

Integration of Project-Based Learning, STEM, and Digital Modules in Vocational Education: Systematic Literature Review

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ABSTRACT

This article aims to synthesise the trends, design characteristics, effectiveness, and challenges of integrating Project-Based Learning (PjBL), Science, Technology, Engineering, and Mathematics (STEM/STEAM) approaches, and e-modules in vocational education. This Systematic Literature Review (SLR) was conducted based on the PRISMA 2020 guidelines. The literature search retrieved 189 records from six databases: Google Scholar, Portal Garuda, DOAJ, ScienceDirect, ERIC, and Scopus. The inclusion criteria focused on empirical and R&D studies published between 2020-2025 that applied PjBL, STEM, and digital modules within vocational and applied engineering contexts. After the screening and eligibility processes, 21 key articles were included for thematic synthesis. The findings indicate that the integration of PjBL-STEM e-modules contributes to (1) enhancing cognitive skills, including problem-solving, mathematical, and visual literacy; (2) supporting psychomotor readiness through pre-workshop digital simulations; (3) fostering scientific communication, collaboration, and self-efficacy; and (4) contextualising learning through Ethno-STEM and socio-scientific issues. However, implementation faces significant challenges, particularly regarding teachers' TPACK readiness, the quality of e-module UI/UX design, and digital infrastructure stability. This study recommends strengthening inclusive digital learning ecosystems and project-based teacher training in vocational schools.

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INTRODUCTION

Vocational education in mechanical engineering and manufacturing is currently facing a critical transition driven by the demands of the Industrial Revolution 4.0, such as workshop automation, Computer Numerical Control (CNC) machining, and intelligent manufacturing systems (Suparmi et al., 2024). Traditional learning orientations that merely focus on mechanistic procedural mastery are no longer sufficient. The modern manufacturing industry demands graduates who not only act as machine operators but can also integrate blueprint interpretation, precision machining, and complex engineering problem-solving. However, there is a significant learning gap in workshop-based practice. Conventional

teacher-centered learning, which relies heavily on theoretical lectures and manual procedural exercises, limits students' opportunities to engage in authentic manufacturing processes (Agustian et al., 2024).

Empirical evidence indicates that vocational students often experience cognitive overload and learning gaps when transitioning from classroom theory to physical workshop execution. For instance, students frequently struggle with technical drawing visualization, lack autonomous problem-solving skills when facing machining errors, and are prone to practical mistakes that lead to material wastage and Occupational Health and Safety (OHS) risks (Dzulkurnain, Iskandar, et al., 2024; Fitra et al., 2024). The learning model that only emphasizes material reproduction is proven to be inadequate for mitigating these risks. The gap between theoretical abstraction in the classroom and the intensive practical demands of the workshop is one of the crucial reasons for pedagogical innovation. Vocational education needs to shift from mere knowledge transfer to active, technology-assisted learning experiences that position students as designers, implementers, and evaluators of engineering solutions.

The condition indicates that conventional teacher-centered learning is increasingly inadequate to meet the needs of modern mechanical engineering education. Empirical studies in vocational workshops reveal that teacher-centered models, which primarily rely on one-way theoretical lectures and demonstrations, fail to equip students with autonomous problem-solving skills when facing real machining errors (Dzulkurnain, Iskandar, et al., 2024). Furthermore, learning that only emphasizes procedural material reproduction limits students' spatial visualization abilities in blueprint interpretation and leaves them prone to practical mistakes, material wastage, and Occupational Health and Safety (OHS) risks during direct manufacturing execution (Fitra et al., 2024). The gap between passive classroom learning and the dynamic technical demands of the industry is a primary catalyst for pedagogical innovation. Therefore, vocational education must shift from mere knowledge transfer to active, technology-assisted learning experiences that position students as independent designers, implementers, and evaluators of engineering solutions (Agustian et al., 2024). One of the approaches relevant to the characteristics of vocational education is Project-Based Learning (PjBL). PjBL places projects at the core of learning, so students do not just receive material but engage in investigation, planning, decision-making, production of engineering artefacts, and reflection on the processes undertaken. Through PjBL, students learn to understand problems contextually, devise solution strategies, divide roles within groups, and test the feasibility of the products or technical solutions produced. As one of the most promising vocational education and training (TVET) learning strategies to stimulate practice in mechanical engineering workshops, the characteristics of PjBL align closely with the work culture of the manufacturing industry. This is because the learning process directly replicates the authentic professional work cycle, starting from the blueprint design stage, through the machining process, to the quality control stage of engineering products. Students are not only directed to understand mechanical concepts but also trained to apply them in real work situations in the workshop. Therefore, PjBL is seen as capable of strengthening critical thinking skills, engineering

problem-solving, responsibility, and the ability to work collaboratively among vocational mechanical engineering students (Rizal et al., 2024).

The strength of PjBL in the context of vocational schools is also evident in its ability to simultaneously integrate cognitive, affective, and psychomotor aspects. In the cognitive realm, students are required to understand the concepts and principles underlying the project. In the affective realm, students learn to manage responsibility, discipline, communication, and perseverance in completing tasks. In the psychomotor realm, students gain hands-on experience in designing, creating, testing, and improving products. This characteristic makes PjBL not only relevant for productive subjects but also applicable to adaptive and normative subjects that require strengthening of the vocational context. Thus, PjBL can serve as a bridge between academic learning and more meaningful work practice for vocational high school students (Herlambang et al., 2023).

In addition to PjBL, the Science, Technology, Engineering, and Mathematics (STEM) approach also has high relevance in vocational education. STEM serves as an integrative framework that connects theory with practice through the integration of science, technology, engineering, and mathematics. Science provides the conceptual foundation for understanding the phenomena or working principles of a product. Mathematics provides quantitative logic, measurement, calculation, and data analysis. Technology serves as both a medium and a tool that helps students explore and generate solutions. Engineering guides students to design, test, and refine solutions based on real-world problems. The integration of these four elements makes learning more contextual because students can see the direct relationship between academic concepts and their application in the vocational world (Hadiyanti et al., 2021). When PjBL is integrated with STEM, the learning process has a stronger potential to build 21st-century competencies. PjBL provides a project-based learning structure, while STEM offers a cross-disciplinary framework for problem-solving. The combination of the two allows students to start learning from authentic problems, conduct investigations, use scientific reasoning, apply mathematical calculations, utilise technology, and design engineering-based solutions. In the context of vocational schools, the integration of PjBL-STEM can help students understand that theory does not stand alone, but serves as the foundation for technical actions and product innovations. Several studies show that this integration can strengthen students' mathematical literacy, mathematical communication, problem-solving, and creativity in cross-disciplinary project-based learning (Wandani et al., 2023).

Previous research findings show that the PjBL and STEM approaches have very strong relevance and have been effectively implemented in the fields of engineering and mechanical expertise. In technical drawing education, the implementation of PjBL has been reported to improve technical accuracy, blueprint design skills, and vocational students' practical readiness (Fitra et al., 2024). In the subject of electronic control systems, the use of digital media has proven to support the strengthening of engineering technical learning and provide the much-needed flexibility in learning access (Hariyanto et al., 2021). In addition, the implementation of PjBL significantly helps optimise vocational practical

skills through project activities that simulate real-world work situations in workshops (Dzulkurnain, Aminuddin, et al., 2024). The overall findings indicate that the integration of PjBL-STEM has proven effective in facilitating practical needs in engineering workshops and laboratories. However, the complexity of PjBL-STEM also presents its own challenges. Mechanical engineering students must understand theoretical concepts, follow the stages of the manufacturing project, operate tools, and produce engineering artefacts in a single series of activities. If not supported by systematic, visual, and easily accessible teaching materials, the process has the potential to cause excessive cognitive load. Therefore, the integration of PjBL-STEM in the field of engineering requires learning tools that can provide step-by-step guidance, offer visualisations of the machining process, include contextual examples, and assist students in managing projects independently.

At this point, digital modules or e-modules hold a strategic position as a form of applied technology in modern vocational education. E-modules not only serve as a replacement for printed teaching materials but also as an integrated digital learning environment that presents texts, technical blueprints, demonstration videos, mechanical movement animations, and process simulations. In the context of a mechanical engineering workshop, the multimodal presentation in the e-module serves a vital function as a "pre-workshop simulation." This digital simulation facilitates students in mastering Occupational Health and Safety (OHS) standards and thoroughly understanding the sequence of machining procedures, which is essential for minimising workplace accidents and procedural errors before they operate real machines (Dzulkurnain, Aminuddin, et al., 2024; Herlambang et al., 2023). The systematic structure of the e-module allows engineering students to follow the learning path according to the stages of PjBL-STEM, starting from the design of technical designs, planning of manufacturing processes, execution, testing of engineering results, to reflection. Furthermore, mobile learning-based education allows students to access project instructions, rewatch machine operation demonstrations (such as lathes or CNC machines), and document their work results more flexibly from anywhere (Yusril Imamuddin et al., 2024). Thus, the presence of the e-module acts as a strong bridge between the exploration of engineering theory and the demands of intensive practice in the physical workshop.

The development of research that forms the basis of this article shows a strong trend in the period 2020–2026 regarding the effectiveness of integrating PjBL, STEM/STEAM, and e-modules in the context of vocational education in the field of mechanical engineering and manufacturing. The mapped study is specifically focused on disciplines relevant to engineering, such as technical drawing, electronic control systems, vocational practical skills, applied physics, and vocational mathematics. The variation in engineering areas shows that the PjBL-STEM e-module can be relied upon to support higher-order thinking skills, visual literacy in technical design, engineering problem-solving abilities, vocational communication, self-efficacy, and the precision of students' psychomotor skills in practical workshops. However, empirical findings in this engineering domain are still fragmented based on expertise specifications, media development models, digital platforms used, and measurement

parameters. Therefore, a Systematic Literature Review (SLR) is needed to summarise, compare, and synthesise the direction of applied technology research development more systematically (Nuralita et al., 2025).

Although several previous literature reviews have been conducted, such as a systematic review of PjBL implementation (Suparmi et al., 2024) or the study of interactive PjBL-based e-modules (Nuralita et al., 2025), these previous SLRs largely focused on isolated variables or general educational contexts without addressing the specific pedagogical needs of applied engineering and manufacturing. Previous reviews did not cover how the convergence of PjBL, STEM, and digital modules simultaneously resolves complex learning problems in vocational workshops. Combining these three elements provides a distinct contribution: PjBL offers an authentic industry-aligned work cycle, the STEM framework provides the cross-disciplinary analytical foundation required for engineering problem-solving, and e-modules deliver the essential digital scaffolding such as pre-workshop simulations and dynamic visualizations to prevent cognitive overload during practical execution. Therefore, this SLR aims to fill that gap by comprehensively integrating a blend of PjBL, STEM approaches, and e-module media into a single synthesis framework. Through this approach, this article is expected to provide conceptual contributions to the development of digital project-based vocational learning theory. Specifically, this study aims to answer the following research questions: 1) What are the trends in the design of PjBL-STEM e-modules in vocational education? 2) How effective is the integration of PjBL-STEM e-modules on the cognitive, psychomotor, and affective competencies of vocational students? 3) What are the main challenges in implementing the PjBL-STEM e-module? 4) What are the implications of developing PjBL-STEM e-modules for improving the quality of vocational learning? METHOD

This research uses the Systematic Literature Review (SLR) method based on the PRISMA 2020 guidelines (Page et al., 2021). To ensure methodological transparency, a review protocol was prepared and agreed upon by all authors prior to conducting the study. This study maps and synthesizes literature published between 2020 and 2025 that focuses on the integration of PjBL, STEM/STEAM, and digital modules within vocational education (Nuralita et al., 2025; Suparmi et al., 2024). The literature search was conducted in February 2026 across six databases: Google Scholar, Portal Garuda, DOAJ, ScienceDirect, ERIC, and Scopus. To ensure the specificity and replicability of the search, database-specific Boolean strings were applied, systematically accommodating both English and Indonesian terms. For international databases (Scopus, ScienceDirect, ERIC, DOAJ), the primary string used was: ("Project-Based Learning" OR "PjBL") AND ("STEM" OR "STEAM") AND ("e-module" OR "digital module") AND ("vocational education" OR "TVET" OR "engineering"). For regional databases (Google Scholar and Portal Garuda), Indonesian terms were systematically integrated: ("Project-Based Learning" OR "PjBL") AND ("STEM") AND ("e-module" OR "modul digital") AND ("sekolah menengah kejuruan" OR "SMK" OR "vokasi"). Specifically for Google Scholar, the search was limited by sorting

results by relevance, applying a strict 2020-2025 publication date filter, and screening only the first 10 pages (100 records) to maintain focus and manage overly broad results.

The screening procedure was conducted independently by two reviewers. Both reviewers examined the titles, abstracts, and full texts of the retrieved records. Any disagreements regarding article eligibility were resolved through discussion; if consensus was not reached, a third reviewer was consulted to make the final decision. The inclusion and exclusion criteria were strictly defined to maintain the focus of the study, as presented in Table 1 (Agustian et al., 2024; Hadiyanti et al., 2021).

Table 1. Inclusion and Exclusion Criteria for Literature

Aspect	Inclusion Criteria	Exclusion Criteria
Year	Most publications from 2020 to 2025.	Published outside the 2020-2025 range
Topic	Discussing PjBL, STEM/STEAM, digital modules, e-modules, or their integration.	Not discussing the main variables substantially.
Context	Vocational education in applied engineering, manufacturing, technical drawing, workshop practice, or related applied science fields.	Educational contexts outside technology and engineering expertise, or general education contexts, are irrelevant to vocational education.
Type of article	Empirical studies, R&D, mixed-methods, or specific literature reviews.	General popular opinions without clear research procedures, articles lacking full-text access, or written in languages other than English or Indonesian.

The entire methodological sequence is visualized using the PRISMA 2020 flowchart to transparently show the stages of identification, screening, eligibility, and inclusion (Page et al., 2021)

At the identification stage, 189 articles were obtained from the six databases. After duplicates and inaccessible articles were removed, 136 articles remained for the title and abstract screening stage. A total of 71 articles were eliminated because they were not relevant to the study focus. Next, 65 full-text articles were reviewed based on the inclusion and exclusion criteria, and 44 articles were excluded due to incompatible contexts or methodology. Consequently, a final total of 21 key articles were included for thematic synthesis.

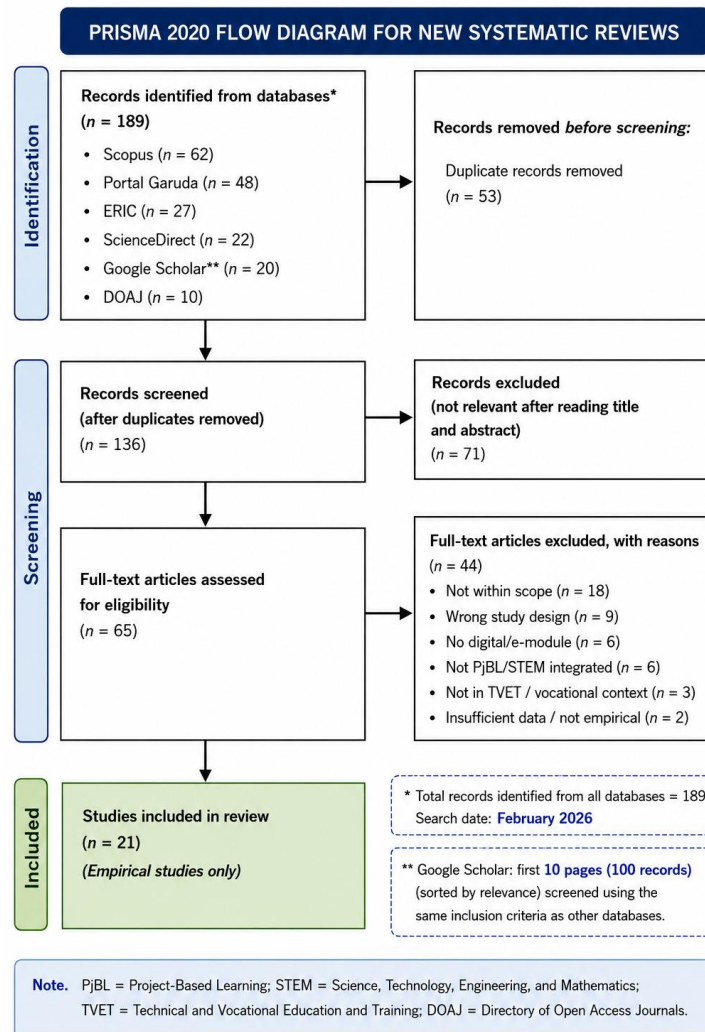


Figure 1. PRISMA 2020 flow diagram of the study selection process

After the eligibility stage, the 21 included articles were evaluated using a Quality Assessment (QA) procedure to minimize bias and ensure the reliability of the findings (Page et al., 2021). The assessment utilised a predefined appraisal checklist consisting of four criteria adapted from standard review protocols: (QA1) clarity of research objectives and problem formulation; (QA2) appropriateness of methodological design; (QA3) adequacy of data collection and analysis instruments; and (QA4) relevance and depth of empirical findings related to the integration of PjBL, STEM, and e-modules in vocational contexts. Each criterion was scored using a 3-point rubric: Yes (1 point), Partial/Unclear (0.5 points), and No (0 points). The maximum achievable score is 4. Studies were then classified into three quality categories: High (scores 3.0–4.0), Medium (scores 1.5–2.5), and Low (scores 0–1.0). Only articles categorized as Medium or High quality were included in the final synthesis. The appraisal checklist and scoring rubric are presented in Table 2, while the QA results for each included study are summarised in Table 3.

Table 2. Quality Assessment Checklist and Scoring Rubric

Code	Appraisal Criteria	Scoring Rubric
QA1	Are the research aims and problem formulation clearly stated?	Yes = 1, Partial = 0.5, No = 0
QA2	Is the methodological design clearly described and appropriate?	Yes = 1, Partial = 0.5, No = 0
QA3	Are the data collection and analysis instruments adequate and reliable?	Yes = 1, Partial = 0.5, No = 0
QA4	Are the empirical findings relevant to PjBL, STEM, and e-modules in vocational/engineering contexts?	Yes = 1, Partial = 0.5, No = 0

(Quality Categories: High Quality = 3.0–4.0; Medium Quality = 1.5–2.5; Low Quality = 0–1.0)

Table 3. Quality Assessment Results for Included Studies

No	Author & Year	QA1	QA2	QA3	QA4	Total Score	Quality Category
1	(Hadiyanti et al., 2021)	1	1	1	1	4.0	High
2	(Wandani et al., 2023)	1	1	0.5	1	3.5	High
3	(Ni Wayan Sri Maeti et al., 2025)	1	1	1	1	4.0	High
4	(Yusril Imamuddin et al., 2024)	1	1	1	1	4.0	High
5	(Rahman et al., 2021)	1	0.5	1	1	3.5	High
6	(Arnita et al., 2021)	1	1	0.5	1	3.5	High
7	(Cahyani et al., 2020)	1	1	1	1	4.0	High
8	(Dzulkurnain, Iskandar, et al., 2024)	1	1	1	1	4.0	High
9	(Herlambang et al., 2023)	1	1	1	1	4.0	High
10	(Fitra et al., 2024)	1	1	0.5	1	3.5	High
11	(Andriani et al., 2023)	1	1	1	1	4.0	High
12	(Heryensi et al., 2025)	1	1	1	1	4.0	High
13	(Suparmi et al., 2024)	1	0.5	1	1	3.5	High
14	(Nuralita et al., 2025)	1	1	1	1	4.0	High
15	(Agustian et al., 2024)	1	0.5	0.5	1	3.0	High
16	(Hariyanto et al., 2021)	1	1	1	1	4.0	High
17	(Asikin et al., 2021)	1	1	1	1	4.0	High
18	(Rizal et al., 2024)	1	1	1	1	4.0	High
19	(Sulistiyawan & Masturi, 2025)	1	1	1	1	4.0	High
20	(Yanti et al., 2025)	1	0.5	1	1	3.5	High
21	(Oksa & Soenarto, 2020)	1	1	1	1	4.0	High

RESULTS AND DISCUSSION

Results

To clarify the basis of the synthesis, articles that meet the inclusion criteria are mapped based on the author and year, field or subject, development model or research design, as well as the main findings. This mapping is important as it serves as a basis for identifying design trends, effectiveness, challenges, and implications of the PjBL-STEM e-modules in the context of vocational high school education. A summary of the 22 analysed literature sources is presented in Table 2.

Table 4. Mapping of Literature Analysed in SLR

No	Author & Year	Academic Subject / Area of Expertise	Developmental Model / Design	Principal Findings
1	(Hadiyanti et al., 2021)	Vocational Mathematics / Mathematical Literacy	4D R&D Model; STEM-Collaborative Project-Based Learning	The STEM-CPBL e-module contributes to improving the mathematical literacy of vocational high school students through investigation and the resolution of contextual problems.
2	(Wandani et al., 2023)	Mathematics / Polyhedra	R&D; PjBL-STEM e-module	The PjBL-STEM-based e-module supports mathematical communication and helps students understand geometric concepts more visually.
3	(Ni Wayan Sri Maeti et al., 2025)	Mathematics / System of Linear Equations in Two Variables	R&D; STEM-oriented PjBL e-module	The e-module assists students in modeling real-world problems into mathematical forms and enhances their problem-solving skills.
4	(Yusril Imamuddin et al., 2024)	Fundamentals of Graphic Design	R&D; Mobile Learning / Project-Based E-Module	The integration of mobile technology expands learning access and supports the flexibility of graphic design instruction in vocational high schools.
5	(Rahman et al., 2021)	Non-metal Chemistry / Carbon and Silicon	R&D; Flip PDF Professional E-Module	The e-module facilitates the visualization of abstract chemistry concepts and supports self-regulated learning.
6	(Arnita et al., 2021)	Physics / Static and Dynamic Fluids	R&D; Kvisoft Flipbook Maker	The STEM-based e-module assists students in understanding fluid concepts through more dynamic digital visualizations.
7	(Cahyani et al., 2020)	Physics / Vocational Education	Experimental; STEM-integrated PjBL e-module	The PjBL-STEM e-module is effective in enhancing vocational high school students' creativity through projects and open-ended problem-solving.
8	(Dzulkurnain, Aminuddin, et al., 2024)	Vocational Practical Skills	Case Study / PjBL in Vocational High Schools	PjBL facilitates the optimization of students' practical skills through project activities that replicate real-world work environments.

9	(Herlambang et al., 2023)	Information Technology in Vocational High Schools	Comparative: PjBL Implementation	PjBL exerts a positive influence on the cognitive and psychomotor learning outcomes of vocational high school students.
10	(Fitra et al., 2024)	Technical Drawing	Exploratory PjBL Implementation (atau: <i>An exploration of PjBL implementation</i>)	PjBL enhances students' technical precision, design capabilities, and readiness in technical drawing instruction.
11	(Andriani et al., 2023)	Scientific Visual Literacy	Teacher and student perspective study; Interactive PjBL-STEM e-module	The interactive PjBL-STEM e-module is considered essential for enhancing visual literacy, yet it demands teacher readiness and well-designed media.
12	(Heryensi et al., 2025)	Applied Science	Needs analysis; STEM-PjBL e-module	The development of the STEM-PjBL e-module must take into account learning needs, local contexts, and implementation readiness.
13	(Suparmi et al., 2024)	Vocational Education / Vocational High Schools	Systematic Literature Review	PjBL in vocational high schools has the potential to strengthen 21st-century skills and align learning relevance with the workforce.
14	(Nuralita et al., 2025)	PjBL E-Module Alternative Energy	A Study on Interactive PjBL-Based E-Modules (atau jika untuk tabel: <i>Study of interactive PjBL-based e-modules</i>)	The interactive PjBL-based e-module supports student learning autonomy and conceptual understanding.
15	(Agustian et al., 2024)	E-Modules in Vocational High School Instruction	Literature review	E-modules play a pivotal role in vocational high school instruction; however, their success depends on design quality and the readiness of the digital ecosystem.
16	(Hariyanto et al., 2021)	Electronic Control Systems	R&D; Android-Based Media Development	Android-based digital media can support the reinforcement of technical instruction and the flexibility of learning access.
17	(Asikin et al., 2021)	Mathematics / STEM	Development of STEM Instructional Materials	STEM-integrated instructional materials assist in strengthening

18	(Andriani et al., 2023)	Applied Chemistry / Colloidal Systems	STEAM-Based E-Modules / E-Worksheets	mathematical reasoning and communication. STEAM integration extends chemistry instruction toward creativity, product design, and practical value.
19	(Sulistiyawan & Masturi, 2025)	Physics / Waves and Electromagnetism	E-Module Development	The e-module facilitates self-regulated learning and assists students in comprehending abstract physics concepts.
20	(Yanti et al., 2025)	Information Communication Technology (atau disingkat: ICT)	Project-Based Digital Modules	Project-based digital modules foster learner autonomy and the formulation of algorithmic solutions.
21	(Oksa & Soenarto, 2020)	Vocational Education / Vocational High Schools	R&D; Project-Based E-Modules	Project-based e-modules assist vocational high school students in comprehending the subject matter, navigating project stages, and enhancing learning motivation.

The literature review shows that the integration of Project-Based Learning (PjBL), the STEM approach, and digital modules has been applied across a wide range of learning fields in vocational education. In the field of applied mathematics, the integration of PjBL-STEM-based e-modules is used to help students understand abstract concepts through project activities that are closely related to vocational problems (Wandani et al., 2023). In the field of computer systems and digital simulation, project-based e-modules are utilised to enhance critical thinking skills, problem-solving abilities, and mastery of technology concepts in a more contextual manner (Rizal et al., 2024). In the field of graphic design and technical drawing, digital modules help students develop visual skills, technical precision, and the ability to design products according to engineering principles (Yusril Imamuddin et al., 2024). In the field of applied physics and chemistry, STEM e-modules play a role in visualising concepts that are difficult to observe directly, such as fluids, waves, molecular structures, and colloidal systems (Rahman et al., 2021). In the field of electronic control systems, project-based digital learning provides space for students to apply technical engineering concepts in a more practical manner (Hariyanto et al., 2021). Although many of these studies focus on subjects outside specific machining practices, their findings are highly transferable to mechanical engineering vocational education. This generalization is explicitly justified because mechanical engineering is a multidisciplinary field that heavily relies on these foundational competencies. For instance, mastery of applied mathematics and physics is crucial for calculating machining parameters and understanding material properties, while technical drawing

and computer systems are fundamental for reading blueprints and operating CAD/CAM or CNC machines. Therefore, the diversity of these fields shows that the PjBL-STEM e-module is flexible, adaptive, and can be developed specifically to support the complex, multidisciplinary characteristics of mechanical engineering programs (Rizal et al., 2024).

From the development model perspective, the quantitative mapping of the included studies reveals that the majority of the reviewed research (12 out of 21 studies, or 57.1%) uses the Research and Development (R&D) approach. This dominant trend occurs because the main focus of these studies is to produce, validate, and test the feasibility of digital learning products before they are implemented in vocational schools. Among the various R&D frameworks, the 4D model is widely used because it provides systematic stages starting from needs definition, product design, development through expert validation, to dissemination of the product to the target users (Hadiyanti et al., 2021). The define stage in the 4D model allows researchers to identify student needs, material characteristics, and gaps in learning media in vocational schools (Ni Wayan Sri Maeti et al., 2025). The design stage is used to organise the structure of the e-module, determine the flow of PjBL-STEM, design the media appearance, and prepare learning evaluation instruments (Wandani et al., 2023). The development stage emphasises validation by subject matter experts, media experts, and practicality testing to ensure that the produced product meets learning feasibility standards (Rizal et al., 2024). The dissemination stage is used to expand the use of the product while also testing the responses of students and teachers in a real learning context (Hadiyanti et al., 2021)..

Besides the 4D model, the ADDIE model is also used in several studies because it has a flexible development flow and is evaluative at every stage. The analysis stage in ADDIE helps researchers map out learning needs, student characteristics, and the limitations of media available in schools (Heryensi et al., 2025). The design stage allows developers to create learning scenarios, project syntax, module appearances, and performance-based assessment strategies (Rizal et al., 2024). The development stage is used to produce e-modules by combining text, images, videos, simulations, links, and project instructions (Rahman et al., 2021). The implementation stage provides an opportunity to test the applicability of the module in direct learning processes with students (Yusril Imamuddin et al., 2024). The evaluation stage functions to assess the effectiveness of the product, improve deficiencies, and ensure that the e-module truly supports the achievement of student competencies (Rizal et al., 2024). Meanwhile, the Borg & Gall model is used in research that emphasises gradual product testing, starting from preliminary studies, prototype development, limited trials, revisions, to broader field trials (Ni Wayan Sri Maeti et al., 2025).

From the perspective of learning media, the research reviewed shows the utilisation of various authoring tools and digital platforms to develop PjBL-STEM e-modules. Moodle is used as a Learning Management System because it can manage learning activities, material distribution, discussions, assignments, and track student progress in an integrated manner (Rizal et al., 2024). Schoology is

utilised to support project-based learning because it provides a space for digital classroom management, assignment collection, and interaction between teachers and students (Gede Risdha Pra Rendra et al., 2018). Heyzine and Canva are used because they allow developers to create visually appealing modules that are accessible and aligned with the characteristics of digital learners (Rizal et al., 2024). The 3D FlipBook application is used to provide a more interactive digital reading experience through page effects, visualisation, and multimedia integration (Suryani et al., 2020). Kvisoft Flipbook Maker and Flip PDF Professional are utilised to enhance visual appearance, integrate animations, and facilitate navigation of learning materials (Rahman et al., 2021). Web-based platforms are also used because they allow students to access modules without having to install special applications on their devices (Rizal et al., 2024). The variation of these media shows that the development of e-modules is not only oriented towards text digitisation but also towards enhancing interactivity, concept visualisation, learning accessibility, and learning project management (Yusril Imamuddin et al., 2024).

Based on the thematic synthesis using an inductive coding approach (Braun & Clarke, 2006), the principal findings extracted from the included studies were systematically coded and grouped into five main clusters. These themes were generated by extracting specific learning outcomes and instructional patterns from the 21 empirical studies, assigning initial codes, and subsequently categorising them into broader thematic clusters to illustrate the specific contributions of the PjBL-STEM e-modules in vocational school learning.

The first cluster, representing cognitive and higher-order thinking skills, shows that the PjBL-STEM e-module is capable of enhancing complex cognitive competencies. As evidence from the included studies, (Cahyani et al., 2020) demonstrated that higher-order thinking skills improved because students were involved in the processes of problem analysis, strategy design, solution testing, and project outcome reflection. Similarly, (Hadiyanti et al., 2021) provided evidence that the e-module contributes to the improvement of mathematical literacy because students are trained to use concepts, symbols, calculations, and data interpretation in the context of real-world problems. Furthermore, students' mathematical communication skills also develop because project-based learning encourages them to explain ideas, present reasons, and defend solutions logically (Wandani et al., 2023). Other studies within this cluster provide evidence for visual literacy enhancement because digital modules provide images, animations, and visual representations that aid in understanding abstract concepts (Andriani et al., 2023). Computational thinking skills are also strengthened because students are guided to decompose problems, recognise patterns, formulate algorithms, and develop technology-based solutions (Rizal et al., 2024). Ultimately, conceptual understanding becomes stronger because students not only read the material but also apply it in projects that require the connection between theory and practice (Ni Wayan Sri Maeti et al., 2025).

The second cluster shows that the PjBL-STEM e-module supports the strengthening of vocational high school students' psychomotor skills. The digital module can function as a pre-workshop

simulation because students receive guidance, examples, visualisations, and work instructions before performing hands-on practice (Dzulkurnain, Aminuddin, et al., 2024). Pre-workshop simulations help students minimise procedural errors because they have understood the work sequence, tools, materials, and safety standards before entering the practice room (Herlambang et al., 2023). Prototype design in PjBL-STEM gives students the opportunity to test ideas, revise designs, and refine products before they are presented or used (Fitra et al., 2024). That process is important in vocational education because students' competencies are not only measured by knowledge but also by their ability to produce products or performance that meet standards (Rizal et al., 2024).

The third cluster shows that collaborative projects in the PjBL-STEM e-module strengthen students' affective aspects. Student motivation and independence significantly increased when they successfully completed project challenges and saw that the engineering artefacts they created had real functions (Nuralita et al., 2025; Oksa & Soenarto, 2020). Collaboration develops because the project demands role distribution, task coordination, idea negotiation, and collective responsibility (Hadiyanti et al., 2021). Student communication becomes more focused because they have to convey ideas, provide feedback, and present project results in front of teachers and peers (Wandani et al., 2023). Learning responsibility also increases because e-modules provide space for students to manage their time, monitor their progress, and complete tasks more independently (Yusril Imamuddin et al., 2024). Thus, the PjBL-STEM e-module not only strengthens cognitive learning outcomes but also shapes work character relevant to the needs of the industrial world (Herlambang et al., 2023).

The fourth cluster shows that the integration of Ethno-STEM, STEAM, and Socio-Scientific Issues (SSI) makes learning more contextual and meaningful. Ethno-STEM helps students connect the concepts of science, technology, engineering, and mathematics with local potential, cultural wisdom, and community life practices (Heryensi et al., 2025). STEAM enriches vocational learning because the element of art encourages students to consider aesthetics, design creativity, ergonomics, and the commercial value of products. SSI makes learning closer to real-world issues as students are invited to analyse environmental, energy, food, health, and technology issues from both scientific and social perspectives (Andriani et al., 2023). The contextual integration is important for vocational schools because vocational graduates are not only required to work technically but also to produce solutions that are relevant to the needs of society and the environment (Heryensi et al., 2025).

The fifth cluster shows that the success of implementing the PjBL-STEM e-module highly depends on teacher readiness, the quality of module design, and digital infrastructure support. Teacher readiness is a crucial factor because implementing PjBL-STEM requires the ability to design projects, manage collaboration, facilitate inquiry, and authentically assess learning products (Andriani et al., 2023). Teacher TPACK competence is necessary so that the integration of technology, pedagogy, and content can run smoothly in project-based digital learning (Heryensi et al., 2025). The quality of e-module design also determines the success of learning because a good module must have a clear

structure, an attractive appearance, easy navigation, relevant multimedia, and operational project instructions (Rizal et al., 2024). Digital infrastructure support is an important prerequisite because limitations in devices, internet networks, and platform access can hinder the implementation of e-module-based learning (Yusril Imamuddin et al., 2024). Therefore, the success of the PjBL-STEM e-module in vocational schools is not only determined by the quality of the media product but also by the readiness of the school ecosystem to support sustainable digital vocational learning (Nuralita et al., 2025).

Table 5. Thematic Synthesis of Literature Findings

Clusters of Findings	Forms of Implementation	Enhanced Competencies	Significance for Vocational High Schools	Supporting Evidence
Cognitive and HOTS	STEM projects, open-ended problems, digital simulations, product-based evaluation.	Critical thinking, problem-solving, mathematical literacy, visual literacy, computational thinking.	Assists students in comprehending abstract concepts through real-world work contexts.	(Andriani et al., 2023; Cahyani et al., 2020; Hadiyanti et al., 2021; Ni Wayan Sri Maeti et al., 2025; Rizal et al., 2024; Wandani et al., 2023)
Psychomotor Domain	Digital pre-workshop activities, prototyping, blueprints, engineering design, simulative testing.	Precision, working procedures, technical decision-making, reduction of practical errors.	Enhancing training efficiency and readiness for workshop/laboratory practice.	(Dzulkurnain, Iskandar, et al., 2024; Fitra et al., 2024; Herlambang et al., 2023; Rizal et al., 2024)
Affective and Social Domains	Project collaboration, presentations, reflections, team role assignment..	Scientific communication, self-efficacy, responsibility, autonomy, resilience.	Fostering a productive work culture and professional readiness.	(Hadiyanti et al., 2021; Herlambang et al., 2023; Nuralita et al., 2025; Oksa & Soenarto, 2020; Wandani et al., 2023; Yusril Imamuddin et al., 2024)
Contextualization	Ethno-STEM, STEAM, socio-scientific issues,	Creativity, environmental awareness, cultural	Aligning vocational competencies with the needs of the	(Andriani et al., 2023; Heryensi et al., 2025)

	local entrepreneurship.	appreciation, product innovation.	community and local industries.	
Digital Ecosystem	LMS, websites, mobile learning, flipbooks, videos, automated quizzes.	Learning access, project monitoring, self-regulated learning, process documentation..	Unlocking opportunities for flexible and measurable hybrid learning.	(Andriani et al., 2023; Heryensi et al., 2025; Nuralita et al., 2025; Rizal et al., 2024; Yusril Imamuddin et al., 2024)

Discussion

The first finding indicates that PjBL-STEM e-modules significantly strengthen students' cognitive competencies. Moving beyond a mere increase in learning scores, we interpret that this cognitive enhancement occurs because the interactive e-modules function as vital cognitive scaffolding. Under conditions where students face high cognitive load such as when dealing with abstract spatial geometry or complex quantitative formulas the e-modules effectively reduce this load by translating abstract mathematical symbols into concrete, interactive digital visualisations (Hadiyanti et al., 2021; Wandani et al., 2023). In these specific problem-solving conditions, the digital platform allows students to mentally model real-world vocational problems before executing them, shifting the learning focus from merely memorising final answers to logically structuring computational thought processes. However, it is important to acknowledge the limitations of this evidence. The cognitive improvements reported in these reviewed studies are predominantly based on short-term project assessments within isolated foundational subjects (such as applied mathematics). Currently, there is limited empirical evidence demonstrating whether these cognitive gains are sustained over long-term periods, or how seamlessly this mathematical problem-solving ability transfers when students are faced with highly complex, multidisciplinary machining projects in a real workshop environment.

In the material on Systems of Linear Equations in Two Variables, the PjBL-STEM e-module helps students model real-world problems into mathematical forms relevant to life and vocational contexts. Students are guided to understand the relationships between variables, formulate equations, interpret calculation results, and connect them with practical situations. This process makes mathematics learning more meaningful because concepts are not studied separately from their application. Therefore, the PjBL-STEM e-module has the potential to strengthen students' conceptual understanding as well as their problem-solving skills (Ni Wayan Sri Maeti et al., 2025). In computer and information technology learning, project-based e-modules encourage students to decompose problems, abstract, and gradually formulate algorithmic solutions. Students not only follow technical instructions but also learn to identify problems, break them down into smaller parts, recognise patterns, and formulate logical solutions. These

activities are relevant to the needs of vocational education in the field of technology because the workforce demands systematic and adaptive thinking skills. Thus, project-based e-modules can strengthen the computational thinking abilities of vocational high school students (Heryensi et al., 2025). E-modules also play an important role as cognitive load controllers in vocational learning. Vocational materials often contain abstract concepts, technical procedures, symbols, and spatial visualisations that are difficult to understand if only presented through linear text. Through digital displays, the material can be organised gradually so that students do not receive excessive information at one time. E-modules also allow students to review the material according to their learning needs. Thus, e-modules can function as scaffolding devices that help students understand complex information in a more directed manner (Suryani et al., 2020).

In physics learning, flipbook-based e-modules help students understand fluid concepts through more dynamic and easily followed visualisations. Concepts such as pressure, density, buoyant force, and fluid flow are often difficult to observe directly in conventional learning. Through digital visualisation, students can see the relationships between variables more clearly. The presentation helps students build conceptual understanding before conducting further analysis or practice (Arnita et al., 2021). In chemistry learning, e-modules help students understand the structure of matter and chemical processes through digital representations that support the readability of abstract concepts. Applied chemistry material often requires the ability to visualise particles, bonds, reactions, and changes in substances that cannot always be observed directly. With the help of images, animations, and links to learning resources, students can build a more concrete understanding. This shows that e-modules can enhance concept visualisation while also supporting independent learning (Rahman et al., 2021).

The second finding relates to strengthening the psychomotor aspects of vocational high school students. Vocational education in mechanical engineering cannot be separated from physical workshop practice, the use of heavy machinery (such as lathes and milling machines), the production of precision workpieces, procedural accuracy, and Occupational Health and Safety (OHS) standards. In this context, student success is not only measured by conceptual understanding but also by the ability to apply complex work procedures accurately, such as translating 2D technical drawings into physical products or configuring CNC (Computer Numerical Control) parameters. Therefore, the PjBL-STEM e-module must be designed to help students master these work steps before entering direct practice. This role is crucial so that students have better initial readiness when dealing with cutting tools, raw materials, and machining procedures in the workshop or laboratory (Herlambang et al., 2023). Direct machining practice in vocational schools often requires substantial costs, materials, time, and rigorous safety supervision that are not always optimally available. Under such conditions, the PjBL-STEM e-module serves as a vital initial simulation space for instance, through embedded CAD/CAM simulations before students engage in physical practice. Through digital design, students can learn the exact work sequence, recognise specific machining tools, and anticipate potential OHS risks before practical activities take

place. This initial simulation significantly reduces critical work errors (such as machine crashes or incorrect material feeding) and increases the efficiency of raw material usage in the production process (Dzulkurnain, Iskandar, et al., 2024). In the study of technical drawing and engineering fields, blueprints and visual examples in e-modules help students review product designs before entering the physical production stage. Students can examine the shape, size, proportion, and technical accuracy through the visual representations available in the module. This activity makes students more prepared to revise designs before the product is realised. Thus, the e-module can enhance the technical precision and psychomotor readiness of students (Fitra et al., 2024). The third finding shows that PjBL-STEM not only impacts cognition and psychomotor skills but also affects the affective domain of vocational mechanical engineering students. Collaborative projects require students to divide tasks, coordinate workshop work, negotiate engineering ideas, and take responsibility for the team's final product. The success of a manufacturing or machining project does not only depend on the individual technical abilities but also on the quality of cooperation among students. In the process, students learn to appreciate technical opinions, solve problems together, and build independence through tangible contributions within the group. Thus, PjBL-STEM has the potential to strengthen students' learning motivation, independence, and collaborative work character, which are highly needed by the modern industry (Hadiyanti et al., 2021; Oksa & Soenarto, 2020).

Students' scientific communication develops when they are asked to explain designs, defend arguments, and present project results based on data. In project-based learning, students are not only required to produce a product but also to explain the reasoning behind the decisions they make. This process trains students to convey ideas in a coherent manner, use technical terms accurately, and respond to questions from both peers and teachers. Therefore, the PjBL-STEM e-module can serve as a means to strengthen students' academic and workplace communication (Wandani et al., 2023).

The fourth finding highlights the importance of contextualisation in the development of PjBL-STEM e-modules. The integration of Ethno-STEM provides students with the opportunity to connect the concepts of science, technology, engineering, and mathematics with local potential and cultural wisdom in their surroundings. Learning becomes more meaningful because the projects developed are closely tied to the social life and environment of the students. This contextualisation can also strengthen students' awareness of local potential and community needs. Thus, Ethno-STEM can be an important approach in developing vocational education that is relevant to the local context (Heryensi et al., 2025). The integration of STEAM expands the orientation of learning because the artistic element helps students consider aesthetics, design, creativity, and the utility value of products. In the context of vocational schools, a good product is not only assessed by its technical function but also by its appearance, comfort, appeal, and commercial potential. The artistic element provides space for students to develop design sensitivity and product creativity. Thus, STEAM can enrich vocational learning to be more innovative and user-oriented (Andriani et al., 2023).

Despite its pedagogical benefits, the implementation of PjBL-STEM e-modules in vocational education encounters multifaceted challenges, which our synthesis categorizes into five structural domains: teacher readiness, media design, infrastructure, assessment, and institutional support. First, regarding teacher readiness, the literature consistently highlights that teachers' Technological Pedagogical Content Knowledge (TPACK) remains a primary barrier, as many still perceive e-modules as static digital textbooks (Andriani et al., 2023). From our perspective, this highlights a difficult pedagogical shift, where vocational teachers struggle to transition from traditional workshop instructors to facilitators who seamlessly weave complex STEM calculations into hands-on mechanical projects. Second, in terms of media design, previous studies emphasize that poor UI/UX design and a lack of interactivity hinder student engagement (Agustian et al., 2024; Suryani et al., 2020). We argue that designing effective e-modules for mechanical engineering is exceptionally demanding, requiring advanced visual features like responsive 3D part viewers that demand a level of instructional design expertise most vocational teachers currently lack. Third, concerning infrastructure, device incompatibility and unstable networks are frequently reported as major hindrances (Rizal et al., 2024; Yusril Imamuddin et al., 2024). We interpret this issue as particularly critical in engineering contexts, as running heavy simulations requires high-specification devices that are not universally accessible to all students. Fourth, regarding assessment, although less explicitly detailed in the literature, our synthesis reveals a significant challenge in evaluating PjBL-STEM outcomes. We emphasize that developing real-time digital rubrics to simultaneously evaluate physical machined parts, theoretical STEM calculations, and collaborative processes remains highly complex for educators. Finally, concerning institutional support, the literature implies that e-modules must be part of a broader learning ecosystem. We emphasize that without strong institutional backing such as providing dedicated workshop Wi-Fi, upgrading laboratory hardware for CAD/CAM software, and allocating continuous development funding individual teachers' efforts to sustain PjBL-STEM integration will remain isolated and ultimately unsustainable.

In addition to teacher readiness, the design of learning also poses an important challenge in the implementation of the PjBL-STEM e-module. The e-module must not only provide material but also guide students towards activities of investigation, collaboration, production, and reflection. The problems presented need to be authentic so that students can relate their learning to real situations in their field of expertise. Project instructions also need to be designed clearly so that students understand the workflow and the expected achievement targets. Therefore, the quality of pedagogical design becomes the main determinant of the success of the PjBL-STEM e-module (Agustian et al., 2024). The next challenge relates to the quality of e-module design. Some digital modules still have the potential to be PDF versions of printed materials, thus failing to maximise interactive functions in digital learning. High-quality e-modules for vocational schools should include clear navigation, procedure visualisations, practice videos, simulations, project worksheets, formative assessments, performance rubrics, and

feedback. The quality of UI/UX is also important because students need learning materials that are easily accessible, responsive to devices, and support independent learning. Thus, the technical and visual quality of the e-modules needs to be considered so that the learning is not only digital but also interactive and meaningful (Suryani et al., 2020).

In the development of mobile device-based e-modules, accessibility and ease of use become very important aspects. Vocational high school students need learning materials that can be accessed through available devices, both at school and outside of school. The module's display needs to be responsive so that it can be used on various screen sizes. Instructions also need to be structured simply so that students can learn independently without always relying on the teacher's explanations. Thus, mobile learning-based e-modules can expand students' learning space and support the flexibility of vocational education (Yusril Imamuddin et al., 2024). Another challenge that needs to be addressed is the disparity in access to devices and networks. The implementation of digital learning requires adequate devices so that students can access e-modules, complete assignments, and document project results optimally. A stable internet connection is also necessary because some e-module platforms, LMS, and task storage spaces require continuous online access. In the context of vocational high schools (SMK) with diverse socio-economic conditions, limitations in devices and networks can hinder the equitable distribution of digital learning innovations. Therefore, schools need to prepare hybrid learning strategies and alternative access so that digital innovations do not widen the learning gap (Rizal et al., 2024).

Support for the Learning Management System is necessary so that teachers can manage materials, monitor progress, collect assignments, and provide feedback in an organised manner. LMS can also assist in the project documentation process because all student activities can be recorded on a single platform. In project-based learning, features such as task submission, discussion forums, and activity tracking are crucial to ensure the learning process progresses through its stages. Thus, LMS can strengthen the management of PjBL-STEM learning in the context of digital or hybrid classrooms (Gede Risdha Pra Rendra et al., 2018). Based on the discussion results, the integration of PjBL-STEM and digital modules can be viewed as a potential learning model to improve the quality of vocational high school education. This potential arises because PjBL-STEM is capable of connecting theory, practice, technology, and authentic problem-solving in a structured learning experience. Learning no longer focuses solely on mastery of the material, but also on students' ability to generate solutions through projects relevant to their field of expertise. Thus, this integration can strengthen the relevance of vocational school learning with the needs of the workforce (Suparmi et al., 2024).

E-modules enhance that potential because they provide learning media that is visual, interactive, flexible, and can be accessed independently by students. However, the success of the implementation is not solely determined by the presence of the e-module as an educational product. Success also depends on the alignment between competency goals, project design, content quality, teacher readiness, authentic assessment, and school infrastructure support. In other words, the PjBL-STEM e-modules need to be

positioned as part of the learning ecosystem, not just as additional digital media (Nuralita et al., 2025). The e-module approach of PjBL-STEM is important for vocational education because it can sustainably integrate media, pedagogy, content, assessment, and institutional support. Learning designed through this approach not only targets theoretical understanding but also the ability to work, innovate, collaborate, and solve real-world problems. That orientation aligns with the needs of vocational education, which must produce adaptive, creative graduates who are ready to face changes in the workforce. Therefore, the PjBL-STEM e-module can be a relevant learning strategy to enhance the quality of vocational high school graduates (Heryensi et al., 2025).

Table_6. Practical Implications for the Development of PjBL-STEM E-Modules in Vocational High Schools

Component	Development Recommendations	Quality Indicator	Supporting Evidence
Instructional design	The e-module is structured according to the PjBL syntax and STEM integration.	It incorporates authentic problems, project design, investigation, product creation, presentation, and reflection.	(Hadiyanti et al., 2021; Rizal et al., 2024)
Vocational content	The material is aligned with core competencies and the industrial context.	It features operating procedures, case studies, product standards, and performance rubrics.	(Fitra et al., 2024; Herlambang et al., 2023)
Digital media	It utilizes visuals, videos, simulations, hyperlinks, quizzes, and worksheets.	It is interactive, lightweight, mobile-friendly, and suitable for self-paced learning.	(Rahman et al., 2021; Yusril Imamuddin et al., 2024)
Assessment	It employs product, process, and reflective assessments.	The rubrics evaluate knowledge, skills, collaboration, communication, and creativity.	(Andriani et al., 2023)
Teacher preparedness	Teachers are trained in TPACK and cross-disciplinary project development.	It involves collaboration between vocational (productive) and foundational (adaptive) subject teachers, alongside periodic evaluations.	(Andriani et al., 2023; Heryensi et al., 2025)
Accessibility	The e-module is compatible with low-specification devices and limited network conditions.	An offline version, lightweight files, and clear user guidelines are provided.	(Rizal et al., 2024; Yusril Imamuddin et al., 2024)

Research Limitations

Although this Systematic Literature Review (SLR) has been conducted comprehensively in accordance with the PRISMA 2020 guidelines, several limitations should be considered when interpreting the findings. First, the publication period of the articles analysed was strictly limited to the years 2020 to 2025. Although these restrictions aim to ensure the study's relevance to the latest

educational technology trends, research published before this period is not included. Second, the literature search focused on specific databases (such as Portal Garuda, DOAJ, Scopus, and ScienceDirect), which limited most of the search results to articles in Indonesian and English. This introduces potential database and publication bias because innovations in the PjBL-STEM e-modules in countries with different languages of instruction or in unindexed journals may not be represented. Third, there is significant heterogeneity of study contexts among the 21 reviewed articles. The variation in evaluation methods and the contexts of expertise fields (ranging from mathematics to machining practices and engineering) is quite broad, so the narrative thematic synthesis conducted does not yet include quantitative effect-size measurements from the learning interventions. Therefore, future research is recommended to expand the range of publication languages and to use a meta-analysis approach to statistically assess the effectiveness of the PjBL-STEM e-modules in vocational schools.

CONCLUSION

Based on the results of this Systematic Literature Review of 21 key empirical studies, the integration of Project-Based Learning (PjBL), STEM/STEAM approaches, and e-modules indicates significant potential as a highly relevant learning innovation for vocational education. Although the reviewed studies encompass various disciplines such as applied mathematics, physics, and ICT their underlying pedagogical principles are highly transferable to mechanical engineering contexts because they provide essential cognitive scaffolding and pre-workshop simulations needed for complex machining tasks. Specifically, the trend in the design of PjBL-STEM e-modules is largely developed through the Research and Development (R&D) model, utilising various digital platforms to present interactive instructional designs that include authentic problems, structured project stages, concept visualisation, and performance rubrics.

In terms of effectiveness, this review suggests that this integration holistically strengthens students' competencies in the cognitive domain (such as mathematical and visual literacy), the psychomotor domain (serving as a pre-workshop simulation that minimises practical errors), and the affective domain (encouraging collaboration, self-efficacy, and vocational communication). Nevertheless, its implementation still faces five major structural challenges: teachers' readiness in mastering TPACK, complex media design demands, digital infrastructure disparities, comprehensive assessment difficulties, and the lack of institutional support. Therefore, the development of PjBL-STEM e-modules carries crucial implications that digital modules should not merely be positioned as digitized substitutes for print media, but must be fully integrated into a broader, well-supported vocational learning ecosystem that synergises competency goals, project contexts, authentic assessments, and institutional backing to produce adaptive and job-ready graduates.

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