

Mapping Digital and AI Competence of Secondary Vocational Teachers Toward Industry 5.0

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Abstract

Digital and AI competencies are becoming central to secondary vocational teachers as industry moves from Industry 4.0 to 5.0, yet evidence on these competencies is scattered across frameworks, instruments, and settings. This study aimed to synthesise empirical evidence on the frameworks used, the measurement and attainment of competence, its determinants, and professional development for secondary vocational teachers. A systematic literature review was chosen because it allows a transparent and reproducible synthesis of fragmented primary studies. Following PRISMA 2020, one Scopus search covering 2019 to 2026 returned 61 records, and 11 studies were included after screening and full-text assessment. Quality was appraised with the Mixed Methods Appraisal Tool, and findings were synthesised following the Synthesis Without Meta-analysis guideline and thematic synthesis. Screening, extraction, and coding were performed by an AI model under the lead author's direction, and two authors verified the full-text decisions and a sample of exclusions. The studies used varied frameworks, most often technological pedagogical and content knowledge (TPACK) and usually in part, and only one addressed generative AI. Competence was measured by self-report with author-defined categories, so levels could not be compared. Digital competence positively predicted school digital transformation or adoption in three studies, but its effect was small relative to leadership and organisational culture. No study evaluated a professional development intervention, and methodological quality was low. Research needs a vocationally anchored framework that joins pedagogical competence, occupational digital practice, and AI literacy and that is measured with performance evidence. Professional development should be evaluated with specified content and comparative designs.

Keywords: Digital Competence, AI Competence, Vocational Teachers



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INTRODUCTION

Industry 4.0 has been characterised as technology-driven, whereas Industry 5.0, announced by the European Commission, is described through human-centricity, sustainability, and resilience (Leng et al., 2022; Xu et al., 2021). These characteristics place weight on the people who prepare the future workforce, and secondary vocational teachers are central among them. They teach technologies that keep changing, for workplaces that are digitalising, in vocational systems that differ across countries and are often transferred between them (Li & Pilz, 2023; Suharno et al., 2020; Widaningsih et al., 2025b). The urgency is practical. Generative AI has entered education quickly, and its implications for teaching are still debated (Kasneci et al., 2023; Selwyn, 2022). Vocational teachers therefore face change twice, as users of AI in their own teaching and as preparers of students for AI-supported work. Decisions on teacher training and competence standards need evidence organised by framework, measure, and context.

Digital competence is not a single, settled construct. Reviews show that digital literacy and digital competence are used inconsistently (Pettersson, 2018; Spante et al., 2018) and that teacher-specific conceptualisations differ in scope (Falloon, 2020; Skantz-Åberg et al., 2022). Technological pedagogical and content knowledge (TPACK) has been reviewed across empirical studies (Willermark, 2018) and extended to generative AI (Mishra et al., 2023). Syntheses exist for teachers in general (Fernández-Batanero et al., 2022; Starkey, 2020), for teacher preparation (Instefjord & Munthe, 2017; Tondeur et al., 2018), and for higher education (Zhao et al., 2021). Competence has been linked to self-efficacy and the use of information and communication technology (ICT) (Hatlevik, 2017), to personal and contextual factors (Lucas et al., 2021), and to technology acceptance (Scherer et al., 2019). School conditions also shape digital learning (Sailer et al., 2021). AI literacy has been conceptualised (Ng et al., 2021), and frameworks of AI literacy and teachers' AI competencies have been proposed (Chiu et al., 2024; Ng et al., 2023). Intelligent-TPACK models the ethical integration of AI-based tools (Celik, 2023). Reviews of AI in education have noted the limited involvement of educators (Zawacki-Richter et al., 2019) and have mapped the state of the art (Holmes & Tuomi, 2022).

Research on vocational teachers is smaller. Among Swiss vocational teachers, attitude towards technology and frequency of tool use were the main personal factors for digital competence, and curriculum support was the largest contextual factor (Cattaneo et al., 2022). Digital competence mattered less for perceived digital transformation than strategy and leadership (Rauseo et al., 2023), and Antonietti et al. (2022) examined whether it influences technology acceptance. Willermark and Carlsson (2026) began to ask what vocational teachers need to know in the era of generative AI. Five reviews are specific to vocational teachers. Lahn and Berntsen (2023) reviewed frameworks for vocational teachers and found a narrow focus on technical skills, with little attention to the connection between school and work. Mohd Rokeman et al. (2024) scoped the challenges of digital competence in technical and vocational education and training (TVET) and the strategies to overcome them. Purnama et al. (2026) reviewed ten articles on vocational teachers' digital competence in the Industry 4.0 era and reported limited device access, few training opportunities, and weak institutional support. Du and Kushairi (2026) synthesised 27 studies on the digital literacy competencies of TVET educators in the era of AI and proposed a contextual competency framework. Ismail et al. (2026) reviewed 20 empirical studies on factors influencing the digital competencies of vocational teachers and reported training as perhaps the strongest factor.

Five reviews are the most relevant to this review (Du & Kushairi, 2026; Ismail et al., 2026; Lahn & Berntsen, 2023; Mohd Rokeman et al., 2024; Purnama et al., 2026).

Relevant Previous Studies

No	Authors/ Year	Title	Aim	Method	Results	Contribution and relevance
1	Du & Kushairi (2026)	Digital literacy competencies for TVET educators in the age of artificial intelligence: A systematic review and contextual competency framework	To identify, synthesise, and categorise the competencies TVET educators need in the AI era and to propose a competency framework	Systematic review following PRISMA 2020 in Scopus, Web of Science, ERIC, and ProQuest with backward snowballing, 27 empirical and conceptual studies	Educators need a multidimensional competency set, including AI pedagogical application, ethical and social awareness, technical knowledge and operation, and professional attributes. General frameworks	Closest review on AI. The framework is conceptual and not yet validated, education level is not reported, no formal quality appraisal is reported, and Industry 5.0 is not addressed



					lacked industry specificity and ethical depth. A modular framework was proposed	
2	Ismail et al. (2026)	Factors influencing vocational education teachers' digital competencies: A systematic literature review	To examine factors influencing the digital competencies of teachers in higher vocational colleges, with attention to professional development	Systematic review in Scopus, Web of Science, and CNKI, 20 empirical studies, quality appraised with the MMAT by two reviewers	Nine factors were identified, including training, self-efficacy, attitudes, age, frequency of tool use, infrastructure, teacher background, workload, and gender. Training was described as perhaps the strongest factor	Closest review on determinants and training. Studies of several education levels are included without reporting level per study, and attainment levels and AI are not examined
3	Purnama et al. (2026)	Digital competence of vocational teachers in the industrial era 4.0: Literature analysis with the PRISMA approach	To review research on vocational teachers' digital competence	Systematic review following PRISMA, Google Scholar and manual reference search, 2019 to 2025, 10 articles	Teachers recognised the need for digital skills but faced limited device access, few training opportunities, and weak institutional support. Digital pedagogy, educational technology use, and digital content creation were most emphasised	Closest review in the Indonesian context. One database (Google Scholar), education level not specified, AI mentioned only in passing, Industry 5.0 not addressed
4	Mohd Rokeman et al. (2024)	Navigating digital competence in TVET education: Overcoming challenges and harnessing opportunities for Industry 4.0	To address the knowledge gap on challenges to digital competence in TVET and strategies to overcome them	Scoping review with thematic analysis following PRISMA, Scopus and Google Scholar, 2020 to 2024, 16 studies	Two themes were identified, challenges and strategies to overcome them. Continuing professional development and regular training were recommended	Mixes TVET, college, and higher education settings. AI appears in one included study, no quality appraisal
5	Lahn & Berntsen (2023)	Frameworking vocational teachers' digital competencies: An integrative literature review and synthesis	To ask whether leading frameworks (TPACK, DigCompEdu, and professional digital competence) fit vocational teachers	Integrative review in Web of Science, Scopus, ERIC, SSCI, and VOCED+, last 15 years, 145 publications screened, 48 full texts, 15 core studies	Studies had a narrow focus on technical skills and gave little attention to school-work connection, subject specificity, and adaptive pedagogy. A middle-range framework was proposed	Framework-focused. Education level not coded, AI not addressed, no formal quality appraisal

Taken together, these reviews did not restrict their evidence to secondary vocational teachers, and none placed the evidence in the transition to Industry 5.0. Only Du and Kushairi (2026) centre AI, and they catalogue the competencies required and propose a conceptual framework that has yet to be validated. Three limitations follow. First, little is known about secondary vocational teachers, whose subject matter is tied to industry. Second, the vocational studies use different frameworks and instruments, so it is unclear which dimensions of competence are measured, how, and at what level. Third, what raises teachers' competence remains open. Professional development improves teaching in ways that depend on programme design (Kennedy, 2016), and it is not clear how far this has been tested for digital and AI competence among vocational teachers. The four questions are linked: the framework chosen determines what is measured, what is measured determines which levels and determinants can be compared, and the determinants indicate where professional development should act. A single synthesis of all four is therefore more informative than separate reviews of each. The novelty of this review lies in restricting the evidence to empirical studies of secondary vocational teachers, in bringing frameworks, measurement, determinants, and professional development into one appraised synthesis, and in examining how far the evidence addresses AI competence and the transition to Industry 5.0.

This systematic literature review synthesises empirical studies from 2019 to 2026 on the digital and AI competencies of secondary vocational teachers. RQ1 asks which digital and AI competence frameworks are used and which dimensions are operationalised. RQ2 asks how competence is measured and what levels of attainment are reported. RQ3 asks which barriers and enablers are reported as influencing competence. RQ4 asks which forms of professional development are reported and in which direction they affect teacher competence. The review offers a transparent map of what is known and what is not, and it identifies where research and teacher-development policy should concentrate.

RESEARCH METHOD

This systematic literature review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 (Page et al., 2021) and PRISMA-S for searches (Rethlefsen et al., 2021). A written protocol fixed the four research questions (RQ1 to RQ4), the eligibility criteria, and the synthesis plan. It was not prospectively registered.

Search Strategy and Eligibility Criteria

Search. One Scopus Advanced Search string was applied to TITLE-ABS-KEY. Blocks were joined with AND (Table 1).

Table 1. Scopus Search String

Block	Terms (joined with OR)
Teachers	teacher* OR instructor* OR educator* OR "teaching staff"
Setting	"vocational high school*" OR "vocational secondary" OR "vocational secondary" OR "upper vocational secondary" OR "vocational upper secondary" OR "vocational school*" OR "technical and vocational" OR "technical vocational" OR TVET OR "vocational education"
Phenomenon	"digital competenc*" OR "digital literacy" OR "digital skill*" OR "digital capabilit*" OR "digital proficienc*" OR "ICT competenc*" OR "technological pedagogical content knowledge" OR TPACK OR DigCompEdu OR "AI literacy" OR "AI competenc*" OR "artificial intelligence" OR "generative AI" OR ChatGPT
Context	"Industry 4.0" OR "Industry 5.0" OR "Industrie 4.0" OR "Fourth Industrial Revolution" OR "Industrial Revolution 4.0" OR "digital transformation" OR digitalization OR digitalisation
Limits (joined with AND)	PUBYEAR > 2018 AND PUBYEAR < 2027 AND DOCTYPE(ar) AND SRCTYPE(j) AND LANGUAGE(english)

Screening. Table 2 summarises the criteria. At title and abstract stage, records were coded Yes, Partial, Unclear, or No on four criteria (design, population, focus, context), and a fixed rule produced a binary outcome. An unclear education level passed to full text. At full-text stage, seven criteria (FT1 to FT7) were applied with one primary exclusion reason. Education level was judged only from statements in the full text, never from affiliations or programme names.

Table 2. Eligibility criteria

Criterion	Inclusion	Exclusion
Document	Peer-reviewed journal article indexed in Scopus	Review, editorial, or conceptual paper without data
Population	Teachers or instructors in vocational secondary schools. Mixed samples if secondary data were separable or secondary teachers were at least 50% (team-set threshold)	Only lecturers, students, or pre-service teachers; level not determinable
Focus	Teachers' digital or AI competence as a main variable or theme in the results	Competence only as background or recommendation
Context	Digital transformation of vocational education or Industry 4.0 and 5.0	No digital or industrial context
Design	Empirical study with data extractable for at least one research question	Full text not obtainable

Extraction and appraisal. A standardised form captured study characteristics, education-level evidence, framework, instrument and scale, results per research question, and professional development features. Unreported items were coded as not reported, never inferred. Quality was appraised with the Mixed Methods Appraisal Tool (MMAT) 2018 (Hong et al., 2018) using the five criteria of the relevant design category. The score counts criteria rated Yes (0 to 5), and Can't tell was not counted as Yes. Quality informed sensitivity analysis and certainty ratings, not eligibility.

Data Collection

The search was run once on 1 September 2026. Records were exported as CSV and RIS files and left unedited. The yield of 61 records was below the pre-specified broadening threshold of 100, but it was judged sufficient, so the string was not modified. Only Scopus was searched, no independent validation set tested the string, and citation searching was not performed. Duplicates were checked by identifier, DOI, title, and abstract similarity. Two reviewers (R1 and R2) screened all records independently, and a third (R3) resolved disagreements with the same criteria. All three roles were performed by an AI language model (Claude, Anthropic) following identical written instructions under the lead author's direction, and the lead author could override any decision. R1 and R2 agreement was quantified with percentage agreement and Cohen's kappa (Cohen, 1960), interpreted with Landis and Koch (1977) benchmarks and a working threshold of 0.60. Every evidence excerpt behind a full-text decision was checked automatically against the converted full text. Two authors (YH and RR) then verified, each deciding individually, all 21 full-text decisions, the six reviewer conflicts, and a stratified random sample of 20 of the 40 title-abstract exclusions (random seed 2026). Both verifiers agreed with each other on every record (Cohen's kappa = 1.00 for the 21 full-text decisions). Title-abstract exclusions outside the sample, data extraction, and theme coding were not verified by humans. Figure 1 shows the selection flow.

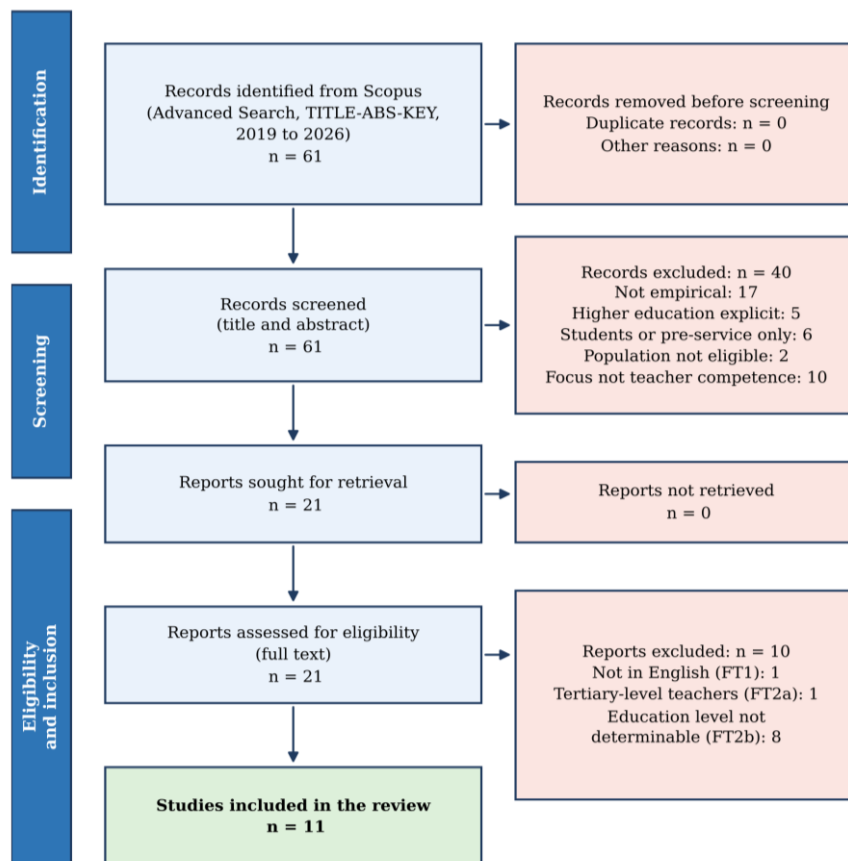


Figure 1. PRISMA 2020 flow diagram of study selection

One reviewer role extracted data from the full texts, and key numerical values (sample sizes, means, coefficients, reliability, response rates) were checked automatically against the text for every included study. Two reviewer roles appraised quality independently and settled disagreements by consensus.

Data Analysis

Meta-analysis was not planned because instruments, scales, and constructs differed. Synthesis followed the Synthesis Without Meta-analysis (SWiM) guideline (Campbell et al., 2020). For RQ1, studies were grouped by framework and frequencies and dimensions tabulated. For RQ2, instruments and reported means were tabulated. To compare attainment across scales, the scale position was computed as $(\text{mean} - 1) / (\text{maximum} - 1)$, assuming each scale starts at 1. This is an indicative reviewer calculation, neither pooled nor author-reported. For RQ3, thematic synthesis (Thomas & Harden, 2008) used inductive codes from the results sections. Only empirical results were counted, not authors' interpretations. Studies treating competence as a predictor were analysed apart from studies of its determinants, and pooled samples without separable secondary data were flagged. For RQ4, context, intervention, mechanism, and outcome were tabulated following CIMO logic (Denyer et al., 2008). One reviewer role coded the themes. Certainty was rated qualitatively from the number of studies, consistency, and MMAT scores, without the full Grading of Recommendations Assessment, Development and Evaluation (GRADE) procedure. Two sensitivity analyses excluded studies flagged for borderline eligibility during full-text screening and restricted the synthesis to MMAT scores of 3 or more. Counts and agreement were computed in Python 3.10. The review used published literature only, so ethical approval was not required.

RESULTS AND DISCUSSION

Research Results

Study selection and reviewer agreement

Figure 1 presents the flow of records. The Scopus search returned 61 records, and no duplicates were found. At the title and abstract stage, R1 and R2 agreed on 58 of 61 records (95.1%, $\kappa = 0.895$, almost perfect agreement; Landis & Koch, 1977). R1 included 21 records and R2 included 24, and R3 excluded all three disputed records. Of the 21 reports assessed in full text, R1 and R2 agreed on 18 (85.7%, $\kappa = 0.717$, substantial agreement). The three disagreements all concerned whether digital competence was a main variable in the results, and R3 included all three. Ten reports were excluded at full text. One was not written in English, one sampled teachers in tertiary education, and eight did not state the education level of their teachers in the text. Two of these eight evaluated professional development interventions. Eleven studies were included.

Characteristics and quality of included studies

The 11 studies were published between 2022 and 2026 (2022, $n = 1$; 2023, $n = 1$; 2024, $n = 3$; 2025, $n = 2$; 2026, $n = 4$). Four were conducted in Indonesia, two in Malaysia, and one each in China, Switzerland, Sweden, South Africa, and the Czech Republic. Eight were quantitative surveys, two were qualitative, and one used mixed methods. Samples ranged from 6 to 2,514 teachers. Six studies placed their work explicitly in Industry 4.0, and five framed it as digital transformation or digitalisation without that term. Teachers worked in vocational high schools or equivalent upper secondary vocational settings. Technical and non-technical subjects were both represented, for example 55% technical teachers in Idrus et al. (2026) and ten productive subject areas in Widaningsih et al. (2025b). Table 3 summarises each study.

Table 3. Characteristics of the included studies

Study	Country	Design	Teachers (n)	Competence framework	MMAT (0 to 5)
Berková et al. (2024)	Czech Republic	Cross-sectional survey	147	None operationalised	2
Dayi et al. (2026)	South Africa	Qualitative case study, classroom observation	6	TPACK	2
Idrus et al. (2026)	Indonesia	Cross-sectional survey, PLS-SEM	200	DigCompEdu-based items within UTAUT	5
Noor et al. (2024)	Malaysia	Descriptive survey	66	TPACK	4
Rauseo et al. (2023)	Switzerland	Two cross-sectional surveys	1,739	DigCompEdu-based items	1
Salleh et al. (2022)	Malaysia	Cross-sectional survey	187 (secondary subgroup of 388)	TPACK	2
Widaningsih et al. (2025a)	Indonesia	Mixed methods, survey and focus group	209 (survey), 12 (focus group)	AQF-based	1
Widaningsih et al. (2025b)	Indonesia	Descriptive survey	356	KKNI technical competence	1
Willermark & Carlsson (2026)	Sweden	Qualitative, written reflection and group discussion	15	TPACK plus contextual knowledge	5
Xin et al. (2024)	China	Scale development, cross-sectional survey	2,514 (secondary subgroup 386)	Own five-domain model	2
Zaenudin et al. (2026)	Indonesia	Cross-sectional survey, PLS-SEM	182	Not reported	1

Note. AQF = Australian Qualifications Framework; KKNI = Indonesian National Qualifications Framework; MMAT = Mixed Methods Appraisal Tool.

MMAT scores ranged from 1 to 5 (median 2). Only Idrus et al. (2026), Willermark and Carlsson (2026), and Noor et al. (2024) scored 3 or higher. Most missing points were ratings of Can't tell, mainly because sampling frames, response rates, or measurement validity were not reported. Reviewers agreed on 46 of 55 ratings (83.6%, $\kappa = 0.676$, substantial agreement), and disagreements were settled by consensus. Two studies sampled several education levels and reported secondary-level data separately (Salleh et al., 2022; Xin et al., 2024). Their findings on determinants and professional development come from pooled samples and are flagged below. Where text and table disagreed, we report 388 teachers for Salleh et al. (2022), which is consistent with the reported degrees of freedom, and 209 survey respondents for Widaningsih et al. (2025a), which is the text value (the table gives 210).

Competence frameworks and dimensions

No single framework dominated. TPACK was the most frequent, used by four studies (Dayi et al., 2026; Noor et al., 2024; Salleh et al., 2022; Willermark & Carlsson, 2026), but these operationalised it differently. Noor et al. (2024) measured only technological knowledge, technological content knowledge, technological pedagogical knowledge, and TPACK in the use of one platform (Google Classroom), and acknowledged that content, pedagogical, and pedagogical content knowledge were not measured. Salleh et al. (2022) measured technological, content, and pedagogical knowledge together with TPACK. Dayi et al. (2026) observed all components in programmable logic controller lessons. Willermark and Carlsson (2026) extended TPACK with contextual knowledge for generative AI.

Two studies built their instruments on DigCompEdu items (Idrus et al., 2026; Rauseo et al., 2023). Idrus et al. (2026) covered the use of applications, instructional design, critical evaluation, ethics and data security, and platform selection. Two studies used their own or a foreign qualification framework. Xin et al. (2024) proposed five domains, namely digital mindset and attitude, knowledge and skills, digital education and teaching, digital care and support, and digital collaboration and development. This was the only model that included affective and collaborative dimensions. Widaningsih et al. (2025a) drew on the Australian Qualifications Framework. Widaningsih et al. (2025b) mapped training access against Indonesian technical competence units rather than a digital competence framework. Berková et al. (2024) and Zaenudin et al. (2026) did not operationalise a standard framework. The former recorded the use of digital tools, and the latter described competence conceptually as knowledge, skills, and attitudes.

Using technology in teaching and pedagogical design appeared in seven studies (Dayi et al., 2026; Idrus et al., 2026; Noor et al., 2024; Salleh et al., 2022; Widaningsih et al., 2025a; Willermark & Carlsson, 2026; Xin et al., 2024). Ethics and data protection appeared explicitly in four (Idrus et al., 2026; Rauseo et al., 2023; Willermark & Carlsson, 2026; Xin et al., 2024). Only Willermark and Carlsson (2026) made AI the focus of competence. No framework for AI competence of secondary vocational teachers was found in the other ten studies.

Measurement and attainment

Seven studies measured competence by self-assessment on Likert scales: five or six points in Noor et al. (2024), Idrus et al. (2026), Widaningsih et al. (2025a), Xin et al. (2024), and Rauseo et al. (2023), and scale length not reported in Salleh et al. (2022) and Zaenudin et al. (2026). Widaningsih et al. (2025b) and Berková et al. (2024) used dichotomous items on training access and tool use. Dayi et al. (2026) used classroom observation, and Willermark and Carlsson (2026) used written reflections and group discussion. No study used a performance-based competence test. Xin et al. (2024), Rauseo et al. (2023), and Idrus et al. (2026) acknowledged

the limits of self-assessment. Reliability was reported for six instruments. Cronbach's alpha ranged from 0.897 to 0.957 across the TPACK constructs of Noor et al. (2024) and was 0.988 for the 51-item scale of Xin et al. (2024), 0.883 for digital literacy in Idrus et al. (2026), 0.909 for digital competency in Zaenudin et al. (2026), 0.98 in Widaningsih et al. (2025a), and 0.758 in Berková et al. (2024). Salleh et al. (2022) and Widaningsih et al. (2025b) did not report reliability.

Table 4 lists the studies that reported a score or an equivalent summary. To compare scales, the reviewers calculated each mean's position as $(\text{mean} - 1) / (\text{maximum} - 1)$. These figures are indicative and are not results reported by the authors.

Table 4. Reported attainment of digital competence

Study	Instrument	Reported result	Scale position (reviewer calculation)
Noor et al. (2024)	Self-report, 5-point	M = 3.29 (SD = 0.82), categorised moderate	57%
Rauseo et al. (2023)	Self-report, 6-point	Teachers M = 3.82 (SD = 0.86); school management M = 3.58 (SD = 0.69), d = 0.278	56% (teachers)
Xin et al. (2024), secondary subgroup	Self-report, 6-point, 51 items	M = 4.48 (SD = 1.01), n = 386, highest of three institution types	70%
Xin et al. (2024), national sample	Self-report, 6-point, 51 items	M = 4.19 (SD = 0.756), n = 2,514, judged moderate to low	64%
Salleh et al. (2022), secondary subgroup	TPACK scale, points not reported	TPACK M = 3.82 (SD = 0.366); technological knowledge M = 3.64	Not calculable
Widaningsih et al. (2025a)	Self-report, 5-point	More than 70% of productive teachers judged insufficient	Not calculable
Widaningsih et al. (2025b)	Yes or no training access	Mean access to technical training 32.4% of 130 units	Not applicable

Among the four studies with calculable means, positions ranged from 56% to 70% of the scale. The lowest component in Noor et al. (2024) was technological content knowledge (TCK, M = 3.22), and the highest was technological knowledge (M = 3.39). In Salleh et al. (2022), secondary-school teachers scored lower than Vocational College teachers on technological knowledge (M = 3.64 vs. 3.82, $t = 3.984$, $p < .001$) and on TPACK (M = 3.82 vs. 3.92, $t = 2.563$, $p = .011$). In Xin et al. (2024), secondary TVET school teachers scored highest among the three institution types. Widaningsih et al. (2025b) stated that digital competence had the lowest attainment among the competences studied but reported no separate figure. Berková et al. (2024) found that basic Microsoft Teams functions were used by 54.4% of teachers, polling tools by 37.4%, and Moodle by 12.9%. Only 16.3% (24 of 147) cited a lack of teachers' digital competence as a reason for not using tools. Rauseo et al. (2023) also reported that teachers rated their school's stage of digital transformation at M = 4.32 (SD = 1.05) and management at M = 4.09 (SD = 0.93). Idrus et al. (2026) and Zaenudin et al. (2026) reported no descriptive scores.

Determinants of competence and its role as a predictor

Competence as a predictor. Digital competence was the independent variable in three studies. In Rauseo et al. (2023), it predicted perceived progress in school digital transformation ($\beta = 0.071$, $p = .001$ in the teacher model; $\beta = 0.180$, $p = .035$ in the management model). In Zaenudin et al. (2026) it predicted digital transformation ($\beta = 0.194$, $p = .015$) and organisational commitment ($\beta = 0.301$, $p < .001$), and commitment partly mediated the effect. In Idrus et al. (2026), digital literacy predicted performance expectancy ($\beta = 0.650$), effort expectancy ($\beta = 0.686$), social influence ($\beta = 0.553$), facilitating conditions ($\beta = 0.624$), and perceived training ($\beta = 0.577$), all $p < .001$. Performance expectancy ($\beta = 0.349$, $p = .005$) and

effort expectancy ($\beta = 0.319$, $p = .011$) predicted intention. In the Rauseo et al. (2023) teacher model ($R^2 = 0.509$), the coefficient for digital competence was smaller than those for strategy and leadership ($\beta = 0.483$), equipment and technology ($\beta = 0.319$), and culture ($\beta = 0.099$). In Zaenudin et al. (2026), innovation culture ($\beta = 0.280$, $p = .001$) and organisational commitment ($\beta = 0.459$) also predicted digital transformation ($R^2 = 0.668$). In Idrus et al. (2026), social influence ($\beta = 0.180$, $p = .133$) and facilitating conditions ($\beta = 0.137$, $p = .342$) did not predict intention. All three studies reported positive associations for digital competence.

Determinants and barriers. Table 5 groups the factors reported in results sections. Authors' untested interpretations (Noor et al., 2024; Widaningsih et al., 2025b) were not counted.

Table 5. Themes on determinants and barriers, with certainty of evidence

Theme	Studies	Direction and nature of evidence	Certainty
Competence as predictor	Idrus et al. (2026); Rauseo et al. (2023); Zaenudin et al. (2026)	Positive, tested, consistent	Low
School environment and support	Salleh et al. (2022); Xin et al. (2024)	Positive, tested, pooled samples	Very low
Training and mentoring	Salleh et al. (2022); Xin et al. (2024)	Positive, tested, pooled samples	Very low
Teacher characteristics	Berková et al. (2024); Xin et al. (2024)	Mixed, tested	Very low
Infrastructure and equipment	Berková et al. (2024); Dayi et al. (2026); Widaningsih et al. (2025a)	Barrier reported or observed, not tested against competence	Very low
Fit of tools to subject and time	Berková et al. (2024)	Barrier reported by teachers	Very low
Ethics, authenticity, attitudes	Willermark & Carlsson (2026)	Qualitative	Very low

School environment and mentoring explained 49% of variance in TPACK in the pooled sample of Salleh et al. (2022) (school environment $\beta = 0.570$; mentoring $\beta = 0.209$; $F(2, 385) = 185.169$, $p < .001$). In Xin et al. (2024), higher scores were associated with government and school informatisation training, skills-competition participation, dual qualification, demonstration schools, and the eastern region. Lower scores were associated with no training, higher education level, 5 to 10 years of experience (a U-shaped pattern), and the central and western regions. Gender had no effect. In Berková et al. (2024), tool use declined with age (polling, $V = 0.348$, $p < .001$) and subject area affected polling ($V = 0.365$, $p < .001$). Women were more likely not to use Moodle ($OR = 4.492$, $p = .002$) and more often cited a lack of digital competence as a reason for not using tools ($p = .049$, $\phi = 0.152$). Among the barriers teachers were asked about, the lack of digital competence was therefore a minor reason overall but differed by gender. Teachers most often gave tool-subject mismatch (72.8%), lack of time (53.7%), and insufficient technical equipment (29.3%) as reasons for not using tools. Dayi et al. (2026) observed lessons without digital tools or simulations and learners without access to programmable logic controller trainers. Focus group participants in Widaningsih et al. (2025a) named infrastructure, learner readiness, individual barriers, and the absence of a national digital competence standard. Participants in Willermark and Carlsson (2026) raised student passivity, doubts about the authenticity of student work, dependence on technology, privacy, and the need for new assessment methods. They named hands-on experience and a curious mindset as enablers.

Professional development and direction of effect

No included study evaluated the effect of a professional development intervention on teachers' digital competence. The available evidence is observational or consists of authors' recommendations, as shown in Table 6. The mechanism of professional development was not reported in any study.

Table 6. Professional development evidence by context, form, and outcome

Study	Context	Form of professional development	Outcome and direction
Xin et al. (2024)	Chinese TVET teachers, pooled sample	Government and school training, skills competitions (observed variables)	Higher competence among participants, positive association
Idrus et al. (2026)	Vocational high school teachers, Jambi	Formal ICT training (30% attended in the last 12 months)	Perceived training not directly related to intention ($\beta = -0.056$, $p = .387$), neutral
Salleh et al. (2022)	Malaysian TVET teachers, pooled sample	Mentoring (observed variable)	Positive association with TPACK ($\beta = 0.209$)
Widaningsih et al. (2025b)	Vocational high school teachers, West Java	Government training (19.4% access), self-directed training (13%)	Access low, effect not measured
Widaningsih et al. (2025a)	Vocational high school teachers, West Java	Proposed AQF-based certification and recognition of prior learning	Not implemented or evaluated
Noor et al. (2024); Dayi et al. (2026)	Malaysia; South Africa	Recommended workshops and pedagogical integration training	Not tested

The only effect direction that can be stated is associational. Training and mentoring were positively associated with competence in two pooled-sample studies, and one study found no direct link between perceived training and intention to adopt technology. The form, duration, and content of training were not specified in these studies.

Sensitivity analysis and certainty of evidence

Excluding the four studies flagged for borderline eligibility (Berková et al., 2024; Rauseo et al., 2023; Widaningsih et al., 2025b; Willermark & Carlsson, 2026) left seven studies. The framework pattern held (TPACK, three studies; DigCompEdu-based, one; own or AQF-based, two; none, one), as did the attainment findings and the conclusion on professional development. Competence as a predictor remained positive but rested on two studies. The barrier themes on tool-subject fit, ethics and attitudes, and part of the teacher characteristics theme disappeared, so in the full synthesis the teacher-level barrier evidence depended on Berková et al. (2024). Restricting the synthesis to studies scoring MMAT 3 or higher left three studies, too few for thematic synthesis. It also showed that the training and school environment findings (Salleh et al., 2022; Xin et al., 2024) came from studies scoring 2.

The descriptive finding that no single framework dominates was rated moderate. Certainty was low for the moderate attainment finding and for competence as a predictor, very low for every determinant theme (Table 5), and not assessable for the effect of professional development because no intervention study was included. Evidence on AI competence rested on one study with an MMAT score of 5 and was rated very low because of its size and single context.

Discussion

This review asked what is known about the digital and AI competencies of secondary vocational teachers, and the answer is less than the policy attention to Industry 4.0 and 5.0 would suggest. Eleven studies met the criteria, only three scored above 2 on the MMAT, and the evidence on determinants was rated low or very low. Three problems stand out: the field lacks a shared, vocationally grounded construct, its measurement cannot yet support claims about levels, and it cannot say what improves competence.

Position relative to earlier reviews

Our findings agree with earlier reviews on vocational teachers, with differences of scope. Lahn and Berntsen (2023) found a narrow focus on technical skills and little attention to the link between school and work, which matches our observation that instruments mostly addressed pedagogical or platform uses of technology. Du and Kushairi (2026) concluded that general frameworks lack industry specificity and ethical depth, which is consistent with our finding that few instruments addressed industry-linked practice and that only one study treated AI as a competence domain. Purnama et al. (2026) reported limited device access, few training opportunities, and weak institutional support, and Mohd Rokeman et al. (2024) called for continuing professional development. Ismail et al. (2026) reported training as perhaps the strongest factor in vocational teachers' digital competencies.

Our review differs in four ways. It restricts the evidence to empirical studies of secondary vocational teachers, so the patterns are not borrowed from higher education samples or conceptual papers. It adds frameworks, measurement, and attainment to determinants in one synthesis. It shows that no included study evaluated a professional development intervention, so calls for more training, including the strong role given to training by Ismail et al. (2026), cannot be supported by tested programmes in this corpus. It also finds that competence predicted transformation only weakly compared with leadership and culture, which qualifies an emphasis on individual training. Appraisal also differed. Ismail et al. (2026) rated 18 of their 20 studies as high quality, whereas only three of our 11 scored above 2 on the MMAT, and Salleh et al. (2022), which appears in both reviews, was rated high by them and scored 2 here.

A construct without a vocational anchor

The absence of a dominant framework mirrors the conceptual fragmentation reported for digital competence in higher education research (Spante et al., 2018; Zhao et al., 2021) and in conceptualisations of teachers' professional digital competence (Skantz-Åberg et al., 2022). TPACK was the most frequent lens (Dayi et al., 2026; Noor et al., 2024; Salleh et al., 2022; Willermark & Carlsson, 2026), which is expected given its long empirical record (Willermark, 2018). Its use was nevertheless partial. Noor et al. (2024) measured four of the seven components and tied them to one learning management system, so the construct captured is a tool-specific proficiency rather than a professional capability. Frameworks that insist on competence beyond technical skill, such as the teacher digital competency framework (Falloon, 2020) or DigCompEdu-based instruments (Cabero-Almenara et al., 2020), were rarely operationalised in full, and only Xin et al. (2024) included affective and collaborative domains.

What the frameworks omitted is equally telling. Six studies invoked Industry 4.0 as context, yet the reported instruments mostly addressed pedagogical or platform uses of technology, such as Google Classroom or polling tools (Berková et al., 2024; Noor et al., 2024). Few, if any, addressed the industry-linked digital practices that vocational curricula prepare students for. Industry 4.0 and 5.0 therefore appear to function as context rather than as defining elements of the constructs measured. A vocationally anchored framework would need to join pedagogical digital competence with occupational digital practice, a combination likely to depend on national vocational arrangements (Li & Pilz, 2023; Suharno et al., 2020).

The AI gap is sharper. Only Willermark and Carlsson (2026) treated generative AI as a competence domain, extending TPACK with contextual knowledge. This is consistent with calls to revisit TPACK for generative AI (Mishra et al., 2023) and with the ethical emphasis of Intelligent-TPACK (Celik, 2023). Frameworks for AI literacy and teachers' AI competence now exist (Chiu et al., 2024; Ng et al., 2021, 2023), but none of the other ten studies used them. The concerns raised by Willermark and Carlsson's (2026) participants about authenticity, student

passivity, and assessment echo analyses of the opportunities and risks of large language models (Kasneci et al., 2023). Research on AI in higher education has been criticised for giving little voice to educators (Zawacki-Richter et al., 2019) and for treating adoption as politically neutral (Selwyn, 2022). A typology of AI systems makes their pedagogical assumptions explicit (Holmes & Tuomi, 2022), which is the kind of knowledge teachers need to evaluate such tools. Competence claims about AI for vocational teachers therefore rest on one qualitative study of 15 participants, and the Industry 5.0 framing currently outruns the evidence.

Levels of competence cannot yet be compared

The moderate attainment reported here is better read as a property of measurement than of teachers. Every score-based study relied on self-assessment, and categories were author-defined, for example 2.34 to 3.67 labelled moderate on a five-point scale in Noor et al. (2024). Our own scale positions of 56% to 70% rest on the assumption that scales start at 1. Self-assessed competence overlaps conceptually with self-efficacy, which has been studied as a related but distinct construct (Hatlevik, 2017), and DigCompEdu-based self-assessment tools have been validated in specific samples (Cabero-Almenara et al., 2020). Because digital competence is related jointly to personal and contextual factors (Lucas et al., 2021), a single mean without context is hard to interpret.

The contrast between Xin et al. (2024) and Salleh et al. (2022) illustrates the problem. In the first, secondary school teachers rated themselves highest among three institution types. In the second, they scored lower than vocational college teachers on technological knowledge. The two studies used different instruments and national systems and recruited differently, online without a sampling frame in Xin et al. (2024) and by drop-and-pick in Salleh et al. (2022). Moreover, about 85% of Xin et al.'s sample came from higher education, so the secondary subgroup ($n = 386$) is a small minority. The data do not permit a claim that secondary teachers are stronger or weaker than tertiary peers. An additional concern is construct validity. Competence limited to technical skill misses the ethical, safe, and productive use that Falloon (2020) emphasises, so high scores on tool-use items may overstate competence as professionally defined.

Competence alone is not sufficient

Digital competence predicted school digital transformation or adoption intention in all three studies that tested it, but the effects were small relative to organisational factors. In Rauseo et al. (2023), the coefficient for digital competence ($\beta = 0.071$) was far smaller than that for strategy and leadership ($\beta = 0.483$). In Zaenudin et al. (2026), innovation culture and organisational commitment carried larger weights than competence. This agrees with evidence that digital learning in schools depends on conditions beyond technology itself (Sailer et al., 2021). In Idrus et al. (2026), digital literacy acted mainly through performance and effort expectancy, in line with the technology acceptance tradition (Scherer et al., 2019) and with the role of attitudes in pre-service teachers' TPACK (Scherer et al., 2018). The assumption that raising competence alone will drive digital transformation therefore finds weak support.

Two cautions apply. First, all tests were cross-sectional, so competent teachers may simply perceive transformation more favourably, and the studies rarely modelled nesting. Multilevel designs, as used in research on teacher education (Tondeur et al., 2018), would suit pooled samples such as those of Xin et al. (2024) and Salleh et al. (2022). Second, the barrier evidence is inconsistent. Infrastructure was reported as a barrier in three studies, yet in Berková et al. (2024) most teachers judged equipment sufficient, only 16.3% cited insufficient competence, and the leading reason for non-use was a mismatch between tools and subject

(72.8%). This pattern suggests a pedagogical fit problem rather than a hardware or competence deficit, which accords with the logic of TPACK itself (Willermark, 2018) but remains a hypothesis because Berková et al. (2024) did not test it.

Professional development, an evidence gap

The most consequential gap concerns professional development. No study evaluated an intervention, and the variables available record participation, for example 30% trained in the previous year in Idrus et al. (2026), rather than design features. Participation is a weak proxy. Kennedy (2016) showed in a review of rigorous studies that popular design features were not systematically associated with effectiveness, and that programmes differed in their theories of how teachers learn and in the pedagogies supporting enactment. Judged against this standard, the positive associations in Xin et al. (2024) and Salleh et al. (2022) and the null link between perceived training and intention in Idrus et al. (2026) cannot be interpreted in terms of programme design. They concern different outcomes, competence versus intention, and none specifies what training was delivered. Reviews of digital competence for teacher professional development (Fernández-Batanero et al., 2022) and of teacher preparation for the digital age (Starkey, 2020), together with work on integrating professional digital competence into initial teacher education (Instefjord & Munthe, 2017), show that these questions are being studied in general education. Equivalent evidence for secondary vocational teachers is missing from our corpus.

The selection process yielded a related finding. Eight reports, two of them intervention studies, were excluded because the education level was not stated. In vocational research this is not a technicality. Labels such as vocational college and TVET are used across educational levels, and poor reporting of level may hide relevant intervention evidence.

Implications

Theoretically, a framework for secondary vocational teachers should integrate pedagogical digital competence, occupational digital practice, and AI literacy including ethics (Chiu et al., 2024; Falloon, 2020). Methodologically, studies should pair self-assessment with observed or performance evidence, report education level and sampling frames, and use designs suited to nested data. Practically, because competence effects were small relative to leadership and culture, training that targets individuals without strategic and organisational support is unlikely to be sufficient, although this inference rests on associations only.

Limitations

Several limitations qualify these conclusions. The search used one database and English-language articles. Retrieval quality differs widely among academic search systems (Gusenbauer & Haddaway, 2020). The search yield was small, no validation set was used, and citation searching was not performed, so relevant studies in other indexes or languages may be missing. Methodological quality was low in most included studies. Screening, extraction, and theme coding were performed by an AI model, so the reviewer roles were not independent humans. Two authors verified the full-text decisions, the reviewer conflicts, and a sample of 20 of the 40 title-abstract exclusions, but the remaining exclusions, the extraction, and the theme coding were not verified by humans. Evidence on large language models in review tasks shows that accuracy can fall once chance agreement and class imbalance are accounted for, and that performance varies across stages (Khraisha et al., 2024). Machine-learning-aided screening tools keep a human reviewer in the loop and report transparently (van de Schoot et al., 2021). The high agreement between our reviewer roles thus reflects the consistency of one system

under shared instructions more than independent judgement. Future updates should add independent human screening of all records and human verification of extraction and coding. Finally, the rule that education level must be determinable from the text ties each inclusion to stated evidence but excluded eight reports, and the sensitivity analyses show that the barrier themes depend on few studies.

CONCLUSION

This review shows that evidence on the digital and AI competencies of secondary vocational teachers is thin, fragmented, and of limited quality. No vocationally anchored framework has emerged. The instruments used mostly capture pedagogical and platform use of technology rather than industry-linked digital practice, and only one study treated AI as a competence domain. Reported levels of competence rest on self-assessment with author-defined categories, and they therefore cannot be compared across studies or education levels.

Where associations were tested, digital competence predicted school-level digital transformation or adoption, but its effect was small relative to leadership, strategy, and innovation culture. No study evaluated a professional development intervention, so the review cannot say what raises competence. Industry 4.0 and 5.0 currently serve as context for this research rather than as defining elements of the competence measured. These conclusions are bounded by reliance on a single database and by screening and coding performed by an AI model without full human verification.

Three priorities follow. Researchers should develop and validate a framework that joins pedagogical competence, occupational digital practice, and AI literacy including ethics, and should measure it with performance evidence as well as self-report. Primary studies should state the education level and sampling frame and use designs suited to nested data. Evaluations of professional development should specify content, duration, and enactment, use pre-post or comparative designs, and examine school leadership and organisational conditions alongside individual training.

The novelty of this study lies in its critical synthesis of digital and artificial intelligence (AI) competencies among secondary vocational teachers in the transition toward Industry 5.0, integrating four analytical dimensions: competency frameworks, measurement approaches and competency attainment, determinants of competence, and professional development. Unlike previous studies that predominantly examine general digital competence or partially adopt technology-pedagogy frameworks, this study systematically identifies conceptual and methodological gaps in the existing literature through a PRISMA 2020-guided synthesis of 11 empirical studies. The findings reveal the absence of a comprehensive, vocationally oriented competency framework that integrates pedagogical competence, occupation-specific digital practices, and AI literacy within the human-centric, sustainable, and resilient paradigm of Industry 5.0. Furthermore, the dominance of self-reported assessments, the limited empirical coverage of generative AI, and the absence of evaluated professional development interventions highlight critical limitations in the assessment and advancement of teachers' competencies. Accordingly, this study advances the field beyond descriptive evidence mapping by establishing an integrated research agenda for developing and validating performance-based competency frameworks tailored to vocational education and for evaluating evidence-based professional development interventions using rigorous comparative designs. This contribution provides a conceptual and methodological foundation for aligning vocational teachers' digital and AI competencies with the evolving demands of human-centric industrial transformation.

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Author Contribution

RR: conceptualisation, protocol, search strategy, direction of AI-assisted screening, extraction and synthesis, and writing of the original draft. YH and ES: supervision, validation, and review and editing.

AI Disclosure

The authors used Claude (Anthropic) during the preparation of this work for screening of records, data extraction, quality appraisal, thematic coding, verification of references, and drafting and language editing of the manuscript, all under the direction of the lead author. After using the tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication. The use of AI in screening, extraction, and coding, and the absence of full independent human verification, are described in the Research Method and Discussion sections.

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