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ORIGINAL ARTICLE

Digital competence development in TVET with a competency-based whole-institution approach

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ABSTRACT

This article proposes the necessity of adopting a whole institution approach engaging leaders, teachers, and learners for digital competence development in technical and vocational education and training (TVET). It first emphasizes the commitment of TVET to developing digital competencies by pointing out skill gaps against the background of digital transition. It then illustrates that advocacy for digital competence development in TVET strategies involves developing the digital competence of leaders and teachers as TVET practitioners and developing the digital competence of students as TVET learners. Drawing on the competency-based paradigm of education and the concept of a whole-institution approach, this paper claims that digital competence development in TVET should empower all primary TVET stakeholders—leaders, teachers, and learners. Therefore, it adopts a qualitative research method to examine the anticipated digital competencies of these three stakeholder groups through an analysis of existing digital competence frameworks for leaders, educators, and individuals. Finally, the paper synthesizes the digital competency areas of TVET leaders, teachers, and learners and discusses their relevance, thereby advocating a competency-based whole-institution approach to digital competence development in TVET.

Key words: digital competencies, digital competence framework, a whole institution approach, leaders, teachers, and learners, technical and vocational education and training

INTRODUCTION

Competence development is considered a key issue in education, particularly in technical and vocational education and training (TVET). As long and widely acknowledged, competence development for learners is the main function of the TVET system, as TVET is committed to enhancing learners' employability and addressing industry needs through the provision of relevant vocational and technical skills.[1–3] TVET institutions play a vital role in equipping learners with the competencies required to succeed in the rapidly evolving world of work. Importantly, the effectiveness of TVET in developing learners competencies relies heavily on the competence of TVET practitioners, including leaders and teachers.[4,5] Recent years have witnessed increasing attention to the importance of developing digital competence. The digital transition has profoundly impacted nearly all aspects of work and life, necessitating the integration of digital skills into TVET delivery. There are some studies investigating learner digital skill development, and others inquiring into the digital competence of teachers.[6,7] Consequently, there is a growing emphasis on developing the digital competencies of both TVET providers and learners.

Despite the recognized significance of digital competence development in TVET, there is less

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research focusing on specific mechanisms through which the whole TVET system can effectively and systematically build digital competence. While various initiatives and frameworks related to digital competence have been developed in TVET, few studies have taken a holistic approach that considers the expected digital competencies of both TVET practitioners and learners. This reveals the importance of developing a holistic approach to digital competence development in TVET, one that takes into account the digital competencies required by leaders, teachers, and learners. By addressing this issue, TVET systems should ensure that all stakeholders are equipped with the necessary digital competencies to navigate the challenges and opportunities presented by the digital age.

CONTEXT

Growing demand for digital competence in the changing world of work

Industry Revolution 4.0—characterized by digital technologies, particularly artificial intelligence (AI) and robotics—is reshaping the world of work at an unprecedented rate. The impact of AI development is estimated to be 10 times faster, 300 times larger, and nearly 3000 times more significant than previous industrial revolutions.[8] As a result, AI technologies are replacing outdated jobs.[9] A study involving over 200,000 workers across 29 countries, including 27 Organization for Economic Co-operation and Development (OECD) nations, Singapore, and Russia, projects that the proportion of jobs to be replaced by the early 2030s varies from approximately 20%-25% in Nordic countries and East Asia to over 40% in Eastern Europe.[10] In China, PricewaterhouseCoopers (PwC) estimates that AI and other labor-saving technologies will displace 26% of current jobs in services, construction, industry, and agriculture over the next two decades[11], while the UK estimate stands at 20%.[12] The scale of job replacement is even more significant in the US, with Frey and Osbourne calculating that 47% of jobs in the country are at high risk of automation within the next 20 years.[13] Conversely, digital technologies are opening up significant new job opportunities in fields such as robotics, AI-powered analytics, and machine learning.[14] It is projected that these technologies will generate 297 million new jobs in China,[11] while accounting for 20% of future jobs in the UK between 2017 and 2037.[12]

Such a changing world of work leads to a growing demand for digital competencies involving skilling, upskilling, and reskilling. The International Labour Organization (ILO) forecasts a general increase in the need for technical skills, with the hours worked using technological skills expected to nearly double in the US and Western Europe between 2016 and 2030.[15] This indicates that new entrants to the job market require skilling in relevant technologies to secure initial employment. Moreover, the European Training Foundation indicates that current employees require upskilling in digital competence,[16] in alignment with the finding of a McKinsey Global Survey that up to 87% of 1216 surveyed employers have identified current or anticipated skills gaps within the next five years, particularly in data analytics and information and communication technology (ICT).[17] Concerning reskilling, the World Economic Forum estimates that half of employees worldwide might need to reskill themselves for the application of new technologies by 2025 due to the obsolescence of their old jobs.[18] "Technology use, monitoring, and control" and "technology design and programming" will be among the top 10 skills for reskilling and upskilling the future-ready workforce in 2025, with both not listed in 2015 and 2020 and representing digital competence.[19]

Advocacy for digital competence development in TVET strategies

Global, regional, and national strategies have recognized the need to develop individuals' digital competence or skills in education and training. The latest TVET strategy of United Nations Educational, Scientific, and Cultural Organization (UNESCO), *Transforming Technical and Vocational Education and Training for Successful and Just Transitions: UNESCO Strategy 2022-2029*, identifies TVET's role as a proactive player in multiple transitions and emphasizes skills for transitioning to digital economies.[20] Similarly, the ILO's *Strategy on Skills and Lifelong Learning 2030* recommends that learning programs and pathways support the delivery of digital learning and digital skills.[21] The European Union's *New Skills Agenda for Europe* highlights the significance of digital skills in TVET, encouraging member states to invest in digital infrastructure, promote digital literacy, and integrate digital technologies into their curricula.[22] At the national level, the Chinese government released a policy document titled *Guideline on Improving Digital Literacy and Skills for All* in 2021, and a new document on key tasks in promoting the digital literacy and skills of the public in 2024. Likewise, Singapore's "SkillsFuture Movement", launched in 2015, aims to support adult and vocational learners in digital competence building through a series of initiatives including scholarships, subsidies, and training programs.[23]

By advocating digital competence development for individuals or learners, developing TVET practitioners' digital competence is particularly emphasized in TVET strategies and initiatives. The underlying logic is that TVET practitioners, including leaders/management and teachers/trainers are the key enablers to develop

individuals' digital competence. The UNESCO UNEVOC International Centre for Technical and Vocational Education and Training (UNESCO-UNEVOC) claims that TVET teachers should be "digitally competent" by developing technical skills in terms of digital pedagogy as well as technology-enabled methodologies.[24] The International Federation of Red Cross and Red Crescent Societies' (IFRC's) *Strategic Framework on Education 2020-2030* stresses the importance of fostering creative and innovative approaches to education, as well as leveraging digital technologies to improve teaching and learning,[25] which requires building practitioners' digital competencies. At the regional level, the African Union's *Continental Education Strategy for Africa 2016-2025 (CESA 16-25)* and the European Union's *Digital Education Action Plan (2021-2027)* both emphasize the need for teacher training in digital skills.[26,27] At the national level, China has released a standard on the digital literacy of teachers.[28] Germany's DigitalPakt Schule (digital pact for schools) initiative promotes digital skills among both learners and teachers.[29] Singapore's *"Transforming Education through Technology" Masterplan 2030* makes "strengthen teachers' education technology (EdTech) practice" as one of the strategic thrusts with closer attention to e-pedagogy and the use of EdTech in both pre-service teacher and in-service training.[30]

Literature review on holistic approaches to digital competence development in TVET

The above arguments on digital competence development involve developing the digital competence of leaders and teachers as TVET practitioners and developing the digital competence of students as TVET learners. However, most of current literature seem to focus on the digital competence of specific education stakeholders' rather than that of all education stakeholders. With all specifically discussing digital leadership, De Waal *et al.*, and Leonardus and Sasmoko concentrate on leaders' competence in utilizing digital technology to achieve organizational goals and create organizational value,[31,32] El Sawy *et al.* define digital leadership as competencies for undertaking the right actions for strategic success of digitalization,[33] Magesa and Jonathan comprehensively summarize a leader's digital competence through eight roles of a digital transformation leader.[34] Regarding teachers' digital competence, the literature argues that teachers are expected to be digitally competent for transforming what to teach and supporting digital skills delivery, and for transforming how to teach through the use of digital tools and distance learning.[6,7,35] Additionally, lifelong learning competencies are also a crucial part of teacher's required competencies, as teachers are deemed to keep pace with the new pedagogical knowledge and changing learning demands in the digital era.[7,36] Regarding learners' digital competence, UNESCO articulates that individuals should develop competences for work and life in a digitalized society,[20] and more specifically, OECD implies that individuals should master specialized digital competencies for emerging digital occupations such as digital marketing.[37]

Notably, most studies on digital competence are not targeted at "TVET leaders", "TVET teachers", and "TVET learners", but on business leaders, teachers in broad education contexts, and individuals or citizens. Hence, there is a paucity of research that delves into the specific mechanisms through which the entire TVET ecosystem can effectively and systematically cultivate digital competencies among its stakeholders. To address this literature gap, this paper, rooted in the competency-based educational philosophy and the principle of a whole-institution approach, endeavors to address the comprehensive approach for ensuring the successful integration of digital competencies throughout the TVET system through the examination of various digital competence frameworks targeted at leaders, teachers, and individuals.

THEORETICAL PERSPECTIVES

Competency-based education (CBE)

Differentiated from traditional time-based education, CBE is an educational approach that prioritizes mastery of competencies for real-world needs,[38] and is therefore fit for TVET settings. First, this prioritization can be inferred from the conceptualization of "competence" or "competencies". In Europe, competence is perceived as individual capacity that combines practical and theoretical knowledge and skills, along with personal and social attributes, with which individuals carry out particular tasks and roles within a specific context or occupational area.[39,40] Similarly in Australia, the understanding of competence is about performing a specific function or task from a behavioristic perspective.[41,42] In the US, competency is perceived differently from cognitive perspective without emphasizing the actual output, but still keeping the same essence by emphasizing the potential of achieving some performance.[43] Moreover, studies on CBE argue that this approach enables learners to progress through a program by demonstrating proficiency in specific competencies aligned with industry standards,[44,45] and by developing transferable skills across various settings in authentic contexts.[46] Ultimately, CBE aims to bridge the gap between education and the competence demands of the real-world workplace, which is the very commitment of TVET that focuses on learners' technical and vocational competencies. Evidently, Fan proves the effectiveness of CBE in China's higher TVET through the case of Shenzhen Polytechnic (now

called Shenzhen Polytechnic University).[47]

More than the competence development of learners as a pre-service workforce, the paradigm of CBE is simultaneously applicable to the professional development of an in-service workforce, who are leaders and teachers in the context of TVET. To begin with, competency-based human resource management has gained significant momentum as an approach to developing top leaders and performers.[48,49] This approach is useful for ensuring effective job performance by clarifying roles, accountabilities, and expected output through identification of required competencies, evidenced by a review and synthesis of relevant theories, models, and practices.[48] In terms of leadership building, many of mainstream and contemporary leadership models are competency-based, such as "Transformational and Inspirational Leadership", "Appreciative Leadership", and "Positive Leadership".[50] Specifically in the education context, Alam argues that the competency-based leadership model could ensure the cost effectiveness and sustainability of universities without scarifying the education philosophy, attributed to managerial leaders professionally competent in education management, revenue generation, and social responsibilities.[51] In terms of teacher training, the competency-based paradigm has been employed since the 1960s, with Rosner suggesting more clarity of teacher competence and corresponding assessment tools in teacher training and certification based on the findings of the Committee on National Program Priorities in Teacher Education in the US.[52] The application of the competency-based paradigm to teacher training can also be found in recent studies on competency-based training programs and teacher preparedness for competency-based teaching or curricula.[53–56]

A whole-institution approach

A whole-institution approach is a comprehensive strategy that involves all stakeholders within an educational institution to achieve a common goal.[57] The fundamental key to this approach is to adopt a systematic and holistic perspective instead of individual measures, and to foster a shared vision, collaborative planning, and coordinated actions among key stakeholders (*i.e.*, leaders, teachers, and learners).[57,58] The concept of this approach is first and mostly applied in education for sustainable development (ESD) to address the green transition. In ESD, a whole institution approach incorporates sustainability into all processes engaged by multiple actors, including teaching content and methodology, learning processes, policies and governance, and interaction within the education community.[57,59–61] Research has recognized the instrumental role of this approach in that it could lead to improved student engagement and outcomes, and better alignment of institutional policies and practices.[60–62] In fact, this approach was also recently applied in other educational contexts, such as fostering student engagement[63] and physical and mental health development.[58,64] Therefore, in addressing the digital transition, the TVET system could also draw on the concept of this approach to systematically and holistically consider the digital competence development of leaders, teachers, and learners.

MATERIALS AND METHOD

From the theoretical perspectives of CBE and a whole institution approach, this study has employed a qualitative research approach to review and analyze the existing digital competence frameworks for leaders, educators, and individuals. The research aims to identify and summarize the expected digital competencies for these three key stakeholder groups, which contributes to the development of a competency-based whole-institution approach to digital competence development in TVET.

The research method consists of three major stages. The first stage is the identification of relevant digital competency frameworks. The materials have been selected from UNESCO-UNEVOC's Digital Competence Framework Database, which collects digital strategies developed at the continental, national, and regional levels, and occupational digital competence frameworks.[65] The selection criteria are digital competency frameworks applicable to a worldwide scope and various vocational disciplines that were released after 2011 when the concept of "Industry 4.0" first emerged,[66] in order to ensure that the findings of the study are broadly relevant and can inform digital competence development in TVET systems effectively. The identified materials, as shown in Table 1, have been screened for relevance and categorized based on their target audience (leaders, educators, or individuals).

The second stage is analysis of digital competence frameworks, and the third stage is synthesis of expected digital competencies and summarization of a digital competence development approach in TVET. In the second stage, the selected digital competence frameworks have been subjected to a qualitative content analysis. The key competency areas in the frameworks have been compared and contrasted to identify commonalities and differences in the expected digital competencies for leaders, educators, and individuals in TVET. In the third stage, this paper has synthesized the expected digital competency areas for each TVET stakeholder group based on the above analysis. Such a structured overview has facilitated the integration of digital competency areas for each TVET stakeholder

Table 1: Digital competence frameworks for review

Target audience	Digital competence framework	Development organization	Year
Leaders	Training framework in UNESCO-UNEVOC TVET Leadership Programme 2023	UNESCO-UNEVOC	2023
	Training framework in the TVET Leadership Workshop by the UNESCO Chair on Digitalization in TVET	UNESCO Chair on Digitalization in TVET at Shenzhen Polytechnic University	2023
Teachers	DigCompEdu	European Union	2017
	UNESCO ICT CFT Version 3	UNESCO	2018
	SELFIE for Teachers	European Commission	2021
	The European Training Foundation's READY model	European Training Foundation	2022
	Educators' Digital Competency Framework	UNICEF and ECARO	2022
Learners	DLGF	UNESCO Institute of Statistics	2018
	CFRIDiL	European Union	2019
	DQ Global Standard on Digital Literacy, Digital Skills and Digital Readiness	DQ Institute	2019
	Digital Competence Framework for Citizens (DigComp 2.2)	European Union	2022

UNESCO-UNEVOC, United Nations Educational, Scientific, and Cultural Organization International Centre for Technical and Vocational Education and Training; TVET, technical and vocational education and training; DigCompEdu, Digital Competence of Educators; ICT, information and communication technology; CFT, Competency Framework for Teachers; SELFIE, Self-reflection on Effective Learning by Fostering the use of Innovative Educational technologies; READY, Reference model for Educators' Activities and Development in the 21st-centurY; UNICEF, United Nations International Children's Emergency Fund; ECARO, Europe and Central Asia Regional Office; DLGF, Digital Literacy Global Framework; CFRIDiL, Common Framework of Reference for Intercultural Digital Literacies; DQ, digital intelligence.

group into a competency-based whole-institution approach to digital competence development across the TVET system. Throughout the research process, the researcher will ensure the trustworthiness of the findings by employing strategies such as peer debriefing (discussing the findings with other TVET researchers) and maintaining a detailed audit trail of the research process.

FINDINGS

Expected digital competencies of TVET leaders

We have found that there is a notable absence of research-based digital competence frameworks for leaders in the TVET and even the broad education sector. Therefore, in terms of TVET leadership frameworks, this study has reviewed and analyzed the two frameworks used in two global TVET leadership training initiatives, with one being the TVET Leadership Programme 2023 held by UNESCO-UNEVOC, UNESCO's designated center for TVET, and the other being the TVET Leadership Workshop held by the UNESCO Chair on Digitalization in TVET at Shenzhen Polytechnic University, the only establishment dedicated to digital transformation in TVET among over 900 UNESCO Chairs. The UNEVOC framework, while not solely concentrated on digital competence, incorporates digitalization as one of the essential thematic areas. In comparison, the UNESCO Chair framework explicitly indicates a comprehensive set of digital competencies necessary for TVET leaders. With similar structures, the UNEVOC framework covers four modules—vision, knowledge, skills, and actions for change[67] and the UNESCO Chair framework covers five modules—background, theories, practices, application scenarios, and strategy development on digital transformation of TVET.[68] The results of a systematic analysis of the UNEVOC framework and the UNESCO Chair framework can be observed in Table 2.

On one hand, both frameworks reflect several digital competency areas of TVET leader in common, despite that the emphasis on certain capabilities varies between the two. Above all, both frameworks underscore the significance of TVET leaders having a clear strategic vision and current knowledge of digital transformation in TVET in the first place through the introduction to relevant global TVET strategies. Moreover, both frameworks emphasize the necessity for leaders to possess skills in digital transformation governance. Yet, the UNEVOC framework focuses on the macro level of governance with attention to general leadership and management skills, while the UNESCO Chair framework addresses the micro level of governance by a more contextualized and practical approach to governance practices. Additionally, both frameworks recognize institutional planning for digital transformation as the required digital competence of TVET leaders. The UNEVOC leadership program takes a more structured approach by providing comprehensive guidance from strategic planning for change to preparing action plans for change. In contrast, the UNESCO Chair leadership workshop takes a more collaborative

Table 2: Summary of expected digital competencies for TVET leaders

Summarized digital competency area	Descriptions	UNEVOC framework	UNESCO Chair framework
Strategic vision and knowledge	Ability to recognize and adapt to global digital transformation trends and strategies, and envision of the digital future of TVET	Module 1: "Vision for change" Module 2: "Knowledge for change"	Module 1: "Strategies and Background of TVET Digital Transformation"
Theoretical understanding of digital transformation	Comprehension of digital transformation concepts, frameworks, and their relevance to TVET	Not explicitly mentioned	Module 2: "Theories on Digital Transformation"
Digital transformation governance	Competencies required to effectively oversee, manage, and steer digital transformation initiatives within an institution	Module 3: "Skills for change"	Module 5: "Institutional Digital Transformation Strategy Development"
Facilitating digital transformation of learning contents	Competencies required to design, adapt, and deliver learning materials and curricula to meet industrial skills needs in the digital economy	Not explicitly mentioned	Module 3: "Practices on Digital Transformation in TVET Sectors"
Facilitating digital transformation of learning environments	Preparation for infrastructures, digital facilities, equipment, tools and platforms to create digitalized learning environments	Not explicitly mentioned	Module 4: "Digital Application Scenarios in TVET"
Collaboration with industries	Skills in partnering with the private sector for digital transformation initiatives	Not explicitly mentioned	Module 3: "Practices on Digital Transformation in TVET Sectors"
Institutional planning for digital transformation	Ability to development of institutional strategies and action plans for incorporating digital transformation in TVET	Module 2: "Knowledge for change" Module 4: "Proposals and action plan for change"	Module 5: "Institutional Digital Transformation Strategy Development"

TVET, technical and vocational education and training; UNEVOC, International Centre for Technical and Vocational Education and Training; UNESCO, United Nations Educational, Scientific, and Cultural Organization.

approach by inviting participants to share their institutional strategies for digital transformation, fostering peer learning, and the exchange of best practices.

On the other hand, the UNESCO Chair framework highlights several digital competency areas for TVET leaders that are not explicitly addressed in the UNEVOC framework. This discrepancy can be attributed to the UNEVOC framework's broader focus on the overall competencies of effective TVET leaders, encompassing not only digitalization but also other thematic areas, compared with the UNESCO Chair framework dedicated to building digital competence from the view of a micro-level TVET institution. First, the UNESCO Chair framework, in its Module 2, emphasizes the necessity for TVET leaders to possess a robust theoretical understanding of digital transformation, including the definition of this term and the transformation frameworks in both the private sector and TVET. Secondly, in terms of teaching and learning processes, this framework also accentuates the significance of TVET leaders' facilitating digital transformation of learning contents and learning environments by covering topics of incorporating digital transformation into curriculum design in Module 3 and employing virtual reality/augmented reality (VR/AR) simulation centers and smart classrooms in Module 4. Thirdly, it also indicates collaboration with industries as a required competency area of TVET leaders, through presenting the promising case of "Huawei Certification into ICT Education Programmes" to elaborate on joint development of TVET courses with the private sector.

Through the synthesis of information provided by both frameworks, we can conclude that TVET leaders are expected to possess a blend of strategic insight, theoretical knowledge, competences for governance, competences for transforming teaching and learning, and the ability to develop institutional strategies towards digital transformation of TVET. These digital competencies empower TVET leaders to drive digital change in their institutions and ensure that their organizations remain relevant and responsive to the demands of the digital age.

Expected digital competencies of TVET teachers

Among the five teacher competence frameworks reviewed, the UNESCO's ICT Competency Framework for Teachers (ICT CFT) and the European Framework for the Digital Competence of Educators (DigCompEdu) provide comprehensive guidance on the digital competencies that teachers, including TVET teachers, should possess in their professional practice. ICT CFT is a resource used globally to integrate digital competence into teachers' professional development and to advocate the use of ICTs in education. Version 3, released in 2018, organizes teachers' expected digital competencies into six aspects: understanding ICT in education policy, curriculum and assessment, pedagogy, application of digital skills, organization and administration, and teacher professional learning.[69]

DigCompEdu is a framework developed in 2017 to help teachers and education stakeholders enhance their digital competence across all levels of education. It also covers six areas: professional engagement, digital resources, teaching and learning, assessment, empowering learners, and facilitating learners' digital competence.[70] Meanwhile, the other three reviewed frameworks are less relevant to digital competence development of TVET teachers, as SELFIE for Teachers (a self-reflection tool for teachers' digital competence) and Educators' Digital Competency Framework work on primary and secondary education,[71,72] and the European Training Foundation's READY model (Reference model for Educators' Activities and Development in the 21st-centurY) pays attention to 21st century skills rather than digital competence. Therefore, this session has selectively summarized the expected digital competencies of TVET teachers upon in-depth comparative analysis of ICT CFT and DigCompEdu, as shown in Table 3.

Evidently, ICT CFT and DigCompEdu agree that teachers should cultivate digital citizenship for enhancing teaching and learning. As an educational professional, a TVET teacher should first be a digitally competent citizen who responsibly and safely uses digital technologies to support quality training. The second summarized digital competency area is the pedagogical use of digital technologies, for that both focus on integrating technologies, tools, and digital content into teaching and different ways of learning. Furthermore, facilitating learners' digital competencies is another important competency area of teachers, as recognized by both frameworks. Unlike the former two areas, which concentrate on teachers' digital competence in teaching input, this area prioritizes that in teaching output. Both also converge on the expectation for teachers' digital competence for continuous professional development, with the same concentration on the application of digital technologies to professional lifelong learning.

While the digital competency areas covered by both frameworks largely overlap, there are still inconsistencies in some specific areas of teacher digital competence. Particularly, understanding ICT in education policy, listed as the first aspect of teachers' expected digital competence by ICT CFT, is the sole digital competency area in which only one of the two frameworks exhibits a focus. ICT CFT suggests that teachers should be able to align with ICT-related education priorities in classroom practices, and even engage in policy improvement. Other inconsistencies lie in the interpretations of the same competence domains. Regarding the competency area of digital assessment, ICT CFT highlights the use of digital technologies for authentic assessment to solve real-world problems, and DigCompEdu emphasizes the use of formative and summative assessment to provide targeted student support. In the competency area of digital communication and collaboration, ICT CFT emphasizes the connection with policymakers, technical people and administrative staff to support ICT in education, but DigCompEdu targets interacting with parents, learners, and the broader community, in spite of shared attention to using digital technologies for engaging education stakeholders.

The comparative analysis of ICT CFT and DigCompEdu reveals that TVET teachers are expected to cultivate a comprehensive set of digital competencies. These competencies include fostering digital citizenship, integrating digital technologies into pedagogical practices, facilitating the development of learners' digital skills, comprehending ICT in education policy, engaging in continuous professional development, employing digital assessment techniques, and utilizing digital tools for communication and collaboration. By acquiring and honing these digital competencies, TVET teachers will be digitally competent to leverage digital technologies effectively in their teaching, support the digital literacy of learners, and continuously adapt to the evolving demands of education in the digital era.

Expected digital competencies of TVET learners

The four reviewed digital competence frameworks of individuals have been found relevant to TVET learners. The Digital Literacy Global Framework (DLGF) is built upon the Digital Competence Framework for Citizens (DigComp) and serves as a foundation for monitoring, assessing, and developing digital literacy. It covers six competency areas, including devices and software operations, information and data literacy, communication and collaboration, digital content creation, safety, and problem-solving, plus career-related competencies.[73] Common Framework of Reference for Intercultural Digital Literacies (CFRIDiL) provides guidelines for proficiency and intercultural awareness in multimodal digital literacies by covering three dimensions on multimodal orchestration, digital technologies, and intercultural communication, plus a fourth dimension on transversal skills.[74] *Digital Intelligence Global Standard on Digital Literacy, Digital Skills and Digital Readiness* (DQ Global Standard) defines 24 digital competencies across eight areas: digital citizenship, digital resilience, digital creativity, digital identity, digital use, digital safety, digital security, and digital emotional intelligence, aiming to empower individuals with digital intelligence to thrive in the digital world.[75] DigComp 2.2, as the latest version of DigComp, provides reference to what it meant to be digitally competent through detailed illustrations of 21 competences in five areas. The five areas are consistent with those in DigComp and

Table 3: Summary of expected digital competencies for TVET teachers

Summarized digital competency area	Descriptions	UNESCO ICT CFT	DigCompEdu
Digital citizenship for enhancing teaching and learning	Promoting digital citizenship and ensuring safe, responsible, and ethical use of digital technologies to enhance teaching and learning	Aspect 4: application of digital skills	Area 2: digital resources Area 5: empowering learners
Pedagogical use of digital technologies	Integrating digital tools and resources into teaching practice to enhance student learning	Aspect 3: pedagogy	Area 3: teaching and learning
Facilitating learners' digital competencies	Supporting the development of learners' digital competencies	Aspect 3: pedagogy Aspect 4: application of digital skills	Area 6: facilitating learners' digital competence
Understanding ICT in education policy	Awareness, applications and enhancements of ICT-related education policies	Aspect 1: understanding ICT in education policy	Not explicitly mentioned
Continuous professional development	Using digital technologies for ongoing professional learning and reflective practice	Aspect 6: teacher professional learning	Area 1: professional engagement
Digital assessment	Using digital technologies for assessment and data analysis to inform teaching and support learning	Aspect 2: curriculum and assessment	Area 4: assessment
Digital communication and collaboration	Using digital technologies to communicate and collaborate with stakeholders	Aspect 1: understanding ICT in education policy Aspect 5: organization and administration	Area 1: professional engagement

TVET, technical and vocational education and training; UNESCO, United Nations Educational, Scientific, and Cultural Organization; ICT, information and communication technology; CFT, Competency Framework for Teachers; DigCompEdu, Digital Competence of Educators.

therefore with those in DLGF, with lacking "devices and software operations".[76] The synthesis of the four competence frameworks has resulted in a concise list of seven digital competency areas (Table 4).

There are four competency areas proposed by all four frameworks, despite some variations in the way they are categorized and described. First, all four emphasized the importance of data literacy for digital use. DLGF, DQ Global Stand, and DigComp 2.2 have similar perceptions of digital literacy. DLGF and DigComp 2.2 break it down into the capability to use hardware and software, the capability to use data, and the capability to solve technical problems. CFRIDiL concisely interprets it as the competence for the use of digital tools with awareness of their affordances in "Digital technology" dimension. Second, digital communication and collaboration is identified as a desired digital competency area with a similar focus on the use of digital technologies for interaction and community engagement. Third, all four touch upon the competency area of digital content creation. Different from the area of digital literacy for digital use, this area focuses on creativity rather than the skills of using digital tools. Among the four, CFRIDiL goes a step further by interpreting this area and emphasizing making meaning through digital content. The fourth area is digital emotional intelligence, which is specifically emphasized by the DQ Global Standard guide by the principle "Respect for others". Yet, it is just partially mentioned in the other three frameworks, for instance, as part of transversal skills in CFRIDiL.

There are also three digital competency areas for learners that are not explicitly mentioned in all four frameworks. First, the competency area of digital identity is indicated in three of the four frameworks. It is highlighted in the DQ Global Standard for the sake of building a wholesome online and offline identity and partially mentioned in DLGF and DigComp 2.2 in the interest of digital identity and reputation management when elaborating on Area 2. Similarly, digital safety and security is represented in the same three areas. The DG Global Standard divides it into "Digital Safety", "Digital Security", and "Digital Rights", concentrating on responsible use of technology, protecting digital devices and resources, and protecting oneself in digital environments, respectively, while DLGF and DigComp 2.2 include all these under the umbrella of Area 4: Safety. Unlike the former, problem-solving is addressed by CFRIDiL as well as DLGF and DigComp 2.2, with the spotlight on resolving real-world problems through digital tools. Notably, DLGF and DigComp 2.2 creatively propose solving practical problems through computational thinking. Last but not least, the area of career-related competencies is only mentioned in DLGF, which acknowledges the value of specialized digital competencies to particular occupations.

The above investigation into four digital competence frameworks indicates that the expected digital competence of TVET learners might cover seven areas in digital identity, digital literacy for digital use, digital safety and security, digital emotional intelligence, digital communication and collaboration, digital content creation, problem-solving, and career-related development. Among the four frameworks, DigComp 2.2 and DLGF, with a high degree of similarity, stand out as foundational frameworks that provide the most

Table 4: Summary of expected digital competencies for TVET learners

Summarized digital competency area	Descriptions	DLGF	CFRIDiL	DQ global standard	DigComp 2.2
Digital literacy for digital use	Being able to use digital devices and applications effectively to address information needs, and to locate, retrieve, evaluate, manage data	Area 0: "Devices and software operations" Area 1: "Information and data literacy" 5.1 Solving technical problems under Area 5: "Problem-solving"	"Digital technology" dimension	"Digital Use" area "Digital Literacy" area	Area 1: "Information and data literacy" 5.3 Creatively using digital technologies under Area 5: "Problem-solving"
Digital communication and collaboration	Interacting, communicating and collaborating effectively through digital technologies	Area 2: "Communication and Collaboration"	"Intercultural Communication" dimension	"Digital Communication" area	Area 2: "Communication and Collaboration"
Digital content creation	Creating and editing digital contents	Area 3: "Digital content creation"	"Multimodal Orchestration" dimension	Relevant to all areas in the "Digital Creativity" maturity level	Area 3: "Digital content creation"
Digital emotional intelligence	Being aware of and managing one's emotions and empathy in digital interactions	4.3 Protecting health and well-being under Area 4: "Safety"	"Transversal Skills" dimension	"Digital Emotional Intelligence" area	4.3 Protecting health and well-being under Area 4: "Safety"
Digital identity	Understanding and managing one's digital identity and reputation across digital contexts	2.6 Managing digital identity under Area 2: "Communication and collaboration"	Not explicitly mentioned.	"Digital Identity" area	2.6 Managing digital identity under Area 2: "Communication and collaboration"
Digital safety and security	Protecting devices, personal data, physical and mental health, and the environment from negative impacts caused by use of digital technologies	Area 4: "Safety"	Not explicitly mentioned.	"Digital Safety" area "Digital Security" area "Digital Rights"	Area 4: "Safety"
Problem-solving	Solving problems through use of digital tools, computational thinking ad self-development for keeping up-to-date with the digital evolution	Area 5: "Problem-solving"	"Transversal Skills" dimension	Not explicitly mentioned	Area 5: "Problem-solving"
Career-related competencies	Using specialized digital technologies for a particular field	Area 6: "Career-related competencies"	Not explicitly mentioned	Not explicitly mentioned	Not explicitly mentioned

TVET, technical and vocational education and training; DLGF, Digital Literacy Global Framework; CFRIDiL, Common Framework of Reference for Intercultural Digital Literacies; DQ, digital intelligence.

comprehensive and detailed guidance, addressing nearly each of the outlined digital competency areas, with DLGF addressing one more area in career-related competencies. Comparatively, CFRIDiL provides more integrated guidelines with four broad dimensions of digital competence summarized and some of the competency areas overlooked. The DQ Global Standard attaches more significance to such areas as "digital literacy for digital use" and "digital safety and security", with little attention to some other areas. However, while the terminology and structure varied, the four frameworks largely align on these summarized digital competencies required by learners. The identification of these digital competencies provides robust support for the development of digital skills training programs and curricula for TVET learners.

DISCUSSION

A competency-based, whole-institution approach to digital competence development in TVET has been derived from the findings of our systematic review and analysis of digital competence frameworks relevant to TVET leaders, teachers, and learners, as presented in Figure 1. With adoption of the whole-institution concept and the competency-based paradigm, this approach takes account of all three key stakeholder groups in the TVET systems and provides valuable insights into the expected digital competency areas for each stakeholder, with identification of seven areas for leaders, eight areas for teachers and eight areas for learners.

The expected digital competency areas outlined for each stakeholder group resonate with the current discourse. In practical terms, this proposed approach responds to the growing demand for and advocacy for digital competence development within the TVET system. Seven competency areas revealed for TVET leaders position leaders to initiate and drive digital change in their TVET institutions. These findings are aligned with those in studies on digital leadership in business systems,

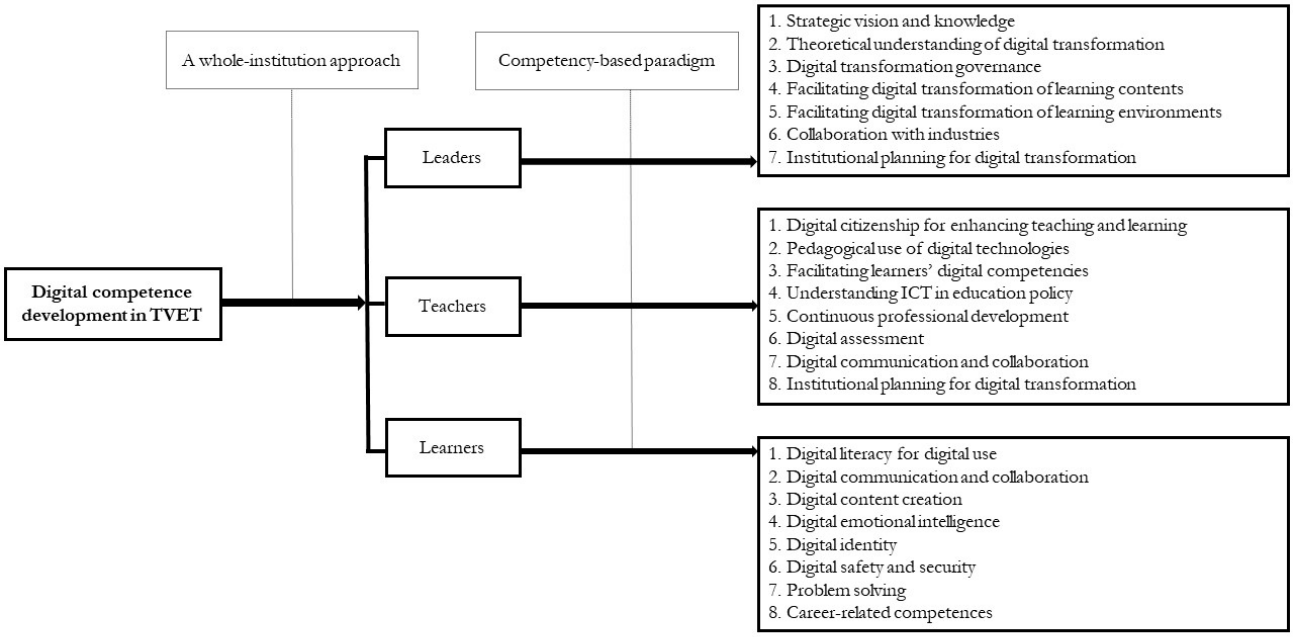

Figure 1. Framework of digital competence development in TVET with a competency-based whole-institution approach. TVET, technical and vocational education and training; ICT, information and communication technology.

for commonly emphasizing leaders' competences to initiate, manage, and enable the digital transformation process.[31–34] Both business and TVET leaders would need strategic vision and knowledge, theoretical understanding of digital transformation, and digital transformation governance in pursuing the digital transformation process. From the perspective of the education sector rather than the business sector, these digital competency areas of TVET leaders are also aligned with the UNESCO, ILO, and European Union strategies on TVET and skills development, which advocate TVET institutional transition towards digitalization, design of digital skills courses, and investment in digital infrastructures from the education management perspective.[20–22]

These competency areas conform to the general standards of a good education leader who shall be an "Equity and Citizenship Advocate", "Visionary Planner", "Empowering Leader", "Systems Designer", and "Connected Learner",[77] with particular emphasis on digital transformation in the settings of Industry 4.0.

For TVET teachers, the analysis of ICT CFT and DigCompEdu frameworks for teachers highlights relevant digital competency areas, including digital citizenship, pedagogical use of technologies, facilitating learners' digital skills, understanding ICT policies, continuous professional development, digital assessment, and communication and collaboration, which could empower TVET teachers to effectively leverage digital technologies in teaching practices, deliver desired digital skills to learners, and support lifelong self-development, as similarly argued by the existing literature.[6,7,35,36] To name some examples, digital citizenship can be exemplified by teachers modeling responsible online behavior and teaching learners about cyber ethics. The pedagogical use of technologies, digital assessment, and communication and collaboration in digital learning environments could be achieved through the adoption of smart classrooms or interactive e-learning platforms, which would enhance student engagement and facilitate personalized learning experiences. More specifically, a study demonstrates that the integration of digital storytelling in vocational classrooms significantly improved learners' digital expression skills and helped develop their disciplinary literacy.[78] Another example from a systematic review shows that teachers who underwent training in AR applications were able to create more immersive and interactive lessons, leading to higher learner satisfaction and learning outcomes.[79] Thereupon, development of these competencies helps teachers meet the requirement for "digitally competent" teachers in pedagogy, training techniques and digital skills provision, as presented in education agendas at international, regional and national levels.[24–28]

The summarized digital competency areas relevant to TVET learners have also been proven significant in

ongoing discussions because they enable learners' full participation in the digital society and economy. From the point of viewing TVET learners as digital citizens, ownership of generic digital competence, which involves digital literacy, digital identity, digital safety and security, and emotional intelligence, is the essential commitment of the skills provision systems admitted by international organizations like UNESCO, the ILO, and national governments.[20–23] Moreover, transversal skills relevant to the digital transition are also recognized as necessary to the UNESCO TVET strategy, which calls for the development of collaboration and civic competencies, creativity, social and emotional skills, and a sense of global solidarity.[20] These competencies correspond to the areas of digital communication and collaboration, digital emotional intelligence, and problem-solving, as listed in our findings. From the point of viewing TVET learners as future labor, mastery of digital content creation competencies and career-related competencies is believed to be an inevitable requirement to acquire or secure jobs in the digitalized world of work. This could be justified by studies on changing skills needs in digital disruptions, demonstrating that some traditional jobs are obsolete, and jobs in digital or digitalized sectors are emerging.[8–18] For example, TVET learners majoring in vehicle maintenance should be competent in using AR tools in failure analysis and repairing, which is a required career-related digital competency in the digitalized auto industry.

In theoretical terms, the competency-based whole-institution approach to digital competence development in TVET we put forward contributes to the literature on holistic mechanisms for digital competence development across the TVET system. While previous studies have examined digital competencies of specific education stakeholders like business leaders, teachers, and individuals, there has been limited research on integrated frameworks covering all key TVET actors.[6,7,31–33,36] Furthermore, the proposed approach substantiates the theoretical underpinnings of theories on CBE and the whole-institution approach. CBE's priority in mastery of competencies aligned with real-world needs makes it particularly suited for TVET's focus on developing TVET learners' vocational and technical skills for employability, and developing TVET practitioners' digital capacities for ensuring quality education.[41–55] The whole-institution approach, a concept from ESD, places emphasis on a shared vision, collaborative planning, and coordinated actions to achieve the common goal for sustainability,[57,58] which could also be innovatively used to serve the common goal of digital competence development. It is a significant theoretical innovation that this study, dedicated to investigating digital competency development in TVET, is grounded in the theoretical perspectives of CBE and a whole-institution approach.

CONCLUSION

This paper reflects on the imperative of integrating a competency-based, whole-institution approach to foster digital competence within the realm of TVET. The evolving landscape of the global job market, significantly influenced by the rapid proliferation of digital technologies, necessitates digital competencies from the workforce. Thus, there is a clear need for an adaptive and forward-thinking approach to digital competence development in TVET institutions, the foremost providers of TVET. Digital competence development is crucial not only for learners, who are direct beneficiaries, but also for leaders and teachers, who play pivotal roles in the implementation and success of these educational practices. Therefore, it should be a competency-based and whole-institution approach that has not yet been explored.

Through a systematic review and analysis of digital competence frameworks relevant to leaders, teachers, and learners, this paper proposes a competency-based whole-institution approach to digital competence development in TVET. The study synthesizes the distinct sets of digital competencies for each TVET stakeholder group, and integrates them into a unified framework. The findings reveal that TVET leaders require competencies in strategic vision and knowledge, theoretical understanding, digital transformation governance, facilitation of digitalized learning, collaboration with industries, and institutional planning. TVET teachers need competencies in digital citizenship, pedagogical use of technologies, facilitating learners' digital skills, understanding ICT policies, continuous professional development, digital assessment, and communication and collaboration. For TVET learners, essential digital competencies include digital identity, digital literacy, digital safety and security, digital emotional intelligence, digital communication and collaboration, digital content creation, problem-solving, and career-related development.

The research is practically and theoretically significant by proposing a competency-based whole-institution approach to digital competence development in TVET. The practical significance of this research lies in its actionable guidance for TVET systems to systematically develop the digital competencies of all key stakeholders, including TVET leaders, teachers, and learners, responding to the growing demand for digital skills and aligning with policy priorities. Operationalizing this approach requires aligning TVET curricula, pedagogies, TVET practitioners' professional development programs, and teaching and learning practices with the

identified digital competency areas, supported by strategic planning, resource allocation, capacity building, and multi-stakeholder partnerships. The theoretical significance of this research lies in that it fills the literature gap on holistic mechanisms for building digital competencies across the TVET system. By grounding the framework in the theoretical perspectives of CBE and the whole-institution approach, the study offers a novel and robust conceptualization of digital competence development in TVET.

Considering the natural limitations of review studies, as in this article, further research could focus on developing assessment tools and metrics, evaluating the impact of competency-based interventions, investigating contextual factors influencing implementation, and conducting comparative studies to adapt the framework to different TVET systems and sociocultural contexts. Different research methodologies could be adopted to generate validated findings about digital competencies in TVET, such as comparative research internationally, mixed-methods research, or even action research, including sub-implementations of various techniques and data sources. As digital technologies continue to evolve rapidly, the proposed competence development framework needs regular review and updating to remain agile and ready for the future.

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Author contributions

Zhong ZY: Conceptualization, Writing—original draft preparation, Writing—review and editing. Juwaheer S: Writing—Review and Editing. All authors have read and approved the final version.

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Conflict of interest

The authors have no conflicts of interest to declare.

Data availability statement

All data has been included in this paper.

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