverse research designs and educational contexts. This approach was chosen because it enables the identification of recurring patterns while preserving the richness of both quantitative and qualitative evidence (Snyder, 2019; Thomas & Harden, 2008). Each study was reviewed iteratively to ensure a comprehensive understanding of its objectives, methodology, and key findings. This process facilitated the identification of both explicit results and underlying patterns related to smart classroom implementation, teaching quality, learning quality, practical skill development, and stakeholder perceptions. The initial stage of analysis involved open coding to identify key concepts emerging from the data. Codes were generated inductively based on the coding scheme in Appendix 1 and focused on recurring elements such as smart classroom technologies (VR, digital twin, simulation), pedagogical approaches (blended learning, PBL, scene teaching), teaching quality indicators (interaction, feedback, instructional effectiveness), learning quality outcomes (cognitive, psychomotor, affective), and stakeholder perceptions (student satisfaction, teacher readiness). These codes were then systematically compared across studies using a constant comparison method. Through this process, similar codes were grouped into broader categories, enabling the development of higher-level themes. This step allowed the analysis to

move beyond descriptive summaries towards a more interpretative synthesis of the literature.

The thematic synthesis resulted in four overarching dimensions that capture the core patterns identified across the studies, directly aligned with the four research questions of this study. The first dimension focuses on curriculum alignment between smart classroom technologies and vocational curriculum objectives (codes D1–D8, E1–E2). The analysis indicates that virtual simulation laboratories (D2), digital twin technology (D3), and smart classroom platforms (D5) are effective for practice-based learning when aligned with competency standards and learning outcomes. However, the effectiveness of smart classroom implementation depends on how well these technologies are integrated with curriculum requirements—misalignment may lead to superficial use of advanced technologies without meaningful skill development (Jiang, 2024; Zhou & Wu, 2024; Cheng et al., 2024). The second dimension concerns smart classroom design and implementation (codes A6–A7, F1–F8, H5). The analysis reveals that successful implementation requires appropriate instructional design, teacher preparedness, technological infrastructure, and pedagogical integration. Case studies from Hunan Automotive Engineering Vocational University and Yantai Automotive Engineering Vocational College demonstrate that "C+R" (Cloud + Remote) smart training systems and "Whole Vehicle Smart Training" with digital twin technology significantly improve practical training outcomes (Hunan, 2026; Yantai, 2026). Similarly, AI-powered NEV fault diagnosis simulation and VR-based automotive maintenance training have shown effectiveness in reducing training costs and enhancing skill acquisition (Mirai Media, 2025; Yu et al., 2024).

The third dimension focuses on the influence of smart classrooms on teaching and learning quality (codes E1–E5, G1–G5). The analysis indicates that smart classrooms significantly improve cognitive outcomes (exam scores +15.3%, Ye & Lu, 2024), psychomotor skills (task completion 32% faster with 45% fewer errors, Yu et al., 2024), and affective outcomes (student

satisfaction +38%, Ye & Lu, 2024). Key contributing factors include interaction quality ($\beta=0.42$), real-time feedback ($\beta=0.38$), and resource accessibility ($\beta=0.31$), which collectively explain 67% of variance in higher-order thinking skills development (Lu et al., 2021). Teacher beliefs significantly predict classroom process quality ($\beta=0.54$), which in turn predicts student engagement ($\beta=0.61$) (Wang et al., 2022). Importantly, smart classroom technology alone without pedagogical change shows minimal impact (effect size $d=0.12$), while smart classroom combined with student-centered pedagogies significantly improves learning outcomes (Cheng & Yang, 2023). The fourth dimension concerns stakeholder perceptions of smart classrooms (codes E5–E6). The analysis reveals that positive perceptions of smart classrooms correlate with higher teaching presence ($\beta=0.52$), social presence ($\beta=0.48$), and cognitive presence ($\beta=0.44$) (Hu, Huang, & Kong, 2022). Students report high satisfaction with smart classroom learning environments (mean=4.967-656.52/5.00), particularly when technologies are perceived as useful and easy to use (Meng et al., 2023; Rattanakha et al., 2025). Teacher readiness and professional development focused on pedagogical beliefs are more effective than technology training alone (Wang et al., 2022).

The analysis also identified key learning outcomes, including cognitive outcomes (knowledge acquisition, theoretical comprehension), psychomotor/technical skills (hands-on performance, diagnostic ability, procedural accuracy), and affective outcomes (motivation, engagement, satisfaction, self-efficacy). These outcomes are closely associated with the use of smart classroom technologies, cooperative learning, and technology-enhanced learning environments. However, the findings also suggest that the effectiveness of these approaches depends on several contributing factors, such as teacher competence, technology access, institutional support, and student factors. The analysis combined both inductive and deductive approaches. Inductive analysis was used to identify patterns emerging directly from

the data, particularly in relation to teaching and learning outcomes in smart classroom environments. Meanwhile, deductive analysis was applied to interpret these findings using established theoretical perspectives, including constructivist learning theory (C1), Technology Acceptance Model (C2), Community of Inquiry framework (C3), Project-Based Learning (C4), blended learning theory (C5), and Self-Determination Theory (C6). This combined approach ensured that the analysis remained grounded in empirical evidence while also being theoretically informed.

2.6 Research Rigor and Validity

To ensure methodological rigor, this study adhered to established principles of systematic literature review, emphasizing transparency, consistency, and systematic data management throughout all stages of the research process (Snyder, 2019; Page et al., 2021). The review was conducted using a clearly defined and well-documented search strategy, including the selection of databases (Scopus, Web of Science, ERIC, and Google Scholar), the formulation of search strings, and the application of Boolean operators. This level of clarity enhances the replicability of the study and allows other researchers to trace and evaluate each stage of the review process. The application of explicit inclusion and exclusion criteria further strengthened the objectivity and consistency of the study selection process. By systematically screening titles, abstracts, and full-text articles, the study minimized potential selection bias and ensured that only studies relevant to smart classrooms, teaching quality, learning quality, and vocational education were included. The multi-stage screening procedure also provided an additional level of verification, reducing the likelihood of including studies that did not meet the methodological and thematic requirements of the review.

A structured coding framework (see Appendix 1) was used to guide the processes of data extraction and analysis. This framework enabled systematic comparison across studies and ensured that key dimensions, such as research design (A1–A7),

educational context (B1–B6), theoretical framework (C1–C7), learning model and pedagogical approach (D1–D8), main variables and focus (E1–E9), technology and intervention type (F1–F8), measured outcomes (G1–G5), research design characteristics (H1–H7), and identified gaps and limitations (I1–I10), were consistently captured. The coding process was conducted iteratively, allowing categories to be refined and interpretations to be validated as new insights emerged from the data. This iterative approach ensured that the findings remained grounded in the evidence rather than being shaped by predetermined assumptions. To further strengthen validity, this study employed methodological triangulation by integrating evidence from studies using diverse research designs, including experimental/quasi-experimental (A2), quantitative survey (A3), qualitative (A4), case study (A6), design and development/R&D (A7), and mixed-method (A1) approaches (Flick, 2018). This diversity provided a more comprehensive understanding of smart classroom implementation and its effects on teaching and learning quality. In addition, the inclusion of studies from various geographical and educational contexts (China, Indonesia, Thailand, Korea, Taiwan, Spain, USA, Denmark, Rwanda) enhanced contextual triangulation, thereby improving the transferability and robustness of the findings.

Finally, internal coherence was maintained by ensuring consistency between the coding framework (Appendix 1), the selected studies (Appendix 2), and the thematic findings presented in the analysis. This alignment demonstrates that the analytical process was systematically executed and logically structured. The use of a PRISMA-based selection process (Figure 1) further enhanced transparency by clearly documenting the number of records identified, screened, excluded, and included at each stage. Together, these measures strengthen the credibility, reliability, and overall trustworthiness of the study.

3. Findings

3.1 Distribution of Studies

The distribution of the selected studies ($n = 20$) was analyzed based on geographical location, year of publication, research methodology, context and targeted group, theoretical framework, and research design characteristics in order to provide an overview of the current research landscape in smart classroom implementation, particularly in relation to teaching quality, learning quality, and vocational education contexts.

3.1.1 Geographical Distribution

In terms of geographical distribution, the findings indicate a strong concentration of studies in Asia, particularly China. China emerged as the most dominant contributor with a total of 11 studies (Jiang, 2024; Zhou & Wu, 2024; Tao, Wang, & Chen, 2024; Ye & Lu, 2024; Yu et al., 2022; Lu et al., 2021; Meng et al., 2023; Liu & Wang, 2023; Dai et al., 2023; Hu, Huang, & Kong, 2022; Wang et al., 2022), reflecting the country's significant investment in smart classroom research, vocational education reform, and technology-enhanced learning. These studies primarily focus on areas such as virtual simulation laboratories, digital twin technology, smart classroom platforms, teaching quality, student engagement, and higher-order thinking skills in both vocational and higher education settings. Other Asian countries including Taiwan (Cheng & Yang, 2023), Thailand (Rattanakha, Chatwattana, & Piriyastrawong, 2025), Indonesia (Setiawan & Syamsuddin Nurul Iman, 2026), Korea (Yu, Son, & Kim, 2024), and Rwanda (Ngendabanga, Nsanizimanac, & Nkurunziza, 2022) also contribute to the literature, although to a lesser extent. These studies generally emphasize smart classroom effectiveness, VR-based training, STEM-based digital modules, and learning outcomes in vocational and secondary education contexts.

In Europe, contributions come from Spain (Beltran Sierra et al., 2022), Denmark (Klingenberg, 2023), and the United Kingdom, with studies focusing on virtual learning platforms, immersive VR, and generative learning strategies. In North America, the United States contributes studies on computer-generated VR and classroom environmental influences on self-

efficacy and achievement (Safadel, 2023; Mantooth, Usher, & Love, 2021). Overall, while the research is geographically diverse, it remains regionally concentrated, with China playing a central role. Notably, no studies were identified from South America, Africa (excluding Rwanda), or the Middle East, indicating significant geographical gaps in the smart classroom literature for vocational education.

3.1.2 Temporal Distribution

From a temporal perspective, the distribution of studies demonstrates a clear concentration in recent years, indicating the growing relevance of smart classroom research as a field. The majority of studies were published between 2022 and 2024, with 2024 representing the peak year (Jiang, 2024; Zhou & Wu, 2024; Tao, Wang, & Chen, 2024; Ye & Lu, 2024; Yu, Son, & Kim, 2024; Rattanakha, Chatwattana, & Piriyastrawong, 2025). This surge suggests that interest in smart classrooms, particularly in relation to vocational education and technical skill development, has increased significantly in the past few years. More recent studies published in 2024, 2025, and 2026 continue to expand this trend by exploring emerging topics such as digital twin technology, AI-powered systems, and STEM-based digital modules. The presence of studies across multiple consecutive years also indicates that smart classroom research is not a transient trend but rather a developing and evolving field with sustained academic interest.

3.1.3 Methodological Distribution

In terms of methodological distribution, the findings reveal a strong dominance of empirical and quantitatively oriented research designs. Experimental and quasi-experimental studies represent the largest proportion ($n = 9$), highlighting a strong emphasis on evaluating the effectiveness of smart classroom interventions through controlled or quasi-experimental approaches with pre-test and post-test designs (Beltran Sierra et al., 2022; Safadel, 2023; Klingenberg, 2023; Ye & Lu, 2024; Ngendabanga, Nsanizimanac, & Nkurunziza, 2022; Liu & Wang, 2023; Yu, Son, & Kim, 2024; Cheng & Yang, 2023). These studies commonly

employ statistical analyses such as t-tests, ANOVA, and effect size calculations to measure outcomes such as learning performance, skill acquisition, and student engagement.

Quantitative survey-based studies also constitute a significant portion of the literature ($n = 5$), often examining relationships between variables using correlation analysis, structural equation modeling, or multilevel analysis (Lu et al., 2021; Mantooth, Usher, & Love, 2021; Hu, Huang, & Kong, 2022; Wang et al., 2022; Yu et al., 2022). Case study and design & development (R&D) approaches are also present ($n = 4$), focusing on construction paths, implementation practices, and module validation (Jiang, 2024; Tao, Wang, & Chen, 2024; Rattanakha, Chatwattana, & Piriya-surawong, 2025; Setiyawan & Syamsuddin Nurul Iman, 2026). Mixed-method approaches are less frequently used ($n = 2$), although they provide valuable insights by combining statistical analysis with qualitative interpretation (Meng et al., 2023; Dai et al., 2023). Theoretical and conceptual studies are represented by two articles (Zhou & Wu, 2024; Cheng et al., 2024). This methodological pattern suggests that the current body of literature is heavily oriented towards measuring intervention effectiveness and quantitative outcomes, with relatively limited attention given to in-depth exploration of implementation processes, teacher perceptions, and contextual factors.

3.1.4 Context and Targeted Group Distribution

In terms of context and targeted group, the findings reveal that the majority of studies were conducted in university or general higher education settings ($n = 8$) (Beltran Sierra et al., 2022; Safadel, 2023; Klingenberg, 2023; Lu et al., 2021; Liu & Wang, 2023; Dai et al., 2023; Hu, Huang, & Kong, 2022; Yu et al., 2022), followed by higher vocational education contexts ($n = 5$) (Jiang, 2024; Zhou & Wu, 2024; Ye & Lu, 2024; Meng et al., 2023; Wang et al., 2022). Vocational secondary education is represented by three studies (Ngendabanga, Nsanzimanac, & Nkurunziza, 2022; Setiyawan & Syamsuddin Nurul Iman, 2026; Cheng & Yang, 2023).

Automotive and engineering-specific studies are limited to four articles (Beltran Sierra et al., 2022; Tao, Wang, & Chen, 2024; Yu, Son, & Kim, 2024; Setiyawan & Syamsuddin Nurul Iman, 2026). Non-automotive vocational contexts, including nursing, economics, finance, and chemistry, are represented by five studies (Jiang, 2024; Zhou & Wu, 2024; Meng et al., 2023; Ngendabanga, Nsanzimanac, & Nkurunziza, 2022). Notably, no studies were identified that specifically target automotive maintenance training at Beijing Changping Vocational School. This represents a significant gap in the literature, as the specific institutional context, curriculum alignment, and stakeholder perceptions at this particular vocational school remain unexamined.

3.1.5 Theoretical Framework Distribution

In terms of theoretical frameworks, the findings reveal that the majority of studies do not explicitly state a theoretical basis ($n = 11$) (Beltran Sierra et al., 2022; Safadel, 2023; Klingenberg, 2023; Jiang, 2024; Zhou & Wu, 2024; Tao, Wang, & Chen, 2024; Ye & Lu, 2024; Rattanakha, Chatwattana, & Piriya-surawong, 2025; Ngendabanga, Nsanzimanac, & Nkurunziza, 2022; Meng et al., 2023; Setiyawan & Syamsuddin Nurul Iman, 2026). This suggests that much of the smart classroom literature is empirically driven rather than theoretically grounded. Among studies that do employ theoretical frameworks, constructivist learning theory is the most frequently cited ($n = 3$) (Liu & Wang, 2023; Dai et al., 2023; Cheng & Yang, 2023). The Community of Inquiry (CoI) framework is used in one study (Hu, Huang, & Kong, 2022). Project-Based Learning (PBL) and blended learning theory are also represented (Dai et al., 2023; Meng et al., 2023). Self-Determination Theory (SDT) is notably absent from the reviewed studies, indicating a gap in motivational frameworks for understanding smart classroom effectiveness.

3.1.6 Research Design Characteristics Distribution

In terms of research design characteristics, pre-test/post-test with control group designs are most common ($n = 6$) (Beltran Sierra et al., 2022; Ye & Lu, 2024; Ngendabanga, Nsanzimanac, &

Nkurunziza, 2022; Liu & Wang, 2023; Cheng & Yang, 2023; Yu, Son, & Kim, 2024). Pre-test/post-test without control group designs are also present ($n = 3$) (Safadel, 2023; Klingenberg, 2023; Setiyawan & Syamsuddin Nurul Iman, 2026). Cross-sectional and correlational designs are represented by four studies (Lu et al., 2021; Mantooth, Usher, & Love, 2021; Hu, Huang, & Kong, 2022; Yu et al., 2022). Case study designs are used in three studies (Tao, Wang, & Chen, 2024; Wang et al., 2022; Jiang, 2024). Mixed methods designs are least common ($n = 2$) (Meng et al., 2023; Dai et al., 2023). Overall, the distribution of studies reflects a rapidly developing research field that is increasingly global, methodologically diverse, and strongly influenced by technological innovation, yet still presents significant opportunities for further exploration, particularly in relation to automotive maintenance training, specific institutional contexts such as Beijing Changping Vocational School, and the integration of teaching quality as a mediating variable.

3.2 Dominant Pedagogical Approaches in Smart Classroom Implementation

3.2.1 Smart Classroom Platforms

Smart classroom platforms emerge as one of the most frequently adopted technological approaches in smart classroom research, particularly in studies that emphasize interactive learning, real-time feedback, and data-driven instruction (Ye & Lu, 2024; Yu et al., 2022; Lu et al., 2021; Wang et al., 2022). Within the reviewed studies, smart classroom platforms are commonly understood as integrated learning environments that incorporate interactive displays, IoT devices, learning analytics systems, and cloud-based platforms. In vocational education contexts, smart classroom platforms are often combined with student-centered pedagogies to create learning environments that support interaction, engagement, and skill development. A key characteristic of smart classroom platforms in vocational education is their focus on supporting teaching quality and learning quality. Studies consistently show that smart classroom platforms enhance teacher-student interaction (+67%),

student-student collaboration (+82%), and engagement (behavioral +54%, emotional +61%, cognitive +48%) compared to traditional classrooms (Yu et al., 2022). The SEEWO smart classroom platform, examined in one quasi-experimental study, significantly improved cognitive outcomes (exam scores +15.3%), behavioral outcomes (participation +42%), and affective outcomes (student satisfaction +38%), with effects being stronger for low-performing students (Ye & Lu, 2024). The literature also shows that smart classroom platforms contribute significantly to the development of higher-order thinking skills (HOTS). Key influencing factors for HOTS in smart classrooms include interaction quality ($\beta=0.42$), real-time feedback ($\beta=0.38$), and resource accessibility ($\beta=0.31$), which collectively explain 67% of variance in HOTS development (Lu et al., 2021).

3.2.2 Virtual Simulation Laboratories

Virtual simulation laboratories are identified as an important pedagogical approach in smart classroom-based vocational education, particularly in studies examining practice-based learning and skill development (Jiang, 2024; Zhou & Wu, 2024; Meng et al., 2023). Virtual simulation laboratories provide risk-free, repeatable practice environments that are particularly valuable for procedural skills requiring repetition and safety considerations.

One construction and practice study found that virtual simulation laboratories are effective for practice-based learning, with success depending on integration of theoretical instruction with simulation activities (Jiang, 2024). Four critical success factors were identified: infrastructure, teacher training, curriculum alignment, and assessment methods. Another conceptual study found that virtual simulation training bases improve vocational learning quality but face significant constraints, including high infrastructure costs (average ¥967-656 million), lack of qualified technical staff, and insufficient curriculum integration (Zhou & Wu, 2024). A mixed-methods study examining blended teaching with virtual simulation in nursing education found significant improvements in

practical clinical skills (post-test score +28.6%, $p < 0.001$), with students reporting high satisfaction (mean=4.35/5.00) (Meng et al., 2023). The study noted that virtual simulation was most effective for procedural skills requiring repetition and risk-free practice environments.

3.2.3 Digital Twin Technology

Digital twin technology has emerged as an innovative approach in smart classroom-based vocational education, offering real-time monitoring, simulation, and training capabilities (Tao, Wang, & Chen, 2024; Yu, Son, & Kim, 2024). Digital twin technology creates virtual replicas of physical systems, enabling students to practice diagnostic and repair procedures in safe, controlled environments. One case study examining digital twin technology for campus management found that it improves efficiency of practical facility management in vocational campuses by 28%, enabling real-time monitoring of equipment status, predictive maintenance scheduling, and resource optimization (Tao, Wang, & Chen, 2024). The study noted that digital twin technology is applicable to automotive workshop management. An experimental study examining VR equipment-based automotive maintenance training found that students using VR completed tasks 32% faster with 45% fewer errors compared to traditional training (Yu, Son, & Kim, 2024). Formative assessment embedded in VR identified specific skill gaps in electrical diagnosis and mechanical assembly, and the approach was most effective for high-risk or expensive-to-repair procedures.

3.2.4 Blended Teaching and Scene Teaching

Blended teaching, combining face-to-face instruction with digital learning resources, and scene teaching, using contextualized scenario-based instruction, are also identified as effective pedagogical approaches in smart classroom environments (Meng et al., 2023; Liu & Wang, 2023). Blended teaching with virtual simulation significantly improved practical clinical skills, while scene teaching in smart classrooms significantly improved learning performance (immediate test +22.4%, delayed test +18.7%,

both $p < 0.01$), with knowledge transfer to novel situations improving by 31% compared to traditional instruction (Liu & Wang, 2023).

3.2.5 Cooperative and Collaborative Learning

Cooperative and collaborative learning approaches are supported by smart classroom technologies, with one study finding that smart classroom-supported PBL increased student interaction (+58%) and collaboration (+71%) (Dai et al., 2023). Video interaction analysis revealed three distinct collaboration patterns: leader-follower (42% of groups), egalitarian (35%), and passive (23%). Egalitarian groups produced the highest quality projects (mean score 88.5 vs 76.2 for leader-follower). Another study examining virtual smart classrooms with cooperative PBL found "very good" outcomes for analytical thinking (mean=7.23/9.00) and curiosity (mean=10.43/12.00), with student satisfaction rated "very good" (mean=4.52/5.00) (Rattanakha, Chatwattana, & Piriya-surawong, 2025).

3.2.6 STEM-Based Digital Modules

STEM-based digital modules represent an emerging pedagogical approach in vocational automotive education (Setiyawan & Syamsuddin Nurul Iman, 2026). One R&D study developing a STEM-based digital learning module for Anti-lock Braking Systems (ABS) found that the module was validated as "very feasible" (media expert 89.5%, material expert 88.9%), with student response 84% "very feasible". Learning outcomes increased significantly (N-Gain = 58% / medium category), and practical skills in ABS diagnosis and repair improved 42%.

3.3 Teaching Quality Outcomes of Smart Classroom Implementation

3.3.1 Teaching Quality Indicators

Teaching quality emerges as a critical outcome variable in smart classroom research, encompassing instructional effectiveness, teacher-student interaction, feedback quality, and classroom management (Wang et al., 2022; Yu et al., 2022; Hu, Huang, & Kong, 2022). The reviewed studies consistently demonstrate that

smart classrooms enhance teaching quality through improved interaction patterns, real-time feedback mechanisms, and data-informed instructional decisions. A multilevel analysis study examining teacher beliefs and classroom process quality found that teacher beliefs significantly predict classroom process quality ($\beta=0.54$, $p<0.01$), which in turn predicts student engagement ($\beta=0.61$, $p<0.001$) (Wang et al., 2022). Constructivist teacher beliefs had stronger positive effects on all three engagement types (behavioral, emotional, cognitive). The study also found that professional development focused on pedagogical beliefs was more effective than technology training alone. A comparative study examining smart versus traditional classrooms found that smart classrooms produce significantly higher teacher-student interaction (+67%) and student-student collaboration (+82%) (Yu et al., 2022). These interaction patterns were associated with higher levels of behavioral engagement (+54%), emotional engagement (+61%), and cognitive engagement (+48%).

3.3.2 Community of Inquiry Framework

The Community of Inquiry (CoI) framework, which conceptualizes teaching presence, social presence, and cognitive presence, provides a useful lens for understanding teaching quality in smart classrooms (Hu, Huang, & Kong, 2022). One quantitative survey study found that positive perceptions of smart classrooms correlate with higher teaching presence ($\beta=0.52$), social presence ($\beta=0.48$), and cognitive presence ($\beta=0.44$). Smart classroom students reported significantly higher scores on all three CoI presences compared to traditional classroom students (all $p<0.001$).

3.3.3 Teaching Quality as Mediator

An important finding from the literature concerns the mediating role of teaching quality between smart classroom technology and learning outcomes (Cheng & Yang, 2023). One experimental study examining smart classrooms combined with student-centered pedagogies found that smart classroom technology alone without pedagogical change showed minimal

impact (effect size $d=0.12$), while smart classroom combined with student-centered pedagogies significantly improved learning outcomes (Cheng & Yang, 2023). Inquiry-based pedagogy outperformed direct instruction for long-term retention (+28%) and skill application (+35%). Pedagogy type and duration were significant moderators, with effects being stronger for longer duration courses (>8 weeks). This finding highlights that teaching quality, particularly the pedagogical approach used in conjunction with smart classroom technology, is a critical mediator of learning outcomes. Technology alone is insufficient; effective implementation requires alignment between technology, pedagogy, and curriculum objectives.

3.4 Learning Quality Outcomes of Smart Classroom Implementation

3.4.1 Cognitive Outcomes

Cognitive outcomes, including knowledge acquisition, conceptual understanding, and exam scores, emerge as the most frequently measured learning quality outcomes across the reviewed studies (Ye & Lu, 2024; Liu & Wang, 2023; Ngendabanga, Nsanzimanac, & Nkurunziza, 2022). The findings consistently demonstrate that smart classrooms significantly improve cognitive outcomes compared to traditional instruction. One quasi-experimental study found that smart classrooms improved exam scores by 15.3% ($p<0.01$), with effects being stronger for low-performing students (Ye & Lu, 2024). Another experimental study found that scene teaching in smart classrooms improved immediate test performance by 22.4% and delayed test performance by 18.7% (both $p<0.01$), with knowledge transfer to novel situations improving by 31% (Liu & Wang, 2023). A quasi-experimental study in Rwanda found that smart classrooms had a significant positive effect on chemistry learning performance (mean difference = 24.5%, $p<0.001$, Cohen's $d = 1.12$), with higher knowledge retention after 4 weeks (+31%) and higher motivation levels (+45%) (Ngendabanga, Nsanzimanac, & Nkurunziza, 2022).

3.4.2 Psychomotor and Technical Skills

Psychomotor and technical skills development is a critical but less frequently measured outcome in smart classroom research (Yu, Son, & Kim, 2024; Setiyawan & Syamsuddin Nurul Iman, 2026; Meng et al., 2023). The findings indicate that smart classrooms, particularly those incorporating VR, simulation, and digital modules, can significantly improve practical skills. One experimental study found that VR-based automotive maintenance training improved task completion speed by 32% and reduced errors by 45% compared to traditional training (Yu, Son, & Kim, 2024). Another R&D study found that a STEM-based digital module for ABS improved practical skills in diagnosis and repair by 42% (Setiyawan & Syamsuddin Nurul Iman, 2026). A mixed-methods study found that blended teaching with virtual simulation improved practical clinical skills by 28.6% ($p < 0.001$) (Meng et al., 2023).

3.4.3 Affective Outcomes

Affective outcomes, including motivation, engagement, satisfaction, and self-efficacy, are also well-represented in the literature (Ye & Lu, 2024; Mantooth, Usher, & Love, 2021; Rattanakha, Chatwattana, & Piriyaawong, 2025). One study found that smart classrooms improved student satisfaction by 38% (Ye & Lu, 2024). Another study found that supportive classroom environments significantly increase self-efficacy ($\beta = 0.47$, $p < 0.001$) and academic achievement ($\beta = 0.38$, $p < 0.001$), with self-efficacy mediating 41% of the relationship between classroom environment and achievement (Mantooth, Usher, & Love, 2021). A pre-experimental study found that virtual smart classrooms with cooperative PBL produced student satisfaction rated "very good" (mean=4.52/5.00) (Rattanakha, Chatwattana, & Piriyaawong, 2025).

3.4.4 Behavioral Outcomes

Behavioral outcomes, including participation frequency, time-on-task, and collaboration behavior, are also positively influenced by smart classrooms (Ye & Lu, 2024; Dai et al., 2023). One study found that smart classrooms improved participation by 42% (Ye & Lu, 2024). Another

study found that smart classroom-supported PBL increased student interaction by 58% and collaboration by 71% (Dai et al., 2023).

3.4.5 Learning Efficiency

Learning efficiency, including time to complete tasks and error reduction, is an emerging outcome measure in smart classroom research (Yu, Son, & Kim, 2024). One study found that VR-based training reduced task completion time by 32% and reduced errors by 45% (Yu, Son, & Kim, 2024). Another study found that blended teaching with virtual simulation improved learning efficiency through reduced resource utilization and repetition opportunities (Meng et al., 2023).

3.5 Stakeholder Perceptions of Smart Classrooms

3.5.1 Student Perceptions and Satisfaction

Student perceptions and satisfaction emerge as important variables for understanding smart classroom effectiveness (Ye & Lu, 2024; Rattanakha, Chatwattana, & Piriyaawong, 2025; Meng et al., 2023). The reviewed studies consistently show that students report positive perceptions of smart classrooms, with high levels of satisfaction and perceived usefulness. One study found that student satisfaction with smart classrooms was 38% higher than with traditional classrooms (Ye & Lu, 2024). Another study found that student satisfaction with virtual smart classrooms was rated "very good" (mean=4.52/5.00) (Rattanakha, Chatwattana, & Piriyaawong, 2025). A mixed-methods study found that nursing students reported high satisfaction with blended teaching and virtual simulation (mean=4.35/5.00) (Meng et al., 2023). The R&D study on STEM-based digital modules found that student response was 84% "very feasible" (Setiyawan & Syamsuddin Nurul Iman, 2026). The Community of Inquiry study found that positive perceptions of smart classrooms correlate with higher teaching presence ($\beta = 0.52$), social presence ($\beta = 0.48$), and cognitive presence ($\beta = 0.44$) (Hu, Huang, & Kong, 2022). Smart classroom students reported significantly higher scores on all three CoI presences compared to traditional classroom students (all $p < 0.001$).

3.5.2 Teacher Perceptions and Readiness

Teacher perceptions and readiness are less frequently examined but are critical for successful smart classroom implementation (Wang et al., 2022). One multilevel analysis study found that teacher beliefs significantly predict classroom process quality ($\beta=0.54$, $p<0.01$), which in turn predicts student engagement ($\beta=0.61$, $p<0.001$) (Wang et al., 2022). Constructivist teacher beliefs had stronger positive effects on all three engagement types. The study also found that professional development focused on pedagogical beliefs was more effective than technology training alone.

3.5.3 Technology Acceptance

Technology acceptance, including perceived usefulness and perceived ease of use, is an important determinant of smart classroom adoption and effective use (Beltran Sierra et al., 2022; Safadel, 2023). The virtual learning platform study found that students perceived Second Life as useful and easy to use for engineering distance learning (Beltran Sierra et al., 2022). The VR study found that students perceived computer-generated VR as effective for spatial framework understanding (Safadel, 2023).

4. Result and Discussion

4.1 Interpretation of Key Findings

The findings of this review reveal a clear and consistent pattern in the current development of smart classroom research in vocational education, particularly in relation to pedagogical approaches, teaching quality, learning quality, and stakeholder perceptions. Three dominant trends emerge: (1) the strong prevalence of smart classroom platforms, virtual simulation laboratories, and digital twin technology as technological approaches; (2) the consistent effectiveness of smart classrooms in enhancing cognitive outcomes, psychomotor skills, and affective outcomes; and (3) the limited integration of teaching quality as a mediating variable, particularly in automotive maintenance training contexts, and the complete absence of studies targeting Beijing Changping Vocational School.

These patterns reflect not only how smart classrooms are currently implemented but also underlying assumptions about technology, pedagogy, and educational priorities in vocational education contexts.

First, the dominance of smart classroom platforms (D5), virtual simulation laboratories (D2), and digital twin technology (D3) as pedagogical approaches indicates that smart classroom-based vocational education is strongly oriented toward technology-driven, interactive, and simulation-based pedagogies. Across the reviewed studies, smart classroom platforms are consistently employed to enhance interaction, engagement, and learning outcomes (Ye & Lu, 2024; Yu et al., 2022; Lu et al., 2021). Virtual simulation laboratories are widely used to provide risk-free, repeatable practice environments for procedural skills (Jiang, 2024; Zhou & Wu, 2024; Meng et al., 2023). Digital twin technology is employed to enable real-time monitoring, predictive maintenance, and resource optimization in vocational campuses (Tao, Wang, & Chen, 2024; Yu, Son, & Kim, 2024). These approaches align with constructivist learning theory (C1) and blended learning theory (C5), which emphasize that meaningful learning occurs through active engagement, authentic tasks, and integration of theory with practice.

At the same time, the widespread use of technology-enhanced learning approaches, including VR-based learning (D1), AI-powered systems (F5), and virtual learning platforms (F7), reflects the increasing influence of digital transformation in vocational education. As shown in Appendix 1, smart classroom platforms (D5) and virtual simulation laboratories (D2) are among the most frequently adopted learning models. This strong orientation toward technology can be explained by broader educational and industrial trends. Vocational education has been increasingly expected to develop not only technical skills but also digital competence, problem-solving abilities, and adaptability to Industry 4.0 requirements (Chen et al., 2024; Liu & Hardy, 2023). As a result, many studies prioritize measurable cognitive and psychomotor outcomes (G1, G2), often using

experimental or quasi-experimental designs to assess the effectiveness of smart classroom interventions (Beltran Sierra et al., 2022; Ye & Lu, 2024; Ngendabanga et al., 2022). Furthermore, the rapid advancement of digital tools has positioned technology as a central enabler of educational innovation, making it a dominant component in smart classroom implementation. However, this emphasis also suggests a tendency to equate innovation primarily with technological advancement, potentially narrowing the broader educational scope of vocational education.

Second, despite being a core component of effective education, teaching quality has received inconsistent attention across the reviewed studies. While some studies explicitly examine teaching quality indicators such as teacher-student interaction, feedback quality, and classroom process quality (Wang et al., 2022; Yu et al., 2022; Hu, Huang, & Kong, 2022), many studies focus primarily on technological outcomes or learning outcomes without examining the mediating role of teaching quality. The findings indicate that teacher beliefs significantly predict classroom process quality ($\beta=0.54$, $p<0.01$), which in turn predicts student engagement ($\beta=0.61$, $p<0.001$) (Wang et al., 2022). Constructivist teacher beliefs had stronger positive effects on all three engagement types. Professional development focused on pedagogical beliefs was more effective than technology training alone. Smart classrooms produce significantly higher teacher-student interaction (+67%) and student-student collaboration (+82%) compared to traditional classrooms (Yu et al., 2022).

However, the findings also reveal that teaching quality as a mediating variable (E1) is less frequently measured compared to learning outcomes (E2) and student engagement (E3). This pattern is reflected in the measured outcomes, where cognitive outcomes (G1) and affective outcomes (G3) are among the most frequently measured, while teaching quality indicators are often treated as contextual variables rather than primary outcomes or mediators. The limited attention to teaching quality as a mediator represents a gap in the literature, as understanding

how teaching quality mediates the relationship between smart classroom technology and learning outcomes is essential for designing effective smart classroom implementations.

Third, and most critically for this review, the findings highlight that automotive maintenance training remains minimally represented across the reviewed studies. Although some research incorporates automotive or engineering contexts (Beltran Sierra et al., 2022; Tao, Wang, & Chen, 2024; Yu, Son, & Kim, 2024; Setiyawan & Syamsuddin Nurul Iman, 2026), these instances are relatively scarce compared to the number of studies focusing on general vocational education or non-automotive contexts. The coding results clearly identify "limited to non-automotive context" (I7) as a major gap in the literature. Even when automotive contexts are studied, they often focus on general engineering principles or campus management rather than specific automotive maintenance training programs. This imbalance is particularly pronounced for specific institutional contexts such as Beijing Changping Vocational School, with no studies identified that specifically target this institution.

Several factors may explain this limited integration. One key reason is the dominance of general vocational education research paradigms in smart classroom literature, which prioritize measurable outcomes such as exam scores and satisfaction over trade-specific technical skills. Automotive maintenance skill development, by contrast, often requires specialized equipment, longer intervention periods, more complex measurement protocols, and industry partnerships for skill assessment. Additionally, the lack of established smart classroom models that explicitly integrate automotive-specific technical skill development further contributes to the marginalization of automotive maintenance training outcomes. Another contributing factor is the perception of technology and pedagogy as separate from trade-specific content. In many vocational education contexts, smart classroom technology and teaching quality are treated as distinct from technical skill development, rather than as interconnected processes that mutually influence each other. This separation limits

opportunities to understand how smart classroom-induced teaching quality gains translate into automotive-specific skill acquisition.

Another critical gap identified in this review is the complete absence of studies specifically targeting Beijing Changping Vocational School as a research context. Despite the growing implementation of smart classrooms in Chinese vocational schools, no studies in the reviewed literature examine how smart classrooms influence teaching and learning quality at this specific institution. Beijing Changping Vocational School may possess unique contextual characteristics, including specific curriculum frameworks, student demographics, teacher readiness levels, and industry partnerships, that influence smart classroom implementation effectiveness. This gap highlights the novelty and importance of the current study.

Taken together, these findings suggest that current smart classroom research in vocational education is characterized by strong technological outcomes but limited integration of teaching quality as a mediating variable and specific institutional contexts such as automotive maintenance training at Beijing Changping Vocational School. While smart classroom platforms, virtual simulation laboratories, and digital twin technology have successfully transformed vocational education into more interactive and engaging environments, the development of trade-specific technical skills and attention to unique institutional contexts remain underdeveloped. This imbalance indicates a gap between the theoretical vision of smart classrooms as holistic frameworks for promoting both teaching quality and learning quality and their practical implementation. Addressing this gap requires not only the inclusion of automotive-specific outcomes but also a reconceptualization of smart classroom research as context-sensitive and teaching quality-focused.

4.2 Alignment with Existing Literature

The findings of this review are largely consistent with existing literature on smart classrooms and educational technology in vocational education,

particularly in highlighting the effectiveness of smart classrooms in enhancing cognitive outcomes, psychomotor skills, and affective outcomes. However, the present study also extends prior research by providing a more focused synthesis on the intersection between smart classrooms, teaching quality, and specific vocational contexts such as automotive maintenance training. First, the strong emphasis on smart classroom platforms, virtual simulation laboratories, and digital twin technology observed in this review aligns with a substantial body of literature that positions smart classrooms as advanced learning environments that integrate educational technology, pedagogy, and data analytics (Kwet & Prinsloo, 2020; Saini & Goel, 2020; Cebrián, Palau, & Mogas, 2020). Previous studies have consistently highlighted the role of interactive technologies, real-time feedback, and personalized learning pathways in promoting student engagement and achievement (Lorenzo et al., 2021; Xing & Zeng, 2025). The current findings reinforce these perspectives by demonstrating that smart classroom platforms effectively support interaction, engagement, and learning outcomes when integrated with student-centered pedagogies (Ye & Lu, 2024; Yu et al., 2022; Cheng & Yang, 2023).

Second, the findings regarding virtual simulation laboratories and digital twin technology are also in line with previous research, which has recognized the value of simulation-based learning and digital twins for technical and vocational education (Karanam & Hartman, 2025; Reyes et al., 2024). The present review confirms that virtual simulation laboratories effectively support practice-based learning when integrated with theoretical instruction (Jiang, 2024; Meng et al., 2023), and that digital twin technology improves efficiency of practical facility management in vocational campuses (Tao, Wang, & Chen, 2024). However, the review also reveals that these technologies have been predominantly studied in non-automotive contexts (nursing, economics, chemistry), with limited application to automotive maintenance training. This extends existing literature by identifying a specific gap in

smart classroom research for automotive vocational education.

Third, the limited integration of teaching quality as a mediating variable identified in this study is partially supported by existing literature in educational technology and vocational education. Prior research has emphasized the importance of linking technological implementation with pedagogical quality (Cheng & Yang, 2023; Wang et al., 2022). However, studies specifically examining the mediating role of teaching quality between smart classroom technology and learning outcomes remain scarce. A systematic review by Alfoudari, Durugbo, and Aldhmour (2021) highlights the socio-technological challenges of smart classrooms but does not demonstrate strong integration of teaching quality as a mediator. Similarly, research on smart classrooms in vocational education predominantly focuses on learning outcomes and student engagement, with limited attention to how teaching quality mediates these effects (Ye & Lu, 2024; Lu et al., 2021).

At the same time, the current findings also reveal some important divergences from existing literature. While previous studies often discuss smart classrooms as universally effective for enhancing learning outcomes, the empirical evidence presented in this review suggests that effectiveness depends heavily on how smart classroom technologies are integrated with pedagogical approaches. In particular, the finding that smart classroom technology alone without pedagogical change showed minimal impact (effect size $d=0.12$), while smart classroom combined with student-centered pedagogies significantly improved learning outcomes (Cheng & Yang, 2023), indicates that technology is not inherently beneficial but must be carefully integrated with effective teaching practices. Furthermore, this review extends existing literature by explicitly identifying automotive maintenance training and Beijing Changping Vocational School as underexplored contexts within smart classroom research. While previous research has acknowledged individual differences in institutional contexts (Alfoudari, Durugbo, & Aldhmour, 2021), it has rarely positioned specific

vocational schools as distinct contexts requiring tailored implementation strategies.

4.3 Theoretical Implications

The findings of this review contribute to the ongoing theoretical development of smart classroom research in vocational education by highlighting the need to move beyond a predominantly technology-focused perspective toward a more integrated framework that encompasses teaching quality as a mediating variable, trade-specific skill development, and context-sensitive implementation. While smart classrooms have been widely conceptualized as technologically advanced learning environments that incorporate digital tools, interactive systems, and data analytics (Kwet & Prinsloo, 2020; Saini & Goel, 2020), the current body of literature suggests that this framework has been predominantly applied to technological and learning outcomes, with limited attention to how teaching quality mediates the relationship between smart classroom technology and learning outcomes.

From a theoretical standpoint, smart classroom implementation is often framed within the context of technology-enhanced learning, where interactive displays, IoT devices, and learning analytics systems support student engagement and achievement (Lorenzo et al., 2021; Xing & Zeng, 2025). The dominance of cognitive outcomes (G1), psychomotor skills (G2), and affective outcomes (G3) as measured outcomes identified in this review reinforces this perspective, as these outcomes are the primary focus of smart classroom research. However, the findings indicate that such frameworks primarily address technological and learning outcomes, rather than how teaching quality mediates the relationship between technology and learning. In other words, the emphasis remains on what technology does rather than on how teachers use technology to enhance learning.

This limitation points to a conceptual gap in the current understanding of smart classrooms in vocational education. While smart classroom frameworks provide robust models for understanding how technology can support

learning, they do not inherently explain how teaching quality mediates the effects of technology on learning outcomes. The finding that teacher beliefs significantly predict classroom process quality, which in turn predicts student engagement (Wang et al., 2022), suggests that teaching quality is a critical mediating variable. However, this mediating role remains undertheorized within smart classroom research. This observation aligns with broader critiques in educational technology research that emphasize the importance of integrating pedagogical and technological perspectives (Mishra & Koehler, 2006). The present study therefore suggests the need to reconceptualize smart classroom research as not only a technological framework but also a teaching quality framework. In this expanded view, smart classroom technologies should be designed not only to support interaction and engagement but also to enhance teaching quality through improved feedback mechanisms, instructional clarity, and classroom process quality.

Another important theoretical implication concerns the role of context in smart classroom effectiveness. While smart classroom research recognizes that different educational contexts have different characteristics, the reviewed studies rarely examined how specific institutional characteristics, such as those of Beijing Changping Vocational School, moderate the effects of smart classroom implementation. Vocational schools may possess unique contextual characteristics, including specific curriculum frameworks, student demographics, teacher readiness levels, industry partnerships, and resource constraints. These characteristics may influence how smart classrooms are implemented and how effective they are for improving teaching and learning quality. This perspective aligns with socio-cultural theories of learning, which emphasize that learning is situated within specific institutional and cultural contexts. Incorporating institutional context characteristics into smart classroom research can therefore enrich theoretical understanding of how contextual factors shape smart classroom effectiveness.

Furthermore, the finding that technical skills development (G2) is enhanced by VR-based training and digital modules (Yu, Son, & Kim, 2024; Setiyawan & Syamsuddin Nurul Iman, 2026) has important theoretical implications for smart classroom research in automotive vocational education. For automotive maintenance training that requires precise, repeatable, and technically complex procedures, structured practice with clear goals, immediate feedback, and progressive challenges may be more effective than open-ended exploration. Smart classroom technologies such as VR, digital twin, and simulation software can support technical skill development by providing structure, clear criteria, and motivation for sustained practice. This suggests that smart classroom research for automotive vocational education should emphasize competence-supporting features that provide clear evidence of skill improvement, rather than only engagement-supporting features that may be more appropriate for general education contexts.

4.4 Practical Implications

The findings of this study offer several important implications for educational practice, particularly in relation to smart classroom implementation strategies, teaching quality enhancement, and curriculum design for automotive maintenance training at Beijing Changping Vocational School. These implications highlight the need to move beyond a predominantly technology-focused approach toward a more balanced and teaching quality-sensitive implementation of smart classrooms that integrates both technological and pedagogical considerations. First, at the level of classroom practice, automotive maintenance teachers play a crucial role in facilitating the integration of smart classroom technologies into training programs. The results suggest that while smart classroom platforms, virtual simulation laboratories, and digital twin technology are effective in enhancing learning outcomes, they rarely incorporate automotive-specific technical skill development in a systematic way. Therefore, teachers are encouraged to design smart classroom activities that explicitly target automotive maintenance technical skills such as

engine diagnosis, electrical system testing, brake repair, and transmission service. For example, VR-based training can be used to simulate high-risk or expensive-to-repair procedures, digital twin technology can enable real-time monitoring of diagnostic accuracy, and smart classroom platforms can provide immediate feedback on technical performance. By doing so, students are not only engaged but also develop measurable technical competencies. This approach can enhance both teaching quality and learning outcomes, making automotive maintenance training more effective and industry-relevant.

Second, for Beijing Changping Vocational School specifically, administrators and curriculum planners should consider adapting smart classroom implementation strategies to align with the school's specific curriculum frameworks, student demographics, and industry partnerships. The school may have unique characteristics, including specific automotive maintenance curriculum standards, student skill levels, teacher readiness, and relationships with local automotive industry partners. Therefore, smart classroom implementation should be tailored to these specific characteristics rather than adopting one-size-fits-all approaches. In addition, professional development for teachers should focus not only on technology operation but also on pedagogical integration, as teacher beliefs significantly predict classroom process quality and student engagement (Wang et al., 2022). Constructivist teacher beliefs had stronger positive effects on engagement, suggesting that professional development should emphasize student-centered pedagogies rather than only technology training.

Third, at the curriculum level, there is a need to reconsider how smart classroom technologies are integrated into automotive maintenance training programs. Current practices often emphasize technological outcomes and student engagement, sometimes at the expense of teaching quality and trade-specific skill development. The findings of this review indicate that teaching quality (E1) is significantly underrepresented compared to learning outcomes (E2) and student engagement (E3). As such, curriculum designers should aim to create more balanced frameworks that integrate

teaching quality as a mediating variable. This may involve incorporating teaching quality indicators into smart classroom evaluation frameworks, developing progressive skill mastery systems with clear criteria and feedback, and ensuring that learning objectives reflect not only technological engagement but also technical competency and teaching effectiveness.

Fourth, the role of technology in smart classrooms should be reoriented to support not only engagement and learning outcomes but also teaching quality. Technologies such as learning analytics systems, real-time feedback tools, and video analysis have demonstrated strong potential in enhancing teaching quality (Lu et al., 2021; Wang et al., 2022). However, as highlighted in the findings, their use is often limited to supporting student outcomes rather than teaching quality. Educators and instructional designers should therefore explore ways to use these technologies to provide immediate, specific, and actionable feedback to teachers on their instructional effectiveness, interaction patterns, and classroom process quality. Such approaches can bridge the gap between technology and teaching quality, making smart classroom implementation more effective for improving both teaching and learning.

In addition, teacher training and professional development are essential to support these changes. Integrating smart classroom technologies with automotive maintenance training requires not only technological competence but also pedagogical knowledge and the ability to design technology-enhanced skill progression systems. Teachers need to be equipped with the knowledge and skills to effectively combine smart classroom technologies, teaching quality principles, and technical skill instruction in ways that are both engaging and educationally effective. Professional development programs should therefore include training on smart classroom technology operation, need-supportive teaching, and automotive-specific technical assessment.

4.5 Research Gap and Future Directions

The findings of this review clearly indicate several significant gaps in the current development of smart classroom research in vocational education, particularly in relation to the integration of teaching quality as a mediating variable, the application to automotive maintenance training, and the targeting of specific institutional contexts such as Beijing Changping Vocational School. Although many studies have explored the effectiveness of smart classroom platforms, virtual simulation laboratories, and digital twin technology in enhancing cognitive outcomes, psychomotor skills, and affective outcomes, the inclusion of teaching quality as a mediating variable remains limited. In most cases, smart classroom research is primarily oriented toward technological and learning outcomes, while teaching quality is not systematically integrated as a mediator. This gap is also reflected in how the role of smart classrooms is conceptualized within vocational education. While smart classrooms are formally recognized as technological learning environments, they are often interpreted in terms of engagement, satisfaction, and learning outcomes, rather than as mechanisms for supporting teaching quality and instructional effectiveness. The most prominent gap identified in this review is the complete absence of studies specifically targeting automotive maintenance training at Beijing Changping Vocational School. Despite the growing implementation of smart classrooms in Chinese vocational schools, no studies in the reviewed literature examine how smart classrooms influence teaching and learning quality at this specific institution. Beijing Changping Vocational School may possess unique contextual characteristics, including specific curriculum frameworks, student demographics, teacher readiness levels, and industry partnerships, that influence smart classroom implementation effectiveness. This gap highlights the novelty and importance of future research in this specific context.

A second significant gap is the limited focus on automotive maintenance training specifically. The majority of reviewed studies focus on general vocational education, non-automotive vocational fields (nursing, economics, finance, chemistry), or

engineering principles (Beltran Sierra et al., 2022; Jiang, 2024; Zhou & Wu, 2024; Meng et al., 2023). Only a small number of studies examine automotive or mechanical contexts (Tao, Wang, & Chen, 2024; Yu, Son, & Kim, 2024; Setiyawan & Syamsuddin Nurul Iman, 2026), and none specifically target comprehensive automotive maintenance training programs with smart classroom interventions. This is concerning given that automotive maintenance has unique characteristics compared to other vocational fields, including specific safety requirements, expensive equipment, high-risk procedures, and rapid technological change driven by electric vehicles and intelligent systems. Smart classroom design for automotive maintenance may therefore need to emphasize different elements, such as risk-free simulation, diagnostic accuracy, and real-time feedback on technical procedures. A third gap is the limited integration of teaching quality as a mediating variable in smart classroom research (Wang et al., 2022; Cheng & Yang, 2023). Many studies focus exclusively on learning outcomes such as exam scores and skill acquisition without examining how teaching quality mediates the relationship between smart classroom technology and learning outcomes (Ye & Lu, 2024; Ngendabanga et al., 2022; Liu & Wang, 2023). Conversely, studies that examine teaching quality often provide limited analysis of how it mediates learning outcomes (Wang et al., 2022; Hu, Huang, & Kong, 2022). This fragmentation limits understanding of how smart classroom technology translates into improved learning outcomes through enhanced teaching quality. Future research should integrate teaching quality as a mediating variable to examine causal pathways.

In light of these limitations, future research should focus on developing smart classroom implementation models that more explicitly integrate teaching quality as a mediating variable, particularly for automotive maintenance training at Beijing Changping Vocational School. This includes designing smart classroom frameworks that connect technological implementation with teaching quality enhancement, creating progressive skill mastery systems with clear

criteria and feedback, and examining how teaching quality mediates the relationship between technology and learning outcomes. Such integration would enable smart classroom implementation to become more meaningful and effective, particularly for automotive maintenance training that requires both technical competence and effective instruction. Another important direction for future research is the exploration of how institutional context characteristics moderate the effects of smart classroom implementation. Future studies should investigate how Beijing Changping Vocational School's specific curriculum frameworks, student demographics, teacher readiness levels, and industry partnerships influence smart classroom effectiveness, what types of smart classroom design are most effective for this context, and how smart classroom implementation can be adapted to align with institutional characteristics. This may involve mixed methods approaches that combine quantitative measures of teaching and learning quality with qualitative exploration of teacher and student experiences and perceptions.

Furthermore, there is a need for more diverse research methodologies to better understand the role of teaching quality in smart classroom effectiveness. The existing literature is dominated by quantitative and experimental studies that focus on mean-level effects, which may not capture the complex, contextualized nature of teaching quality. Qualitative and mixed-method approaches are needed to explore how teachers and students experience smart classroom implementation, what factors enhance or inhibit teaching quality, and how teaching quality interacts with smart classroom technology to influence learning outcomes. Finally, future research should consider the importance of long-term sustainability of teaching quality and learning outcomes. The majority of reviewed studies employ short-term interventions with limited follow-up assessment (Ye & Lu, 2024; Liu & Wang, 2023; Cheng & Yang, 2023). Longitudinal studies with extended intervention periods and follow-up measures are needed to assess whether teaching quality improvements and learning gains persist over time and whether

smart classroom implementation leads to sustained improvements in automotive maintenance training outcomes.

5. Conclusion

This systematic literature review synthesizes recent research on smart classroom implementation in vocational education by examining the integration of smart classroom technologies, teaching quality, learning quality, and stakeholder perceptions, with particular attention to automotive maintenance training and the specific institutional context of Beijing Changping Vocational School. The findings show that smart classroom implementation is predominantly realized through smart classroom platforms, virtual simulation laboratories, and digital twin technology, reflecting a strong orientation toward technology-driven, interactive, and simulation-based pedagogies. The review consistently demonstrates that smart classrooms effectively enhance cognitive outcomes (exam scores +15.3% to +24.5%), psychomotor skills (task completion 32% faster with 45% fewer errors), and affective outcomes (satisfaction +38%) across various vocational education contexts. However, the findings also reveal several critical gaps. The role of teaching quality as a mediating variable between smart classroom technology and learning outcomes remains significantly underrepresented. Most studies focus on learning outcomes without examining how teaching quality mediates these effects, and the bidirectional relationship between technology, teaching quality, and learning outcomes remains undertheorized and underinvestigated. Furthermore, and most significantly for this review, no studies were identified that specifically target automotive maintenance training at Beijing Changping Vocational School. This absence represents a major gap in the literature, as this specific institutional context may possess unique characteristics that influence smart classroom implementation effectiveness.

This imbalance suggests that current smart classroom practices tend to prioritize technological and learning outcomes over

teaching quality and context-specific considerations. Accordingly, this study argues for a reconceptualization of smart classroom research as a more holistic and teaching quality-sensitive framework in which smart classroom technology serves not only as a tool for enhancing learning outcomes but also as a mechanism for supporting teaching quality and instructional effectiveness. Integrating automotive maintenance training into smart classroom research has the potential to enrich learning by connecting technology with measurable technical competencies, while also enhancing teaching quality through improved feedback, interaction, and classroom process quality. For Beijing Changping Vocational School specifically, future smart classroom

implementation should consider adapting strategies to align with the school's specific curriculum frameworks, student demographics, teacher readiness, and industry partnerships. Therefore, future development of smart classroom research in vocational education should not only advance technological innovation and learning outcome measurement but also embed teaching quality as a mediating variable and context sensitivity at the core of the research process, enabling smart classroom implementation to become both technologically effective and pedagogically relevant for diverse vocational contexts including automotive maintenance training at Beijing Changping Vocational School.

References

- Abuhassna, H., Alnawajha, S., Awae, F., Adnan, M. A. B. M., & Edwards, B. I. (2024). Synthesizing technology integration within the Addie model for instructional design: A comprehensive systematic literature review. *Journal of Autonomous Intelligence*, 7(5), 967-656.
- Alfoudari, A. M., Durugbo, C. M., & Aldhmour, F. M. (2021). Understanding socio-technological challenges of smart classrooms using a systematic review. *Computers & Education*, 173, 104282.
- AlMalki, H. A., & Durugbo, C. M. (2023). Evaluating critical institutional factors of Industry 4.0 for education reform. *Technological Forecasting and Social Change*, 188, 122327.
- Anwar, A., Sudiyono, Sunyoto, Setiyawan, A., & Budiman, F. A. (2025). Development of K3LH E-Module for automotive engineering students. *Journal of Education and Learning*, 19(2), 967-656.
- Aravind, B. R., & Bhuvaneswari, G. (2023). Utilizing Blogs on ESL learners' vocabulary learning through social constructivist theory: A descriptive study. *MethodsX*, 10, 101970.
- Athanasopoulou, L., Bikas, H., Papacharalampopoulos, A., Stavropoulos, P., & Chrysosolouris, G. (2023). An industry 4.0 approach to electric vehicles. *International Journal of Computer Integrated Manufacturing*, 36(2), 967-656.
- Ayeoribe, O. P., & Ayeoribe, A. E. (2025). Implementing Adaptive Learning Systems to Support Personalized Instruction. *International Journal Evolving Sustainable and Renewable Energy Solutions*, 967-656.
- Bayram, İ. (2024). Experiential learning. In *Exploring Adult Education Through Learning Theory* (p. 55).
- Beltran Sierra, L. M., Martin Llamas Nistal, M., & Fernandez Sanchez, J. (2022). Second Life: A new platform for distance learning in Electrical Engineering. *IEEE Transactions on Education*, 52(2), 967-656.
- Boateng, S., & Kalonde, G. (2024). Exploring the synergy of the SAMR model and technology integration in education. In *Proceedings of the International Conference on Advanced Research in Education, Teaching, and Learning* (Vol. 1, No. 1, pp. 967-656).
- Bowman, M. A., Vongkulluksn, V. W., Jiang, Z., & Xie, K. (2022). Teachers' exposure to professional development and the quality of their instructional technology use. *Journal of Research on Technology in Education*, 54(2), 967-656.
- Braun, V., & Clarke, V. (2013). *Successful Qualitative Research: A Practical Guide for Beginners*. Sage.
- Cao Yang Vocational School. (2025). AI integration in automotive courses: AI+HI dual-teacher mode. *Shanghai Vocational Education Report*, 12(3), 967-656.

- Cebrián, G., Palau, R., & Mogas, J. (2020). The smart classroom as a means to the development of ESD methodologies. *Sustainability*, 12(7), 3010.
- Chang, S.-H., Kuo, P.-J., Xin Kao, J., & Yang, L.-J. (2022). Using an integrative meta-analysis to examine the effects of smart classroom-based instruction on academic achievement. *Interactive Learning Environments*, 967-656.
- Chen, P., Schmidtke, C., & Jin, X. (2024). Chinese technical and vocational education and training, skill formation, and national development. *Vocation, Technology & Education*, 1(3).
- Cheng, C. C., & Yang, Y. T. C. (2023). Impact of smart classrooms combined with student-centered pedagogies on rural students' learning outcomes. *Computers & Education*, 207, 104911.
- Cheng, W., Hou, Z., Niu, J., et al. (2024). Why is a smart classroom "smart"? Discoveries from systematic literature review. *Modern Educational Technology*, 34(4), 967-656.
- Cheung, S. K., & Wang, F. L. (2021). The continuous pursuit of smart learning. *Australasian Journal of Educational Technology*, 37(2), 967-656.
- Dahalan, F., Alias, N., & Shaharom, M. S. N. (2024). Gamification and game based learning for vocational education and training. *Education and Information Technologies*, 29(2), 967-656.
- Dai, Z., Sun, C., Zhao, L., & Li, Z. (2021). Assessment of smart learning environments in higher educational institutions. *IEEE Access*, 9, 3967-6560.
- Dai, Z., Sun, C., Zhao, L., & Zhu, X. (2023). The effect of smart classrooms on project-based learning. *Journal of Science Education and Technology*, 32(6), 967-656.
- Deci, E. L., & Ryan, R. M. (2000). The "what" and "why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological Inquiry*, 11(4), 967-656.
- Deci, E. L., Koestner, R., & Ryan, R. M. (1999). A meta-analytic review of experiments examining the effects of extrinsic rewards on intrinsic motivation. *Psychological Bulletin*, 125(6), 967-656.
- Duan, L., Liu, X., & Li, R. (2024). Research on the construction of smart classrooms for automotive majors in vocational education. In *Proceedings of the 4th International Conference on Internet, Education and Information Technology (IEIT 2024)* (pp. 967-656).
- Firman, A. B. P. D. A., Janah, N., & Siswanto, D. H. (2025). School strategies in instilling student discipline to improving education quality. *Curricula: Journal of Curriculum Development*, 4(1), 967-656.
- Flick, U. (2018). *An Introduction to Qualitative Research* (6th ed.). Sage.
- Grech, M., & al. (2023). The effects of gamification on motivation in physical education. *Computers & Education*, 192, 104654.
- Harlow, L. L. (2023). Structural equation modeling. In *The Essence of Multivariate Thinking* (pp. 967-656).
- He, X. (2025). "Teacher-Student-Machine" multi-interaction matrix for NEV vocational education. *China Vocational and Technical Education*, 15(2), 967-656.
- Hu, Y., Huang, J., & Kong, F. (2022). College students' learning perceptions and outcomes in different classroom environments. *Frontiers in Psychology*, 13, 1047027.
- Hunan Automotive Engineering Vocational University. (2026). Breaking time and space limitations: Building "C+R" practical training system. *China Education Daily*, January 15, 2026.
- IES EL VINALOPÓ. (2024). SimSpray VR for automotive painting training. *Vocational Training Report*, Spain.
- Jammeh, A. L., Karegeya, C., & Ladage, S. (2024). Application of technological pedagogical content knowledge in smart classrooms. *Education and Information Technologies*, 29(8), 967-656.
- Jantakun, T., Jantakun, K., & Jantakoon, T. (2023). Systematic review of smart classroom for hard skills training in augmented and virtual reality environments. *Education Quarterly Reviews*, 6(1), 967-656.
- Jia, Y. (2022). Exploratory research on the practice of college English classroom teaching based on internet and artificial intelligence. *Security and Communication Networks*, 2022, 7133654.
- Jiang, Y. (2024). The construction path and practice of virtual simulation laboratories for economics and management. *Laboratory Research and Exploration*, 43(1), 967-656.

- Jibril, M., & Adedokun-Shittu, N. A. (2024). Enhancing education: A framework for integrating TPACK into teaching and learning. *Indonesian Journal of Multidisciplinary Research*, 4(1), 967-656.
- Jin, N., Yang, F., Yan, M., et al. (2019). User perceptions of smart class services in teaching and learning interactions. *Procedia CIRP*, 83, 967-656.
- Kapp, K. M. (2012). *The Gamification of Learning and Instruction*. Pfeiffer.
- Karanam, S. A. K., & Hartman, N. W. (2025). A systematic review of digital twin and virtual learning environments for smart manufacturing education. *Manufacturing Letters*, 44, 967-656.
- Kaur, A., Bhatia, M., & Stea, G. (2022). A survey of smart classroom literature. *Education Sciences*, 12(2), 86.
- Klingenberg, S. (2023). Investigating the effect of teaching as a generative learning strategy when learning through desktop and immersive VR. *British Journal of Educational Technology*, 51(6), 967-656.
- Kovalchuk, V., Maslich, S. V., Tkachenko, N. M., et al. (2022). Vocational education in the context of modern problems and challenges. *Journal of Curriculum and Teaching*, 8(11), 967-656.
- Kwet, M., & Prinsloo, P. (2020). The 'smart' classroom: A new frontier in the age of the smart university. *Teaching in Higher Education*, 25(4), 967-656.
- Lavigne, H. J., Lewis-Presser, A., & Rosenfeld, D. (2020). An exploratory approach for investigating the integration of computational thinking and mathematics for preschool children. *Journal of Digital Learning in Teacher Education*, 36(1), 967-656.
- Lee, H., Chang, H., & Bryan, L. (2020). Doctoral students' learning success in online-based leadership programs. *International Review of Research in Open and Distributed Learning*, 21(1).
- Lee, J. (2022). Problem-based gaming via an augmented reality mobile game and a printed game in foreign language education. *Education and Information Technologies*, 27(1), 967-656.
- Li, H., Bian, P., & Xu, M. (2024). Development and behavior pattern mining of a dual code analysis system for interactive teaching in mathematics classrooms. *Modern Educational Technology*, 34(3), 967-656.
- Liao, et al. (2023). VR integrated with ZPD instruction strategies for automotive diagnostic troubleshooting. *Journal of Educational Technology Research*, 45(2), 967-656.
- Liu, X., & Wang, J. (2023). The impact of scene teaching in smart classrooms on learners' learning performance and effectiveness. *International Journal of Emerging Technologies in Learning*, 18(24), 967-656.
- Liu, Y., & Hardy, I. (2023). Vocational education and training in China: A systematic review. *Journal of Vocational Education & Training*, 75(3), 967-656.
- Lorenzo, N., Gallon, R., Palau, R., & Mogas, J. (2021). New objectives for smart classrooms from industry 4.0. *Technology, Knowledge and Learning*, 26(4), 967-656.
- Lu, K., Yang, H. H., Shi, Y., & Wang, X. (2021). Examining the key influencing factors on college students' higher-order thinking skills in the smart classroom environment. *International Journal of Educational Technology in Higher Education*, 18(1), 967-656.
- Mantooth, R., Usher, E. L., & Love, A. M. A. (2021). Changing classrooms bring new questions: Environmental influences, self-efficacy, and academic achievement. *Learning Environments Research*, 24(3), 967-656.
- Marín, V. I., & Castaneda, L. (2023). Developing digital literacy for teaching and learning. In *Handbook of Open, Distance and Digital Education* (pp. 967-656). Springer.
- Meng, Y., Song, J., Yu, X., Xu, X., & Zhang, H. (2023). Design and evaluation of blended teaching in the smart classroom combined with virtual simulation training in basic nursing courses. *BMC Medical Education*, 23(1), 752.
- Mirai Media. (2025). AI-powered NEV fault diagnosis simulation software for vocational education. *Educational Technology Report*, Yunnan, China.
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 967-656.
- Morshedian, M., Ghanizadeh, A., & Mirzaee, S. (2023). Smart classroom management: How does it influence EFL learners' anxiety, engagement, and language achievement? *Teaching English Language*, 47(2).

- Ngendabanga, C., Nsanzimanac, P., & Nkurunziza, B. (2022). Effect of smart classroom on learners' performance in chemistry at selected secondary schools in Kicukiro district. *Rwandan Journal of Education*, 6(1), 967-656.
- Olaitan, O. (2024). Determinants of training needs, life long education and learning among roadside motor vehicle mechanics artisans. *Advances in Social Sciences and Management*, 2(2), 967-656.
- Oubibi, M., Zhao, W., Wang, Y., et al. (2022). Advances in research on technological, pedagogical, didactical, and social competencies of preservice TCFL teachers. *Sustainability*, 14(4), 2045.
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71.
- Peng, W., Xu, W., & Ye, W. (2024). Application of VR technology in practical teaching of secondary vocational automotive maintenance. *Automotive Maintenance and Repair*, (14), 967-656.
- Petchamé, J., Iriundo, I., Villegas, E., Riu, D., & Fonseca, D. (2021). Comparing face-to-face, emergency remote teaching and smart classroom. *Sustainability*, 13(12), 6625.
- Prahani, B., Alfin, J., Fuad, A., et al. (2022). Learning management system research during 967-656: How technology affects education. *International Journal of Emerging Technologies in Learning*, 17(17), 967-656.
- Rattanakha, R., Chatwattana, P., & Piriyastrawong, P. (2025). The outcomes of analytical thinking and curiosity from the virtual smart classroom using cooperative problem-based learning. *Higher Education Studies*, 15(2), 967-656.
- REMA TIP TOP North America. (2024). REMA-VRT Academy VR tire repair training. Technical Education Report.
- Reyes, R. L., Isleta, K. P., Regala, J. D., & Bialba, D. M. R. (2024). Enhancing experiential science learning with virtual labs. *Journal of Computer Assisted Learning*, 40(6), 967-656.
- Romanova, O. (2022). Embedding employability skills into vocational education and training. *Journal of Teaching and Learning for Graduate Employability*, 13(1), 967-656.
- Ryan, R. M., & Deci, E. L. (2017). *Self-Determination Theory: Basic Psychological Needs in Motivation, Development, and Wellness*. Guilford Press.
- Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology*, 61, 101860.
- Safadel, P. (2023). Effectiveness of Computer-Generated Virtual Reality (VR) in learning and teaching environments with spatial frameworks. *Applied Sciences-Basel*, 10(1), 1617.
- Saini, M. K., & Goel, N. (2020). How smart are smart classrooms? A review of smart classroom technologies. *ACM Computing Surveys*, 52(6), 967-656.
- Salsabilla, I. S., Bakhri, S., & Asiyah, N. (2025). Evaluation of Vocational Training Programs with CIPP Evaluation Model. *Evaluasi: Jurnal Manajemen Pendidikan Islam*, 9(2), 967-656.
- Saura, J. R., Ribeiro-Soriano, D., & Saldaña, P. Z. (2022). Exploring the challenges of remote work on Twitter users' sentiments. *Journal of Business Research*, 142(1), 967-656.
- Selim, H. M., Eid, R., & Agag, G. (2020). Understanding the role of technological factors and external pressures in smart classroom adoption. *Education + Training*, 62(6), 967-656.
- Septiyanto, A., et al. (2024). Android-based VVA media for motorcycle engineering students. *Indonesian Journal of Educational Technology*, 8(2), 967-656.
- Setiyawan, A., & Syamsuddin Nurul Iman, M. (2026). Developing and evaluating anti-lock braking systems (ABS) through a STEM-based digital learning module for vocational automotive education. *International Journal of Mechanical Engineering Education*, 6(1), 967-656.
- Shadravan, A., & Parsaei, H. R. (2023). The paradigm shift from Industry 4.0 implementation to Industry 5.0. *Application of Emerging Technologies*, 115(1).
- Sharma, P. K., & Masih, E. (2023). The adoption of digital smart board in Delhi government schools: A student's perspective. *Indian Journal of Educational Technology*, 5(1), 967-656.

- Shi, Y., Yang, H., Zhang, J., Pu, Q., & Yang, H. H. (2020). A meta-analysis of students' cognitive learning outcomes in smart classroom-based instruction. In *Proceedings of the 2020 International Symposium on Educational Technology* (pp. 967-656). IEEE.
- Siedentop, D. (1994). *Sport Education: Quality PE Through Positive Sport Experiences*. Human Kinetics.
- Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 967-656.
- Taherdoost, H. (2018). A review of technology acceptance and adoption models and theories. *Procedia Manufacturing*, 22, 967-656.
- Tao, Y., Wang, J., & Chen, W. (2024). Research on the application of digital twin technology in campus management service system. *Journal of Wuhu Vocational and Technical College*, 26(1), 967-656.
- Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC Medical Research Methodology*, 8(1), 45.
- Tumiran, T., Ependi, R., Abrianto, D., & Sitorus, P. A. (2025). Spiritually Based Classroom Management as a Strategy for Improving Learning Quality. *Fitrah: Journal of Islamic Education*, 6(1), 967-656.
- Wang, J., Tigelaar, D. E., Luo, J., & Admiraal, W. (2022). Teacher beliefs, classroom process quality, and student engagement in the smart classroom learning environment. *Computers & Education*, 183, 104501.
- Wang, Y., Huang, R., & Jiao, Y. (2024). Theoretical evolution of smart learning environment in the perspective of digital transformation. *Heilongjiang Higher Education Research*, 42(3), 967-656.
- Wu, H., Bai, S., Liao, Y., & Tan, C. (2024). The academic performance and upward mobility of students in education program. *Journal of World Englishes and Educational Practices*, 6(1), 967-656.
- Xing, D., & Zeng, Y. (2025). Exploring the effects of secondary school student's ICT literacy on computational thinking skills in the smart classroom environment. *Education and Information Technologies*, 30(7), 967-656.
- Xu, D. (2022). Construction of an English research learning model based on constructivism and data mining under a cloud computing platform. *Wireless Communications & Mobile Computing*, 2022, 4579547.
- Yantai Automotive Engineering Vocational College. (2026). Whole vehicle smart training: Aligning vocational students with industry frontiers. *The Paper*, January 20, 2026.
- Ye, L., & Lu, Z. (2024). An empirical study on the learning outcomes of vocational students in a smart classroom. *International Journal of Sociologies and Anthropologies Science Reviews*, 4(6), 967-656.
- Yu, B. K., Son, Y. J., & Kim, G. T. (2024). The impact of automotive maintenance education via VR equipment on students' learning outcomes. *Library of Progress-Library Science, Information Technology & Computer*, 44(2).
- Yu, H., Shi, G., Li, J., & Yang, J. (2022). Analyzing the differences of interaction and engagement in a smart classroom and a traditional classroom. *Sustainability*, 14(3), 8184.
- Yu, M. (2022). Technology-enhanced education: Improving students' learning experience in higher education. In *The Wiley Handbook of Sustainability in Higher Education Learning and Teaching* (pp. 967-656).
- Yuan, X., Huang, L., Li, L., et al. (2023). Multiscale dynamic feature learning for quality prediction. *IEEE Sensors Journal*, 23(17), 1967-6560.
- Yuan, Z., Ma, X., & Su, D. (2025). Are smart classrooms enablers or barriers for high school instruction? *Journal of Modern Education*, (2), 967-656.
- Yudiantoko, R. M. (2025). Metacognition-based digital fault diagnosis worksheet for automotive vocational students. *Journal of Vocational Education Studies*, 8(1), 967-656.
- Zhang, A., & Feng, X. (2022). The concept analysis of smart teaching. *Nurse Education Today*, 112, 105329.
- Zhang, Y. (2022). Analysis of O2O teaching assistant mode of college English in MOOC environment. *Journal of Environmental and Public Health*, 2022, 8164934.
- Zhang, Y. (2024). Exploring a blended teaching model for general education courses in higher education based on smart classrooms. *International Journal of Multiphysics*, 18(3).

Zhang, Y., Zhao, H., & Peng, D. (2022). Exploration and research on smart sports classrooms in colleges in the Information Age. *Applied Bionics and Biomechanics*, 2022, 2970496.

Zhao, Y., & Ko, J. (2024). Vocational teachers' perceptions on workplace learning in facilitating students' professional engagement in China. *Journal of Workplace Learning*, 36(4), 967-656.

Zhou, D. (2024). The influence of smart classroom on students' learning experience in the digital age. *Advances in Educational Technology and Psychology*, 8(2).

Zhou, H., & Wu, Z. (2024). The value connotation, realistic dilemma, and practical path of the construction of virtual simulation training base for higher vocational finance and economics majors. *China Vocational and Technical Education*, (2), 967-656.

Appendix A

Appendix 1. Coding Scheme to Analyse Included Studies (n = 20 Articles)

Category	Code	Label	Definition
Type of the study	A1	Mixed-method	Studies combining qualitative and quantitative approaches (e.g., interviews + surveys, observations + test scores)
	A2	Experimental / Quasi-experimental	Intervention-based studies using pre-test/post-test, control group, or quasi-experimental design without randomization
	A3	Quantitative survey	Studies using structured questionnaires, Likert scales, or survey instruments (cross-sectional, correlational, validation)
	A4	Qualitative	Studies using interviews, classroom observations, document analysis, or thematic analysis
	A5	Theoretical / Conceptual	Studies presenting theoretical frameworks, conceptual models, or policy analysis without primary data collection
	A6	Case study	In-depth investigation of a single institution, program, or implementation context
	A7	Design & Development (R&D)	Studies focused on developing and validating educational products, modules, or systems (e.g., 4D model, ADDIE)
Context and targeted group	B1	Vocational secondary education	Studies conducted in vocational high schools or secondary vocational schools (ages 15–18)
	B2	Higher vocational education	Studies involving vocational/technical college students (ages 18–22)
	B3	University/General higher education	Studies involving university students in non-vocational programs (undergraduate or postgraduate)
	B4	Automotive/Engineering specific	Studies specifically targeting automotive maintenance, mechanical engineering, or technical trade students
	B5	Non-automotive vocational	Studies in other vocational fields (nursing, economics, finance, chemistry, etc.)
	B6	Mixed contexts	Studies involving multiple educational levels or cross-disciplinary settings
Theoretical framework	C1	Constructivist learning theory	Studies using constructivism, social constructivism, or experiential learning as primary framework

	C2	Technology Acceptance Model (TAM) / UTAUT	Studies using TAM, UTAUT, or technology adoption frameworks
	C3	Community of Inquiry (CoI)	Studies using CoI framework (teaching, social, cognitive presence)
	C4	Project-Based Learning (PBL)	Studies using PBL as pedagogical framework
	C5	Blended learning theory	Studies using blended or hybrid learning theoretical foundations
	C6	Self-Determination Theory (SDT)	Studies using SDT (autonomy, competence, relatedness) as motivational framework
	C7	No explicit framework	No clearly stated theoretical basis
Learning model / pedagogical approach	D1	Virtual Reality (VR) based learning	Use of immersive VR, desktop VR, or computer-generated VR for skill development
	D2	Virtual simulation laboratory	Use of virtual simulation platforms for practice-based learning
	D3	Digital twin technology	Use of digital twin for real-time monitoring, simulation, or training
	D4	Blended teaching (online + offline)	Integration of face-to-face instruction with digital learning resources
	D5	Smart classroom platform	Use of integrated smart classroom systems (e.g., SEEWO, interactive displays, IoT devices)
	D6	Scene teaching / Situational learning	Use of contextualized, scenario-based instruction in smart classrooms
	D7	Cooperative / Collaborative learning	Structured peer interaction, team-based tasks, and collaborative problem-solving
	D8	STEM-based digital module	Integration of STEM principles into digital learning modules for technical skills
Main variables / focus	E1	Teaching quality	Instructional effectiveness, teacher-student interaction, feedback quality, classroom management
	E2	Learning quality / outcomes	Student achievement, cognitive outcomes, knowledge acquisition, skill development
	E3	Student engagement	Behavioral, emotional, and cognitive engagement in learning activities
	E4	Practical / Technical skills	Hands-on skills, procedural knowledge, diagnostic abilities, equipment operation
	E5	Student perception / satisfaction	Attitudes, perceived usefulness, satisfaction with smart classroom experience
	E6	Teacher perception / readiness	Teacher beliefs, technology acceptance, perceived competence, professional development needs
	E7	Interaction patterns	Teacher-student interaction, student-student collaboration, feedback mechanisms
	E8	Higher-order thinking skills (HOTS)	Analytical thinking, critical thinking, problem-solving, curiosity
	E9	Academic / exam performance	Test scores, grades, knowledge assessments, certification outcomes

Technology / intervention type	F1	Virtual Reality (VR) - Immersive	Head-mounted displays (HMD), fully immersive 3D environments for training
	F2	Virtual Reality (VR) - Desktop	Computer-based VR without head-mounted displays
	F3	Augmented Reality (AR)	Overlay of digital information onto physical environment
	F4	Digital twin	Virtual replica of physical systems for simulation and monitoring
	F5	AI-powered system	Artificial intelligence for adaptive learning, diagnostics, or assessment
	F6	Smart classroom infrastructure	IoT devices, interactive whiteboards, learning analytics platforms, cloud systems
	F7	Virtual learning platform	Online platforms (e.g., Second Life, Spatial.io) for distance or blended learning
	F8	Simulation software	Computer-based simulation for specific technical procedures
Measured outcomes	G1	Cognitive outcomes	Knowledge acquisition, conceptual understanding, exam scores, theoretical comprehension
	G2	Psychomotor / Technical skills	Practical skills, hands-on performance, procedural accuracy, diagnostic ability
	G3	Affective outcomes	Motivation, engagement, satisfaction, attitudes, self-efficacy
	G4	Behavioral outcomes	Participation frequency, time-on-task, attendance, collaboration behavior
	G5	Learning efficiency	Time to complete tasks, error reduction, resource utilization
Research design characteristics	H1	Pre-test/post-test with control group	Experimental design with baseline and follow-up measures plus comparison group
	H2	Pre-test/post-test without control	Quasi-experimental design with repeated measures but no comparison group
	H3	Post-test only	Single measurement after intervention without baseline
	H4	Cross-sectional / Correlational	Single time-point data collection examining relationships between variables
	H5	Case study	In-depth investigation of single institution or implementation context
	H6	Qualitative / Thematic analysis	Interview or observation data analyzed through thematic coding
	H7	Mixed methods	Combination of quantitative and qualitative data collection and analysis
Identified gaps / limitations	I1	Limited to specific context (China)	Findings limited to Chinese educational or cultural context
	I2	Limited to specific context (non-China)	Findings limited to non-Chinese contexts (Indonesia, Thailand, Korea, Rwanda, Spain, USA, Denmark, Taiwan)

	I3	Small sample size ($n < 100$)	Insufficient statistical power due to limited participants
	I4	Short intervention duration	Brief intervention period (< 8 weeks) limiting long-term effect assessment
	I5	No control group	Lack of comparison group to isolate intervention effects
	I6	No long-term follow-up	Lack of retention or longitudinal measures post-intervention
	I7	Limited to non-automotive context	Findings from other disciplines (nursing, chemistry, economics, English) - generalizability to automotive uncertain
	I8	Technology dependency / cost constraints	Over-reliance on expensive VR/digital twin systems not universally available in vocational schools
	I9	Lack of teaching quality focus	Studies focus on technology or learning outcomes without examining teaching quality as mediator
	I10	No stakeholder perception data	Absence of teacher or student perception data on smart classroom implementation

Appendix 2: Summary of the Included Studies (n = 20)

No	Author(s) (Year)	Research Method	Sample & Context	Learning Model & Main Variables	Main Findings
1	Beltran Sierra, L. M., Martin Llamas Nistal, M., & Fernandez Sanchez, J. (2022)	Quantitative experiment (pretest-posttest control group)	Electrical engineering students in distance learning program, Spain	Learning Model: Second Life virtual world platform for distance learning; Main Variables: Virtual platform effectiveness, academic achievement, student engagement	Second Life virtual platform is effective for engineering distance learning, especially for courses requiring 3D visualization. Students showed significant improvement in understanding complex electrical engineering concepts compared to traditional online methods.
2	Safadel, P. (2023)	Quantitative experiment (comparative design)	University students learning in environments with spatial frameworks, USA	Learning Model: Computer-generated Virtual Reality (VR) with spatial frameworks; Main Variables: VR effectiveness, spatial understanding, knowledge retention	Computer-generated VR significantly enhances learning in environments requiring spatial framework understanding. Students using VR demonstrated 35% better spatial reasoning scores compared to 2D computer-based learning.
3	Klingenberg, S. (2023)	Media & methods experiment (2x2 factorial design)	University students learning procedural tasks through desktop vs immersive VR, Denmark	Learning Model: Generative learning strategy (teaching others) using desktop VR vs immersive VR; Main Variables: Media type, learning method, procedural knowledge acquisition, transfer performance	Immersive VR significantly outperforms desktop VR for generative learning strategies and complex procedural tasks. The "teaching as learning" strategy was most effective in immersive VR environments for complex procedures (effect size $d = 0.78$).
4	Jiang, Y. (2024)	Construction & practice study (path analysis)	Virtual simulation laboratories for economics and management in Chinese universities	Learning Model: Virtual simulation laboratory for practice-based learning; Main Variables: Construction path, theory-simulation integration, practical skill development	Virtual simulation laboratory is effective for practice-based learning. Success depends on integration of theoretical instruction with simulation activities. Identified four critical success factors: infrastructure, teacher training, curriculum alignment, and assessment methods.

5	Zhou, H., & Wu, Z. (2024)	Conceptual study & policy analysis	Higher vocational education (finance and economics majors) in Chinese vocational colleges	Learning Model: Virtual simulation training base for vocational education; Main Variables: Value connotation, realistic dilemmas, practical implementation paths	Virtual simulation training base improves vocational learning quality but faces significant constraints: high infrastructure costs (average ¥967-656 million), lack of qualified technical staff, and insufficient curriculum integration. Recommends public-private partnership models.
6	Tao, Y., Wang, J., & Chen, W. (2024)	Case study (single institution)	Wuhu Vocational and Technical College, Anhui Province, China	Learning Model: Digital twin technology for campus management service system; Main Variables: Technology application, system effectiveness, facility management efficiency	Digital twin technology improves efficiency of practical facility management in vocational campuses by 28%. Enables real-time monitoring of equipment status, predictive maintenance scheduling, and resource optimization. Applicable to automotive workshop management.
7	Ye, L., & Lu, Z. (2024)	Quasi-experimental (10-week course, pretest-posttest)	133 first-year vocational students (Experimental n=67, Control n=66), Yunnan Province, China	Learning Model: SEEWo smart classroom platform vs traditional classroom; Main Variables: Cognitive outcomes (exam scores), behavioral outcomes (participation), affective outcomes (student feedback)	Smart classroom significantly improved all three outcome types: cognitive (exam scores +15.3%, $p<0.01$), behavioral (participation +42%), and affective (student satisfaction +38%). Effects were stronger for low-performing students.
8	Rattanakha, R., Chatwattana, P., & Piriya-surawong, P. (2025)	Pre-experimental (one-group posttest only)	30 vocational certificate students in dual vocational education program, Nakornluang Polytechnic College, Thailand	Learning Model: Virtual smart classroom using Spatial.io platform + cooperative problem-based learning (PBL) with ClickUp; Main Variables: Analytical thinking (7 indicators), curiosity (5 indicators)	Virtual smart classroom with cooperative PBL produced "very good" outcomes: analytical thinking mean = 7.23 (SD=1.41) from maximum 9.00; curiosity mean = 10.43 (SD=1.65) from maximum 12.00. Student satisfaction rated "very good" (mean=4.52/5.00).
9	Yu, H., Shi, G., Li, J., & Yang, J. (2022)	Comparative study (smart vs traditional classroom)	University students in smart classroom and traditional classroom settings, China	Learning Model: Smart classroom with interactive technologies vs traditional lecture-based; Main Variables: Interaction patterns (teacher-student, student-student), engagement levels (behavioral, emotional, cognitive)	Smart classroom produces significantly higher interaction and engagement compared to traditional classrooms: teacher-student interaction +67%, student-student collaboration +82%, behavioral engagement +54%, emotional engagement +61%, cognitive engagement +48%.
10	Lu, K., Yang, H. H., Shi, Y., & Wang, X. (2021)	Quantitative survey (structural equation modeling)	University students (N=432) in smart classroom environments, China	Learning Model: Smart classroom environment for higher-order thinking skills (HOTS); Main Variables: Interaction quality, real-time feedback, resource accessibility, HOTS development	Key influencing factors for HOTS in smart classroom: interaction quality ($\beta=0.42$, $p<0.001$), real-time feedback ($\beta=0.38$, $p<0.001$), and resource accessibility ($\beta=0.31$, $p<0.001$). These three factors explained 67% of variance in HOTS development.
11	Ngendabanga, C., Nsanzimanac, P., & Nkurunziza, B. (2022)	Quasi-experimental (pretest-posttest control group)	Advanced level chemistry students (N=120) in selected secondary schools, Kicukiro District, Rwanda	Learning Model: Smart classroom instruction vs traditional instruction; Main Variables: Chemistry learning performance, knowledge retention, student motivation	Smart classroom had significant positive effect on chemistry learning performance (mean difference = 24.5%, $p<0.001$, Cohen's $d = 1.12$). Students in smart classroom also showed higher knowledge retention after 4 weeks (+31%) and higher motivation levels (+45%).

12	Meng, Y., Song, J., Yu, X., Xu, X., & Zhang, H. (2023)	Design & evaluation (mixed methods: QUANT + QUAL)	Nursing students (N=156) in basic nursing courses, China	Learning Model: Blended teaching in smart classroom + virtual simulation training; Main Variables: Instructional design quality, practical clinical skills, student satisfaction, learning efficiency	Blended teaching with virtual simulation significantly improved practical clinical skills (post-test score +28.6%, $p<0.001$). Students reported high satisfaction (mean=4.35/5.00). Most effective for procedural skills requiring repetition and risk-free practice environment.
13	Liu, X., & Wang, J. (2023)	Experimental study (randomized controlled trial)	University students (N=180) in smart classroom learning environment, China	Learning Model: Scene teaching in smart classroom (situational learning scenarios); Main Variables: Scene teaching effectiveness, learning performance (immediate & delayed), knowledge transfer	Scene teaching in smart classroom significantly improves learning performance (immediate test +22.4%, delayed test +18.7%, both $p<0.01$). Most effective for complex, contextualized learning tasks. Knowledge transfer to novel situations improved by 31% compared to traditional instruction.
14	Dai, Z., Sun, C., Zhao, L., & Zhu, X. (2023)	Video interaction analysis (quantitative content analysis)	Project-based learning (PBL) students (N=96) in smart classroom environment, China	Learning Model: Smart classroom-supported project-based learning (PBL); Main Variables: Video interaction patterns (frequency, duration, quality), collaboration outcomes, project quality	Smart classroom supports PBL through increased student interaction (+58%) and collaboration (+71%). Video interaction analysis revealed three distinct collaboration patterns: leader-follower (42% of groups), egalitarian (35%), and passive (23%). Egalitarian groups produced highest quality projects (mean score 88.5 vs 76.2 for leader-follower).
15	Mantooth, R., Usher, E. L., & Love, A. M. A. (2021)	Quantitative survey (multilevel modeling)	High school and college students (N=845) in various classroom environments, USA	Learning Model: Classroom environmental influences on self-efficacy and achievement; Main Variables: Classroom environment quality, self-efficacy beliefs, academic achievement	Supportive classroom environment significantly increases self-efficacy ($\beta=0.47$, $p<0.001$) and academic achievement ($\beta=0.38$, $p<0.001$). Self-efficacy mediated 41% of the relationship between classroom environment and achievement. Physical comfort, emotional safety, and instructional clarity were strongest predictors.
16	Hu, Y., Huang, J., & Kong, F. (2022)	Quantitative survey (Community of Inquiry framework)	University students (N=568) in different classroom environments, China	Learning Model: Community of Inquiry (CoI) framework in smart vs traditional classrooms; Main Variables: Teaching presence, social presence, cognitive presence, learning perceptions	Positive perceptions of smart classroom correlate with higher teaching presence ($\beta=0.52$), social presence ($\beta=0.48$), and cognitive presence ($\beta=0.44$). Smart classroom students reported significantly higher scores on all three CoI presences compared to traditional classroom (all $p<0.001$).
17	Yu, B. K., Son, Y. J., & Kim, G. T. (2024)	Experimental (formative assessment focus)	Automotive maintenance education students (N=85), Korea	Learning Model: VR equipment-based automotive maintenance training with formative assessment; Main Variables: VR effectiveness, learning outcomes, skill acquisition speed, error reduction	VR equipment significantly improves automotive maintenance learning outcomes. Students using VR completed tasks 32% faster with 45% fewer errors compared to traditional training. Formative assessment embedded in VR identified specific skill gaps (electrical diagnosis, mechanical assembly). Most effective for high-risk or expensive-to-repair procedures.

18	Setiyawan, A., & Syamsuddin Nurul Iman, M. (2026)	R&D (4D model: Define, Design, Develop, Disseminate)	Vocational automotive education students (N=60) in Anti-lock Braking Systems (ABS) training, Indonesia	Learning Model: STEM-based digital learning module for ABS; Main Variables: Module effectiveness (expert validation, student response), learning outcomes, practical skills	STEM-based digital learning module for ABS was validated as "very feasible" (media expert 89.5%, material expert 88.9%). Student response 84% "very feasible". Learning outcomes increased significantly (N-Gain = 58% / medium category). Practical skills in ABS diagnosis and repair improved 42%.
19	Wang, J., Tigelaar, D. E., Luo, J., & Admiraal, W. (2022)	Multilevel analysis (hierarchical linear modeling)	Teachers (N=45) and students (N=1,247) in smart classroom learning environment, China	Learning Model: Smart classroom environment with teacher beliefs and classroom process quality; Main Variables: Teacher beliefs (constructivist vs traditional), classroom process quality, student engagement (behavioral, emotional, cognitive)	Teacher beliefs significantly predict classroom process quality ($\beta=0.54$, $p<0.01$), which in turn predicts student engagement ($\beta=0.61$, $p<0.001$). Constructivist teacher beliefs had stronger positive effects on all three engagement types. Professional development focused on pedagogical beliefs was more effective than technology training alone.
20	Cheng, C. C., & Yang, Y. T. C. (2023)	Experimental (2x2 factorial with moderator variables)	Rural students (N=320) in smart classroom environment, Taiwan	Learning Model: Smart classroom combined with student-centered pedagogies (inquiry-based vs direct instruction); Main Variables: Pedagogy type (inquiry-based vs direct), duration (short-term vs long-term), learning outcomes (knowledge, skills, attitudes)	Smart classroom + student-centered pedagogies significantly improved learning outcomes. Inquiry-based pedagogy outperformed direct instruction for long-term retention (+28%) and skill application (+35%). Pedagogy type and duration were significant moderators: effects were stronger for longer duration courses (>8 weeks). Smart classroom technology alone without pedagogical change showed minimal impact (effect size $d=0.12$).