

DIGITAL TECHNOLOGIES IN VOCATIONAL EDUCATION: FROM TECHNOLOGY ADOPTION TO SOCIO-TECHNICAL TRANSFORMATION

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Abstract

In response to rapid digitalisation, vocational education has increasingly integrated digital technologies such as artificial intelligence (AI) and information and communication technologies (ICT), changing how skills are taught and developed. Although research in this area has grown rapidly, the field still lacks a clear overview of its knowledge structure, major themes, and emerging directions. To address this gap, this study aims to map the knowledge structure, thematic patterns, and emerging directions of research on digital technologies in vocational education. It analyses 203 articles retrieved from the Web of Science (WoS) Core Collection for the period 2021–2025, following a PRISMA-guided screening procedure. Using VOSviewer and CiteSpace, the study conducted performance analysis, bibliographic coupling, keyword co-occurrence analysis, and burst detection to identify publication patterns, thematic clusters, and research frontiers. The findings reveal four major directions of inquiry: learner empowerment and sustainability, teacher digital competence, institutional innovation, and policy-oriented skill development in the context of Industry 4.0. Burst detection further suggests an emerging movement in research attention from technology-focused adoption toward more human-centred, pedagogical, and governance-related perspectives. Overall, the study contributes to the field by clarifying both the intellectual structure and the changing priorities of research on digital transformation in vocational education. It also advances current understanding by showing that digital transformation is increasingly framed not simply as technology adoption, but as a socio-technical process shaped by pedagogy, governance, inclusion, and ethical responsibility.

Keywords: digital transformation, vocational education, bibliometric analysis, digital competence, industry 4.0

Introduction

Vocational education is increasingly expected to prepare learners for workplaces shaped by digital tools, data-based processes, and changing skill requirements. These changes have made digital transformation a major concern for vocational education, as institutions need to update teaching practices, strengthen learners' digital competence, and ensure that vocational skills remain relevant to labour market needs (UNESCO, 2021; OECD, 2023). Within this context, digital technologies have attracted growing attention as tools for improving educational quality and supporting skills formation in the era of Industry 4.0. Artificial intelligence (AI) and information and communication technologies (ICT), in particular, have emerged as prominent areas of research and practice in vocational education (Bolaños & Pilerot, 2021; Vilppola et al., 2022).

However, the integration of digital technologies into vocational education is far from straightforward. AI-supported functions such as intelligent tutoring, automated feedback, and predictive analytics often operate alongside more established ICT tools. Together, they can complicate teaching and learning and raise questions about effectiveness, fairness, and accountability. These challenges are further shaped by differences in teachers' digital competence and willingness to adopt technology (Yang et al., 2023). They are also reinforced by the difficulty of applying digital tools in work-based learning settings, which are a core part of vocational education (Enochsson et al., 2021). For vocational education institutions, a key challenge is to ensure that technological innovation remains aligned with evolving skill demands in the context of Industry 4.0 (Albizu & Estensoro, 2024; Aranda et al., 2023). Understanding how digital technologies, particularly AI and ICT, are addressed in vocational education research is therefore essential for supporting forms of digital transformation that are both context-sensitive and socially responsible.

These concerns extend beyond individual institutions or national systems. Across different vocational education contexts, institutions are being asked to respond to similar changes in work, including automation, data use, platform-based employment, and digitally mediated collaboration. At the same time, the ways in which digital transformation is implemented vary according to policy priorities, infrastructure, teacher readiness, institutional capacity, and links with industry. These contextual differences are also reflected in recent studies on AI integration in vocational and technical education, where institutional policy support and teachers' GenAI adoption have been identified as important conditions for technology use (Ayanwale et al., 2025; Cui & Li, 2025). This combination of shared pressures and context-specific conditions gives the topic clear international relevance. It also suggests the need to examine how digital technologies have been studied across vocational education contexts and how recent research in the field appears to be moving from a narrow focus on technology adoption toward a wider concern with socio-technical transformation.

Research in this area has grown rapidly, alongside the broader acceleration of digitalisation agendas in education during the COVID-19 pandemic (Zawacki-Richter, 2021). Existing studies can be broadly grouped into several related areas. One line of research has examined digital pedagogy and the use of technology to support teaching and learning in vocational settings. Another has focused on teachers' digital competence, professional readiness, and technology adoption. A further body of work has considered institutional preparedness, policy support, and the conditions needed for digital transformation in vocational education (Hassan et al., 2021; Jiang et al., 2024). Earlier reviews and conceptual analyses have also provided useful insights into specific areas such as digital literacy development, game-based learning, technology adoption, and teacher professional preparation (Dahalan et al., 2023; Rusa et al., 2023). However, these studies tend to address separate aspects of digital transformation rather than showing how the field as a whole has evolved.

Collectively, the existing literature points to several unresolved issues. The intellectual structure of the field has not yet been clearly established. It remains difficult to see which areas of research have been most influential, how key themes are connected, and which topics are beginning to shape future directions. Existing syntheses have often focused on particular technologies, teaching applications, or policy discussions, with less attention given to the relationships among learners, teachers, institutions, and labour-market needs. A clearer understanding of these relationships is important for international readers and stakeholders, as curriculum reform, teacher development, technology investment, and policy design increasingly depend on how digital transformation is understood across vocational education contexts.

Against this background, this study examines research on digital technologies in vocational education, with particular attention to AI- and ICT-related scholarship. By analysing publication trends, citation impact, thematic connections, and emerging topics, the study identifies the field's structural characteristics, thematic development, and broader socio-technical concerns. The study is guided by three research questions:

RQ1: How have publication trends and citation impact evolved in research on digital technologies in vocational education?

RQ2: How is the intellectual and thematic structure of the field organised across learner, teacher, institutional, and policy levels?

RQ3: Which emerging topics represent current research frontiers?

Research Methodology

General Background

This study adopted a bibliometric research design to analyse research on digital technologies in vocational education, with particular attention to AI and ICT. In this study, digital technologies were treated as a broad concept that included AI- and ICT-related research, which formed the core scope of the search strategy. Bibliometric analysis has become a widely recognized quantitative method for systematically mapping scientific knowledge and tracing how research fields evolve over time (Bo et al., 2025; Donthu et al., 2021). By combining statistical indicators with network visualization, it enables the identification of emerging topics, conceptual developments, and intellectual connections among publications (Morál-Muñoz et al., 2020; Zhou et al., 2026b). In contrast to narrative reviews, this data-driven method generates transparent and visually oriented representations that allow for a more accurate understanding of research structures and their temporal dynamics (Öztürk et al., 2024; Zhou et al., 2026a).

In this study, the method was used to visualize the field's intellectual structure, identify key thematic clusters, and trace research evolution over time. This provided a quantitative basis for understanding the development of the field and for guiding future educational innovation. To ensure a systematic procedure, the study was carried out in four sequential stages: data collection, PRISMA-guided screening, bibliometric analysis and visualization, and interpretation of the results.

Data Collection

The criteria used for data collection are summarised in Table 1. All bibliographic records were retrieved from the Web of Science (WoS) Core Collection. The WoS Core Collection was selected because it provides standardised bibliographic metadata, consistent indexing criteria, and citation information suitable for bibliometric analysis (Zawacki-Richter et al., 2019). Although other databases such as Scopus, ERIC, and Google Scholar are also important sources for education research, the use of a single database helped maintain consistency in

indexing standards, document classification, and citation data. The dataset covered the period from 2021 to 2025, during which digital and intelligent transformation accelerated in the post-COVID-19 context. In this study, vocational education was used as an umbrella term covering vocational education and training (VET), technical and vocational education and training (TVET), technical and vocational education (TVE), and related terms used in different national or regional contexts. Although “career and technical education” (CTE) is more commonly used in North American contexts, it was included in the search strategy to improve retrieval coverage. In the analysis, CTE was treated as a related regional term within the broader field of vocational and technical education, rather than as a separate conceptual boundary. Boolean operators were used to limit the results to peer-reviewed journal articles indexed in SSCI, ESCI, or SCI-Expanded, thereby enhancing the reliability and reproducibility of the dataset. The search process employed the following Boolean query:

TS = ((“digital technology” OR “AI” OR “artificial intelligence” OR “ICT” OR “Information and Communication Technology”) AND (“vocational education” OR “technical and vocational education” OR “technical and vocational education and training” OR “vocational education and training” OR “vocational training” OR “career and technical education” OR “TVET” OR “TVE” OR “VET” OR “CTE”)).

All records were downloaded on January 1, 2026, and the final dataset was subsequently prepared for bibliometric analysis and visualization.

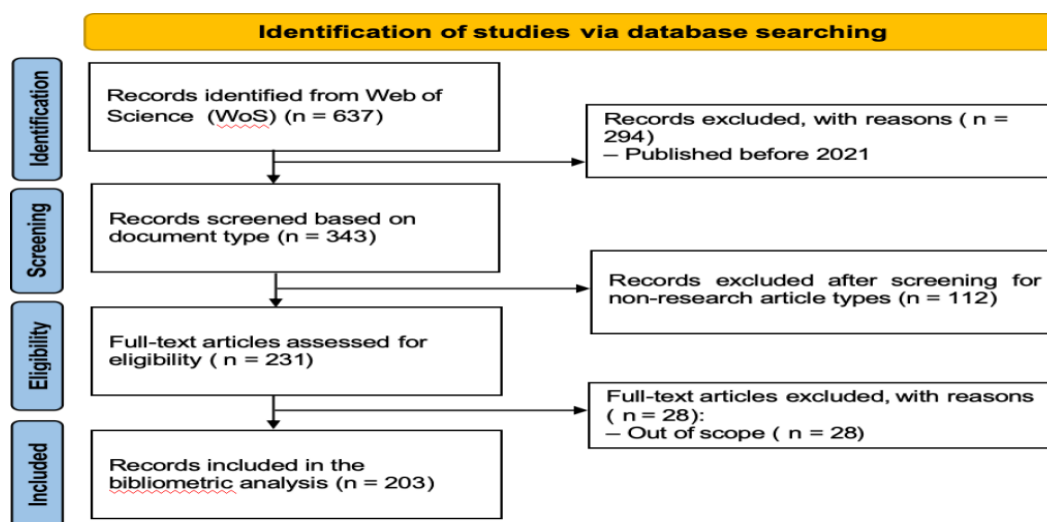
Table 1
Inclusion Criteria for Bibliometric Analysis

WoS Database	Core Collection
Time period	2021 to 2025
Search field	TS
Search keywords	((“digital technology” OR “AI” OR “artificial intelligence” OR “ICT” OR “Information and Communication Technology”) AND (“vocational education” OR “technical and vocational education” OR “technical and vocational education and training” OR “vocational education and training” OR “vocational training” OR “career and technical education” OR “TVET” OR “TVE” OR “VET” OR “CTE”))
Document type	Article
Language	English
WoS Indexes	SSCI / ESCI / SCI-EXPANDED

Instrument and Procedures

The instruments used in this study included the WoS Core Collection for data retrieval and the PRISMA framework for systematic screening and selection. The overall data screening and selection procedure is presented in Figure 1, following the PRISMA stages of identification, screening, eligibility, and inclusion (Page et al., 2021). A total of 637 bibliographic records were initially retrieved from the WoS Core Collection. After applying the publication year filter (2021–2025), 294 records were excluded for falling outside the specified time frame. After this step, 343 records remained for document-type screening. Among these, 112 items, such as editorials, conference papers, and book reviews, were removed because they were not classified as peer-reviewed journal articles. The remaining 231 records were further assessed for eligibility, resulting in the exclusion of 28 non-English publications. In the final stage, 203 studies met all predefined inclusion criteria and were retained for bibliometric analysis. This multi-stage screening procedure ensured that the dataset included only eligible peer-reviewed, English-language publications, which improved the rigour and transparency of the study.

Figure 1
PRISMA Flowchart



Data Analysis

The final dataset was analysed using VOSviewer (version 1.6.20) and CiteSpace (version 6.3.R1, 64-bit Advanced) to examine the intellectual structure and thematic development of research on digital technologies in vocational education. Four bibliometric approaches were used. Performance analysis assessed publication productivity and citation impact. Bibliographic coupling analysis examined intellectual linkages among documents; a minimum citation threshold of four was applied, and 60 of the 203 documents met this criterion. Co-occurrence analysis explored thematic structures based on keyword frequency and co-appearance patterns; a minimum occurrence threshold of 14 was applied, and 59 of the 6,519 extracted terms satisfied this threshold. The citation and co-occurrence thresholds were determined through preliminary testing of different cut-off points. The citation threshold of four retained a manageable and interpretable bibliographic coupling network, while the co-occurrence threshold of 14 reduced low-frequency noise and preserved sufficient keywords for meaningful thematic interpretation. Burst-detection analysis identified emerging topics and shifts in research attention over time. The parameter configuration was set as follows: $\alpha_1/\alpha_0 = 2.0$, $\alpha_i/\alpha_{i-1} = 2.0$, $\gamma = 0.6$, and a minimum duration of 1. These approaches provided a systematic basis for examining the structural organization and thematic evolution of the field. In this context, bibliographic coupling was particularly useful for identifying shared knowledge bases among recent studies, while keyword co-occurrence helped reveal dominant themes and conceptual linkages.

Research Results

Performance Analysis

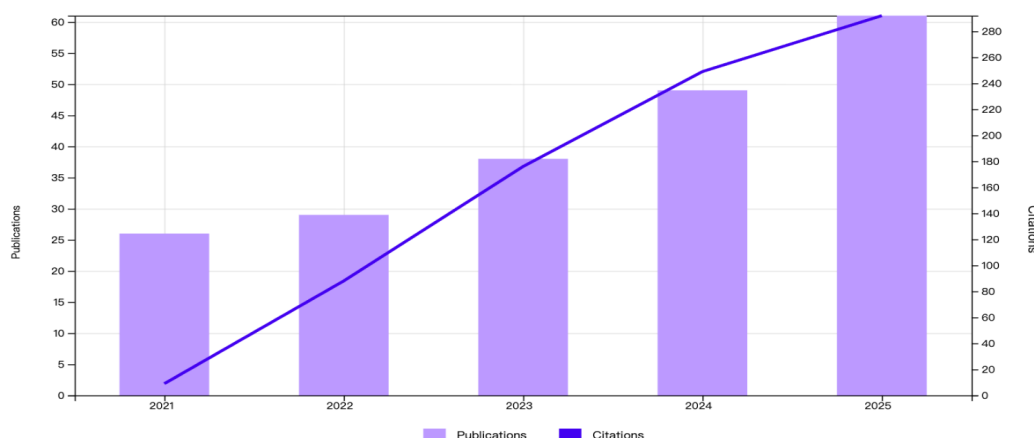
The bibliometric performance analysis of research on digital technologies in vocational education from 2021 to 2025 provides an overview of the field's academic productivity and citation impact. Table 2 shows the main bibliometric indicators derived from the WoS Core Collection, including total publications, citing documents, total citations, average citations per item, and the H-index. The dataset comprised 203 publications, which collectively received

814 citations, or 792 excluding self-citations. These publications were cited by 776 distinct citing documents, or 756 excluding self-citations, resulting in an average of 4.01 citations per item. An H-index of 11 indicates that at least 11 publications were cited 11 times or more, reflecting a moderate but steadily growing academic presence in the field. Figure 2 depicts the yearly distribution of publications and citations in the selected literature. The light-purple bars represent the volume of publications, whereas the dark-blue line indicates citation counts. Both indicators show a steady upward trend from 2021 to 2025, with the highest values recorded in 2025. This pattern reflects the continuing expansion of research interest in digital technologies in vocational education and underscores the growing visibility of this field.

Table 2
Overview of Bibliometric Performance Indicators (2021 to 2025)

Metric	Value
Total Publications	203
Total Citing Articles	776 (756 excluding self-citations)
Total Citations	814 (792 excluding self-citations)
Average Citations per Item	4.01
H-Index	11

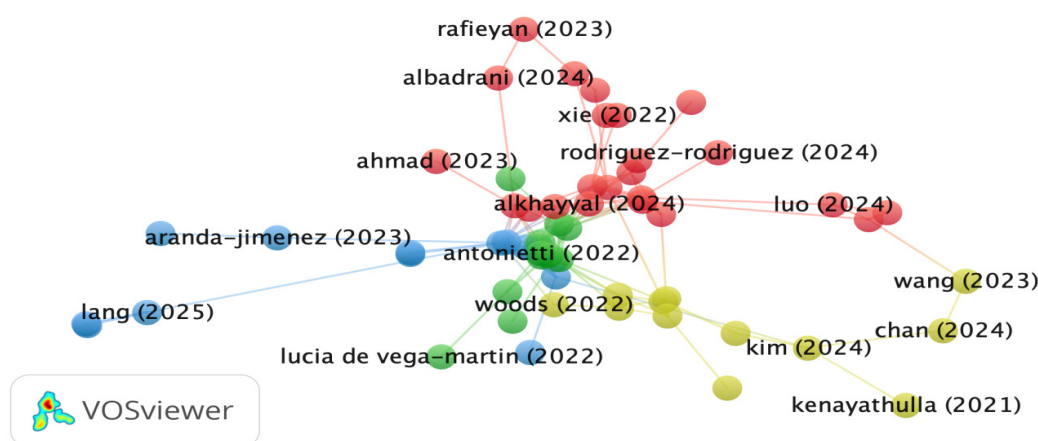
Figure 2
Annual Publication and Citation Trends (WoS database)



Bibliographic Coupling Analysis by Clusters

The bibliographic coupling analysis identified four major clusters, revealing the principal intellectual connections and thematic groupings among the selected studies. As shown in Figure 3, the final network comprised 60 documents, 127 links, and a total link strength of 212. In the visualisation, each colour represents a distinct research cluster, reflecting a particular line of inquiry in the field. Table 3 summarises the four clusters together with their representative publications and thematic orientations.

Figure 3
Bibliographic Coupling Analysis (VOSviewer visualization)



Cluster 1 (Red), with 23 publications, is anchored in a shared reference base concerning digital technologies, AI-enabled learning, learner empowerment, employability, and sustainability in vocational education. Its thematic configuration links self-directed learning, digital engagement, AI literacy, psychological well-being, ethical awareness, and sustainable skill development. Beyond the functional use of digital technologies, this cluster indicates an expanding research interest in the role of AI in supporting learner development, social inclusion, and sustainability in vocational education (Ahmad et al., 2023; Avsec & Rupnik, 2025; Cai et al., 2024). This suggests that the literature is gradually extending beyond performance-oriented applications toward a broader understanding of AI-enabled vocational education.

Cluster 2 (Green), comprising 13 articles, brings together research on teachers' acceptance, digital competence, and institutional readiness for technology integration in vocational education. The common intellectual foundation of this cluster lies in its focus on technology acceptance, teacher beliefs, self-efficacy, ICT competence, professional preparation, and institutional support. Rather than viewing digital transformation as a matter of individual readiness alone, this cluster emphasises the role of organisational and pedagogical conditions in sustaining technology integration (Edeh et al., 2021; Vilppola et al., 2022; Yang et al., 2023). It also highlights the need to align teacher preparation, professional learning, and institutional support.

Cluster 3 (Blue), including 12 studies, is organised around institutional innovation, leadership adaptation, and organisational transformation in vocational education. Its conceptual links connect digital transformation, visionary leadership, workforce development, cross-sector collaboration, value co-creation, and Industry 4.0-oriented organisational change. In this cluster, AI is examined not only as an educational technology but also as part of a wider institutional infrastructure that supports governance, collaboration, workforce competence, and innovation (Aranda et al., 2023; Badawi & Drăgoicea, 2023; Han et al., 2023). The cluster therefore reflects an organisational-level perspective on AI integration, with particular attention to institutional adaptation and transformation.

Cluster 4 (Yellow) consists of 12 publications linked by a shared focus on policy directions, lifelong learning, future skill development, and Industry 4.0-related workforce preparation. Its thematic pattern highlights connections among graduate readiness, policy alignment, adaptability, professional resilience, educational-industrial partnerships, and future-ready competencies. In this cluster, AI and digital transformation are discussed in relation

to broader policy and workforce-development concerns, particularly lifelong learning and cross-sector collaboration in preparing vocational education systems for future labour market demands (Hearn et al., 2023; Kenayathulla, 2021; Kim et al., 2024). This cluster presents a policy-oriented knowledge structure in which technological change, employability, and lifelong learning are closely interconnected.

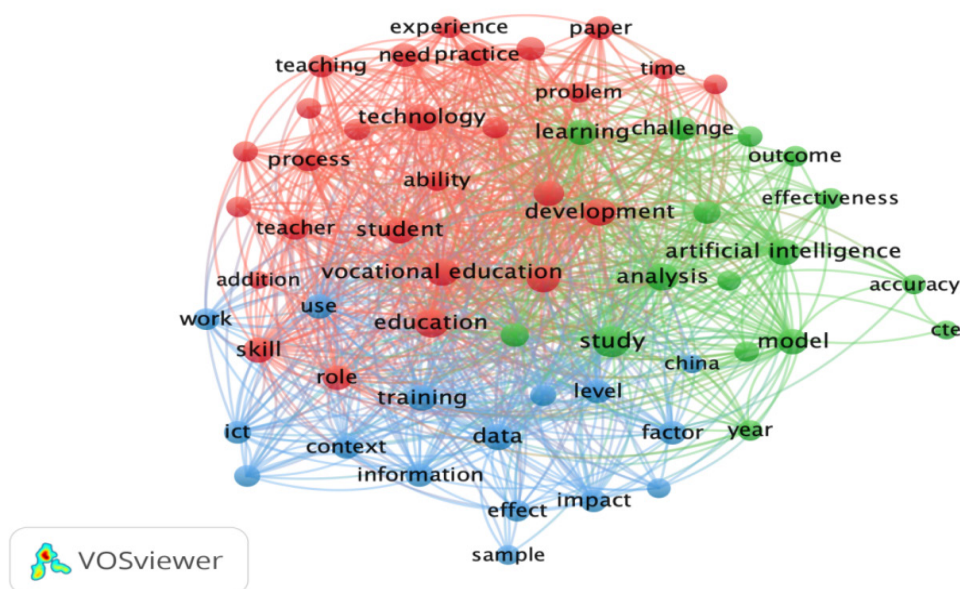
Table 3
Bibliographic Coupling by Cluster

Cluster No. & Colour	Cluster Labels	No. of Articles	Representative Publications
Cluster 1 (Red)	AI, Learner Empowerment, and Sustainable Development in Vocational Education	23	Ahmad et al. (2023), Avsec and Rupnik (2025), Cai et al. (2024), de-la-Peña et al. (2024), Hassan et al. (2024), Ren et al. (2024), Olugbade et al. (2024), Omeh et al. (2025), Petridou and Lao (2024), Wu et al. (2025), Xie (2022).
Cluster 2 (Green)	Technology Acceptance and Digital Competence in Vocational Education	13	Edeh et al. (2021), Yang et al. (2023), Sánchez-Prieto et al. (2021), Vilppola et al. (2022), Kolosnichenko et al. (2021), Enochsson et al. (2021), Do et al. (2023).
Cluster 3 (Blue)	AI-Driven Innovation, Leadership, and Digital Transformation in Vocational Education	12	Alabbas and Alomar (2024), Aranda et al. (2023), Badawi and Drăgoicea (2023), Han et al. (2023), Sajja et al. (2025), Mohd Siraj et al. (2023).
Cluster 4 (Yellow)	Policy, Lifelong Learning, and Future Skills in the Industry 4.0 Era	12	Albizu and Estensoro (2024), Bolaños and Pilerot (2021), Kenayathulla (2021), Kim et al. (2024), Woods et al. (2022), Hearn et al. (2023).

Keyword Co-occurrence Analysis by Cluster

The keyword co-occurrence analysis yielded three major clusters, which capture the main research themes and conceptual relationships across the selected literature. As shown in Figure 4, the resulting network comprised 59 items, 1,673 links, and a total link strength of 17,140. In the visualisation, each colour represents a distinct thematic cluster, corresponding to a coherent strand of inquiry in the field. Table 4 outlines the three clusters together with their representative keywords and thematic directions.

Figure 4
Co-occurrence Analysis (VOSviewer visualization)



Cluster 1 (Red), with 27 keywords, is centred on pedagogical innovation, practice-based learning, and technology-supported teaching in vocational education. The co-occurrence of “vocational education,” “technology,” “teaching,” “skill,” and “practice” indicates a focus on practical competency development through AI- and ICT-supported learning environments. The keyword pattern also connects employability, digital teaching competence, reflective practice, and instructional quality. This suggests that technology use is closely tied to both learner skill formation and teacher professional development (Do et al., 2023; Kolosnichenko et al., 2021; Sánchez-Prieto et al., 2021). This cluster reflects an experiential and practice-oriented strand of vocational education research.

Cluster 2 (Green) contains 16 keywords associated with AI applications, learning processes, model development, effectiveness, and implementation challenges. Terms such as “artificial intelligence,” “application,” “learning,” “model,” “effectiveness,” and “challenge” show that this cluster addresses the use of AI to support learning outcomes and adaptive teaching in vocational and technical education. The co-occurring terms suggest a research emphasis on feedback, personalisation, learner responsiveness, and the evaluation of AI-supported educational tools (De-la-Peña et al., 2024; Hassan et al., 2024; Ren et al., 2024). This cluster captures a learner-centred strand in which AI is linked to more responsive and individualised forms of vocational learning.

Cluster 3 (Blue), comprising 16 keywords, is shaped by the relationship between ICT use, vocational training, work contexts, and institutional conditions. The presence of terms such as “vocational training,” “ICT,” “impact,” “context,” and “work” suggests that this cluster is less focused on technology itself than on the environments in which digital tools are adopted and sustained. Its keyword structure connects school-based learning, workplace learning, leadership, teacher motivation, industry engagement, and knowledge exchange. This indicates that digital transformation in vocational education depends on contextual and organisational support (Albizu & Estensoro, 2024; Enochsson et al., 2021; Mohd Siraj et al., 2023). This cluster highlights a context-sensitive perspective on ICT integration in vocational education.

Table 4
Co-occurrence Analysis by Cluster

Cluster No. & Colour	Cluster Label	Number of Keywords	Representative Keywords
1 (Red)	Pedagogical Development and Skill-Oriented Practices in Vocational Education	27	"vocational education", "technology", "teaching", "teacher", "student", "skill", "development", "integration", "implementation", "industry", "practice", "quality", "experience"
2 (Green)	Artificial Intelligence Applications and Learning Effectiveness in CTE	16	"artificial intelligence", "application", "learning", "model", "effectiveness", "knowledge", "cte", "field", "challenge"
3 (Blue)	ICT Integration and Contextual Impact on Vocational Training	16	"vocational training", "ICT", "communication technology", "impact", "context", "factor", "level", "training", "work"

Burst Detection Analysis by Keywords

Burst-detection analysis identified 13 burst keywords between 2021 and 2025, reflecting shifts in research attention and the dynamic development of emerging topics over time. These burst terms indicate periods in which particular themes attracted intensified scholarly interest. Table 5 displays the keywords with the strongest bursts together with their burst strength, onset year, and duration.

Table 5
Keywords with Strongest Bursts (CiteSpace)

Keywords	Year	Strength	Begin	End	2021 - 2025
Technology Acceptance Model	2021	1.72	2021	2022	
ICT	2021	1.06	2021	2023	
Big Data	2021	1.03	2021	2021	
Work	2022	1.56	2022	2023	
Higher Education	2022	1.22	2022	2022	
Work-based Learning	2022	1.22	2022	2022	
Pedagogical Content Knowledge	2022	1.04	2022	2022	
Integration	2022	1.04	2022	2022	
Teacher Training	2022	1.04	2022	2022	
Digital Competence	2022	1.04	2022	2022	
Information	2023	2.21	2023	2023	
Performance	2023	2.02	2023	2023	
AI	2024	2.63	2024	2025	

The burst-detection results reveal a clear evolution in research attention from 2021 to 2025. In the earlier years, burst terms such as "Technology Acceptance Model" and "ICT" were associated mainly with digital adoption and instructional integration. This indicates that initial studies were largely concerned with the uptake of technology in vocational education. This emphasis later appeared to shift toward keywords such as "work-based learning" and "digital competence," marking a stronger focus on teacher development, curriculum innovation, and the pedagogical conditions required for effective technology use. In the most recent period, "AI"

emerged as the strongest and most sustained burst keyword, lasting from 2024 to 2025, while “performance” also indicated growing attention to learning and training outcomes. Although “generative AI” did not appear as an independent burst term, it may be partly captured under the broader “AI” keyword. These changes suggest that research attention has begun to extend beyond early concerns with adoption toward broader pedagogical, institutional, and practice-oriented questions in vocational education.

Discussion

The bibliometric results suggest an emerging change in research attention on digital technologies in vocational education. The bibliographic coupling and keyword co-occurrence analyses produced different but complementary cluster structures. Bibliographic coupling identified four intellectual groupings around learner empowerment, teacher digital competence, institutional innovation, and policy-oriented skill development. In contrast, keyword co-occurrence analysis identified three broader thematic areas related to pedagogical development, AI applications, and ICT integration. These differences reflect the distinct logics of citation-based and keyword-based mapping. Together, the two analyses show that the field is organised around both actor-level concerns and technology-oriented themes. Earlier studies in the dataset were mainly concerned with technological adoption and instructional integration, whereas more recent work appears to give greater attention to broader pedagogical, institutional, ethical, and policy-related concerns. Although previous reviews have discussed digitalisation trends and implementation challenges in vocational education (Hassan et al., 2021; Jiang et al., 2024), this study offers a more contextualised and multi-level account. Specifically, it links learner development, teacher competence, institutional transformation, and policy-oriented concerns within a single analytical framework.

Theoretical Implications

The bibliometric findings suggest an emerging movement from adoption-oriented perspectives toward a broader socio-technical understanding of digital transformation in vocational education. Early technology adoption models such as the TAM (Davis, 1989) and the Unified Theory of Acceptance and Use of Technology (Venkatesh et al., 2003) provided an important basis for explaining initial uptake. However, digital technologies are no longer understood merely as tools to be accepted or rejected. Rather, they are increasingly approached as integral components of educational ecosystems in which technological affordances interact with human agency, organisational culture, and institutional conditions (Edeh et al., 2021; Han et al., 2023). This bibliometric pattern may extend technology acceptance perspectives by showing that digital transformation in vocational education could be understood as an ongoing socio-technical process shaped by learner agency, teacher readiness, institutional support, and policy conditions.

Another notable development mapped in the bibliometric results is the move away from a narrow concern with performance improvement toward broader affective, ethical, and sustainability-related dimensions. The increasing prominence of learner empowerment, AI literacy, ethical awareness, and sustainability, together with greater attention to adaptive, learner-responsive, and practice-oriented pedagogies, reflects a broader reconceptualisation of digital technologies in vocational education (Avsec & Rupnik, 2025; Hassan et al., 2024). In this view, digital technologies, particularly AI, are increasingly understood not simply as tools for improving performance, but as resources that can also support emotional engagement and responsible educational practice. This may extend the theoretical scope of educational technology research by linking affective learning, digital ethics, sustainability education, and

vocational identity development more explicitly with vocational pedagogy (Kryger & Qvortrup, 2025). It also situates the findings within UNESCO's Sustainable Development Goal 4, which emphasises inclusive, equitable, and high-quality education through responsible innovation (UNESCO, 2021).

Additionally, teachers, institutions, and policy contexts are better seen not as separate background variables, but as interconnected dimensions of digital transformation. Teachers' professional preparation, institutional support, and cross-sector collaboration appear to shape the direction and sustainability of technology integration (Hearn et al., 2023; Vilppola et al., 2022). Theoretically, this finding suggests that digital transformation in vocational education can be conceptualised as a multi-level process shaped by learners, teachers, institutions, and policy environments, rather than as a classroom-level issue alone.

Practical Implications

From a practical perspective, the identified bibliometric themes suggest that digital technologies should be embedded in authentic, experiential, and practice-oriented teaching environments. Vocational education research increasingly links digital tools with active learning, workplace relevance, and learner responsiveness, rather than simply with the digitisation of traditional instruction (Kolosnichenko et al., 2021; Sajja et al., 2025). This pattern points to the need for aligning curriculum design with industry expectations while ensuring that digital tools enhance rather than replace human judgement, creativity, and problem-solving.

Teachers play a central role in sustaining digital transformation. Effective technology integration appears to depend not only on infrastructure, but also on teachers' preparedness, AI literacy, ethical awareness, and opportunities for continuous professional learning (Omeh et al., 2025; Petridou & Lao, 2024; Wu et al., 2025). Professional development could therefore include structured AI literacy training, ethical use of learner data, and practical guidance on designing human–technology collaborative activities, interpreting algorithm-generated feedback, and fostering students' critical digital awareness. Peer mentoring and institutional support structures may also help teachers participate actively in shaping innovation rather than functioning merely as policy implementers.

At the institutional level, leadership, governance, and organisational culture are essential to digital transformation. In vocational education, successful implementation depends on leadership support, governance structures, and the institutional conditions that shape implementation (Mende et al., 2025; Mohd Siraj et al., 2023). Institutions should therefore treat digital technologies not only as classroom tools, but also as part of a broader organisational infrastructure that requires coordinated leadership, transparent governance, and meaningful cooperation with industry partners. Mechanisms such as digital transformation task forces or AI ethics committees may be particularly useful for balancing innovation with inclusion, accountability, and social responsibility.

At the policy level, digital transformation could be linked more closely with lifelong learning and future workforce development. In this context, digital technologies are increasingly connected to wider debates about employability, resilience, and responsible governance (Hearn et al., 2023; Kim et al., 2024; Woods et al., 2022). Policy frameworks could prioritise two actions: establishing clear guidelines for ethical AI use in vocational education and funding continuous AI and ICT professional development for vocational teachers. These measures may help ensure that digital transformation remains inclusive, future-oriented, and socially sustainable.

Limitations and Future Research Directions

Although this study provides an evidence-based overview of research on digital technologies in vocational education, several limitations should be noted. First, the analysis relied only on the WoS Core Collection. Although this choice helped maintain data consistency, it may have narrowed international coverage by excluding studies from Scopus, ERIC, Google Scholar, regional databases, and non-English or practice-oriented vocational education outlets. As a result, relevant studies indexed in Scopus, ERIC, or regional databases may not have been included. Future research could therefore expand the dataset by incorporating non-English and locally published studies. Second, the time frame (2021–2025) captures only the early stage of post-pandemic digital transformation. More longitudinal research is needed to determine whether the patterns identified here remain stable or continue to change as emerging digital technologies, including generative AI, develop further. Third, bibliometric mapping helps reveal the broad structure of the field, but it offers limited insight into how digital transformation unfolds in pedagogical, organisational, and policy contexts. Future studies could combine bibliometric methods with qualitative approaches, such as interviews, case studies, and classroom or institutional observations, to gain a fuller understanding of how digital technologies are experienced and implemented across different vocational settings.

Conclusions and Implications

In conclusion, this study shows that research on digital technologies in vocational education has moved beyond issues of access and adoption toward a socio-technical understanding of digital transformation. The bibliographic coupling and keyword co-occurrence results reveal four interconnected levels of development: learner empowerment and AI literacy, teacher readiness and professional learning, institutional innovation and governance, and policy alignment with lifelong learning and workforce development. This provides a clearer account of how the field is structured and how its priorities are changing. The main contribution of this study is to show that digital transformation in vocational education is not developing as a purely technical agenda, but as a multi-level educational process shaped by pedagogy, human agency, institutional capacity, and governance. On this basis, future research should prioritise the relationship between AI literacy, teacher professional development, and institutional readiness. At the policy level, clearer guidelines for ethical AI use and sustained investment in AI and ICT professional development for vocational teachers are needed.

Declarations

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Author Notes

The authors used AI-assisted tools (ChatGPT and Grammarly) solely for language

refinement and formatting. The content, interpretation, and conclusions remain the authors' own responsibility, consistent with the journal's AI disclosure policy and UNESCO's SDG 4 principles on responsible AI use in education.

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