



Frameworking vocational teachers' digital competencies: An integrative literature review and synthesis

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Abstract

Two decades of international research on the digital competencies of teachers have provided several frameworks for empirical studies and curriculum development. However, research publications addressing the needed digital competencies of vocational (VET) teachers are scarce. In this article, we ask to what extent leading conceptual frameworks on digital competence are fruitful templates for studying such competencies in the case of VET teachers' professional development, and what could be alternative conceptual models that fit this professional category. A synthesis is made of relevant literature based on a theoretical platform in vocational didactics and digitalization that highlights the diversity of international VET systems and the connectivity between work and school. We adopt an integrative literature research approach that combines systematic procedures and supplementary searches iteratively.

Our descriptive analysis of the literature indicated that the international research on VET teachers' digital competencies had in general a narrow focus on technical skills with a lack of perspective on key issues about their digital competencies such as connectivity school/work, subject-specificity, and adaptive pedagogy. The articles tended to leave out contextual issues, for example, the changing

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professional work of vocational teachers and background information about the national VET systems. However, part of the literature pointed to the need for more “grounded” research starting from case studies and qualitative data / mixed-methods research. Our synthesis of the literature in light of our theoretical framing identified four main topics for further research on VET teachers’ digital competencies that were incorporated in a working model or a “frameworking” that needs to be further developed to provide a rich and validated basis for constructing professional programs.

Keywords: *Professional digital competence, conceptual frameworks, vocational teachers, vocational education and training.*

Introduction

Recent expert reports from OECD (2021) and UNESCO-UNEVOC (2022) converge in concluding that the systems of vocational education and training (VET) were strongly impacted by the Covid lockdown necessitating new forms of technology-supported teaching and apprenticeships. However, the pandemic amplified a more fundamental process of digitalization in VET reflecting transformations in the labor market. Vocational teachers (VET teachers) are claimed to be more exposed to such changes compared with general education teachers due to industry demands and a practical orientation (Chakroun, 2019). The former also need to incorporate new technology in their teaching when preparing students and apprentices for working life. The OECD studies (OECD, 2021) identified digital divides along several dimensions substantiating the urgency for provisions that would strengthen the resiliency of VET systems. Although these initiatives used the European Framework for the Digital Competence of Educators (Redecker & Punie, 2017) as a template, they did not explicitly discuss its relevance for VET teachers. Considering the global trends referred to above, the reports concluded that VET graduates and their teachers would need stronger digital skills, even higher-order digital skills that enable the development of digital tools (OECD, 2022). A major concern was the contrast between these ideals and identified deficiencies in the digital competencies of VET teachers and trainers complicating the attainment of high-quality, learner-centered, technology-enhanced training (UNESCO-UNEVOC, 2022).

VET teachers are likely to be more exposed to digitalization than general education teachers for several reasons (Wuttke et al., 2020). Since they prepare students for a labor market where digital skills have become increasingly important, they need to be familiar with occupation-specific hard- and software and to incorporate digital tools into their teaching practices. Given the practical orientation of VET, technologies in the occupational fields may be used as learning tools and combined with digital systems that simulate real-world scenarios (Cedefop, 2020). Thus, a pertinent question is how these aspects of the interface between a digitalized working life and VET influence the profile of VET teachers’ digital competencies. In addition, does the diversity of vocational

subjects in comparison with the broad academic subjects of general education resist any uniform profile for VET teachers?

This article is based on project HELDAL in the initial Norwegian VET (upper secondary) that focuses on the need for VET teachers' professional digital competence development when new tools for bridging the learning arenas of school and work are implemented. In recent years, the literature that derives such competence profiles for general education teachers from digital competence platforms has grown substantially (McDonagh et al., 2021), but research publications addressing the needed digital competencies of VET teachers, are scarce. Given this back-curtain, we decided to do an integrative literature review (Torraco, 2016) of articles that use recognized international conceptual frameworks— either as templates for data collection on pre-service and in-service VET-teachers' profiles and/or as guidelines for curriculum development or design of professional development programs. We aim to identify key elements in a conceptual model of VET teachers' professional digital competence that highlights the connectivity between work and school. The theoretical basis for the review and model construction will be on VET teachers as a profession from an international perspective and key elements of vocational didactics.

Our first question will be to what extent the conceptual frameworks on digital competence, notably TPACK (Mishra & Koehler, 2006), DigCompEdu (Redecker & Punie, 2017), teachers' professional digital competence framework (Kelentric et al., 2017), are fruitful templates for researching such competencies in the context of VET-teachers' professional development. If these frameworks provide scant support for this aim, we will explore the constituents of a model that considers the specific position of VET teachers and key tenets of vocational pedagogy. In this context, our purpose is to develop a vocabulary for the advancement of knowledge and not a policy-oriented framework that defines common professional standards, etc. (Cattaneo et al., 2022), but our exploration could be a step in the process of frameworking. We intend to outline a conceptual model that could serve as a template for research and be validated for further elaboration in programs for VET teachers' digital competence development.

In the following sections, we first present excerpts from the research-oriented discourse on teachers' digital competence framework that are relevant to vocational teachers. We outline our perspective that will provide a background and categories that guide our literature review and synthesis bearing upon the construction of a conceptual model. Then we explain the design of our literature review and its implementation, including the synthesizing process. The integrative review format allows supplementary searches if the output of the review is not providing adequate answers. Thus, our synthesis includes literature that addresses VET teachers' digital competencies about specific issues

of technological integration in vocational subjects and connectivity. The last part is a synthesis and discussion of elements that may provide a template for research on the development of VET teachers' professional digital competencies.

Perspectives on vocational teachers' digital competence

In this section, we present and discuss some focal points of the discourse on teachers' professional digital competence, the professional context of VET teachers, and vocational didactics. It is highly selective in explaining concepts and themes that are instrumental for our literature review and the synthesis that substantiates the proposed conceptual model.

Focal points in the discourses on teachers' professional digital competence.

Recent reviews of the discourses on teachers' digital competence and associated frameworks concur in identifying a trend toward a broader conceptualization (Erstad et al., 2021; McDonagh et al., 2021; Lisborg et al., 2021). The European framework DigCompEdu (Redecker & Punie, 2017) went far beyond a model of technical mastery to include social, ethical, and professional aspects (Falloon, 2020; Lucas et al., 2021). It provides 22 specific descriptors in six areas where areas 2, 3, 4, and 6 specify the need to plan, implement, and assess teaching and learning. Area 5 underlines a student-centered approach and area 1 professional engagement. DigCompEdu features self-assessment tools, proficiency levels, and progression ladders inspired by Bloom's taxonomy. Compared with other and earlier digital competence frameworks and models, TPACK (Mishra & Koehler, 2006), is wider in scope but leaves out the specificities and constraints of different subjects (Caena & Redecker, 2019). The TPACK model is based on three primary interacting forms of knowledge (K); technology (T), pedagogy (P), and content (C). It explicitly draws on Lee Shulman's Pedagogical Content Knowledge (1986) by integrating digital proficiency with subject-specific ways of turning content (representations and procedures) into productive pedagogical formats. In his later work on "signature pedagogies" Shulman (2005) elaborates on the content and pedagogy forms in vocational subjects such as Hairdressing, Construction, and Health Care as distinct from the teaching of academic subjects such as Chemistry, Language, etc. (Hobley, 2021). Drawing on this framework, subject-specificity in the vocational field entails a distinct priority on three dimensions: (1) operative practical teaching skills, (2) transformative skills, and (3) professional attitudes and values (Hobley, 2022). The TPACK model and associated literature do not include discussions of these crucial differences in subject-specificity between vocational and academic subjects.

The conceptual framework PDC Framework includes the focus on pedagogical content knowledge associated with the TPACK model but aligns with the broader contextual scope of DigCompEdu (Ottestad et al., 2014). It also underlines the need for teachers' transformative agency in new professional roles (Brevik et al., 2019). The PDC approach has gained currency in the Nordic discourse and a wider international area (Godhe, 2019). Recently, conceptualizations advocating person-centered, adaptive tools (Tondeur et al., 2021) and stronger attention to attitudinal dimensions (Camilleri et al., 2021) have been implemented in the PEAT framework, which sorts competence dimensions into pedagogical, ethical, attitudinal, and technical dimensions (McDonagh et al., 2021). Without assuming a simple chronology in the nearly two-decade-long discourse on teachers' digital competence and relevant frameworks, we highlight the following focal points or elaborations of the "sliding frameworks" (Voogt et al., 2012); technological, contextual, subject-specific, transformative, adaptive, or person-centered. These categories are meant to be useful for our review and synthesis of the literature (Table 1 below). The expanded versions of digital competence frameworks for teachers align well with the dimensions above derived from Shulman's "signature pedagogies" in the vocational field. However, the nearly 20-year scholarly debate about "sliding frameworks" for understanding digital competencies in education does not address the case of vocational teachers.

The diversity of vocational teacher education and key elements of vocational didactics with digital resources

The literature on international comparative studies of national systems for VET has proposed several typologies, of which the regulatory is the most common (Pilz, 2016). It distinguishes between systems that are market-led, politically controlled, or mixed. To some extent, these types overlap with different forms of curricular integration of school-based and work-based education and training, but alternating learning situations range from largely unregulated work-based learning to apprenticeship schemes within a VET system (Grollmann, 2018, p. 78). From a structural functionalist point of view, new labor-market needs in terms of 21st Century Skills will have a stronger impact on the vocational curriculum, quality standards, and learning outcomes compared with the general education sector as we pointed out above (Fischer, 2020). Such mechanisms are mediated by historical and cultural contexts (Gessler & Moreno Herrera, 2015) and possibly by national and transnational initiatives to establish common qualification frameworks. There is, however, scant evidence that national qualifications in VET are being used as reference points for defining vocational teacher competencies and qualifications (Chakroun, 2019). Even the adopted European VET teachers' professional standards do not easily align with national reforms of qualification systems (Chakroun, 2019, p. 372). Such discrepancies could be traced back to the fragmented character of vocational

teachers' professional position and their "double subject reference" (Bünning et al., 2022), which is a joint reference to the occupations in a vocational area and the corresponding vocational subjects.

When addressing the digital competence of VET teachers, one needs to consider that for several reasons their formal qualifications are lower compared with general education teachers (Broek et al., 2017). According to the OECD study *Teachers and Leaders* (OECD, 2021), it may reflect the flexible and alternative tracks for initial teacher education where in some countries work experience and trade exams may be the major entrance requirements. Moreover, VET teachers' skills can be in high demand in occupations other than teaching, making it harder to recruit and retain VET teachers in related subjects. Consequently, turnover and age of VET teachers in the OECD area is somewhat higher compared with general education teachers (OECD, 2021). A shortage of VET teachers in many European countries has resulted in the recruitment of educators without formal teacher education (Hoppe & Kaiser, 2021) which in turn may have lowered the attractiveness of the VET-teacher professional role (Billett, 2020). Thus, national, and transnational initiatives are taken to raise the attractiveness of the VET professions by prioritizing a conversion to bachelor's and master's degree programs (Bünning et al., 2022). These trends in mobility, labor market position, and formal qualification profile differ strongly between vocational fields and are contingent on both country-specific and international historical patterns (Hoppe & Kaiser, 2021). They add greater complexity to the understanding of professionalism, quality development, and competence frameworks for VET teachers compared with general education teachers.

Vocational didactics is maintained as essential to VET teaching and teacher education, but scholars diverge about the definition of this concept (Gessler & Herrera, 2015). Often, "vocational didactics" is equated with "work-based learning" reflecting the originator's position along the duality continuum (Fischer, 2020). Representatives of dual models tend to underline formal and normative aspects of teaching when vocational subjects are integrated with work processes as learning arenas (Pilz, 2016). Thus, there are in principle specific vocational didactics for each vocational subject, in the German case roughly about 330 vocational subjects or "occupations requiring formal training" (referred in Bünning et al., 2022). In Table 1 we have clustered these subjects in 7 vocational domains based on Lucas et al. (2021) classification of vocational subjects that involves (1) working with people, (2) handling of physical materials and (3) dealing with symbols. This horizontal structure is subject to cultural-historical embedding and interacts with a vertical dimension that defines qualification levels (Gessler & Moreno Herrera, 2015). By implication, vocational didactics emphasize subject-specificity (Bünning et al., 2022) and temporality asking for continuous VET framed by the changing nature of

work. This complexity underlies the need for transformative agency and digital self-efficacy for both students/apprentices and vocational teachers (Roll & Ifenthaler, 2021).

Digitalization affects vocational didactics along several dimensions. It transforms the classification of occupational domains and vocational subjects (Wuttke et al., 2020) and provides new tools for productive work that may be turned into learning resources for apprentices, trainers, and vocational teachers. A direct impact on vocational didactics is the affordances provided by technology-enhanced learning environments in school to simulate work situations and authentic problem-solving (Hämäläinen & Cattaneo, 2015). Multiple ways of bridging the school and work gap are facilitated by digital tools as “boundary objects” (Akkerman & Bakker, 2012) that may generate common visions, goals, and improved exchange, reflection, and joint action (Kilbrink et al., 2021). In the discourse on such connectivity, it may be useful to distinguish between connectivity that integrates knowledge and skills through the facilitation of learning processes and connectivity from a curriculum design perspective (Tynjälä et al., 2022). Whereas digital tools such as simulators support the former, ePortfolio systems facilitating transversal process evaluation across VET schools and workplaces are examples of the latter (Lahn & Nore, 2018). Digitalization may widen or bridge digital gaps in VET, an issue that should have high priority in vocational didactics given the diversity of teachers' and students'/apprentices' technical skills (Choy et al., 2018). Thus, the digital competencies of VET teachers that enhance personalized instruction and an adaptive pedagogy are addressed in our review.

In sum, the purpose of this section is to indicate how the two main perspectives, on the discourse of digital competence frameworks and vocational didactics, could be interconnected in providing a theoretical platform for the coding and synthesis of the literature review including the exploration of a conceptual model.

Explorative literature review

Torraco (2016) makes a distinction between two types of integrative literature reviews—ones that address mature topics and ones that venture into emerging topics with contested concepts. Our version belongs to the second category that according to the author should generate a preliminary conceptualization of the topic. As a thematic guide for our decisions about relevant literature and the descriptive part of our synthesis, we used a predefined coding scheme partly based (Table 1) on our theoretical inquiry. The three frameworks of teachers' digital competence are prominent in the academic debate on this topic, and we exclude policy-oriented frameworks. The classification of vocational domains is based on Bünning et al. (2022). We include VET trainers in the educator

category to cover work-based VET systems. The variables related to research design, data types, and sample size are identified by our review of the debate on teachers' digital competence frameworks presented above which also has determined our coding of teacher profiles. This variable also draws on our presentation of vocational didactics and the context of VET and VET teachers. Thus, it is related to the variable "specific VET issues" that are targeted in our study. The variable "proficiency levels" refers to the grading of VET teachers' digital competence in the reviewed articles.

Table 1. A coding scheme for the literature review.

Variable	Coding
Dig. comp. framework	TPACK. DigCompEdu. Professional Digital Competence (PDCFramework).
Vocational domain	Industry, energy. ICT, media. Business, administration. Agriculture, nutrition, food. Health, social care, education. Tourism, transport. Design, handcraft
Educator category	Pre-service VET teachers. In-service VET teachers. VET trainers.
Research design/data n=	Survey QUAN. Experiment QUAN. Case study QUAL. Observation QUAL Design-based research QUAL Survey and interview MMR
Teacher profile / Proficiency level	Technological. Contextual. Subject-specific. Transformative. Adaptive. / High. Medium. Low
Specific VET-issues	School/work connectivity. Digital integration of vocational subjects. Adaptive pedagogy. Digital self-efficacy.

The integrative review aims to provide coherence and clarity about the relationship between the main concepts of the topic, and it balances coverage criteria of representative (unbiased) and pivotal (key literature) selection but does not pretend to be exhaustive. The steps in our review were first to search and select peer-reviewed articles and occasional papers (in proceedings) of specific relevance published in the last 15 years. Queries were made in Web of Science, Scopus, ERIC, Social Science Citation Index, specific databases for VET research, such as VOCED+, and by citation tracking / manual searches in VET journals. The combinations of keywords "digital competence*" OR "ICT competence*" OR "digital literacy*" OR "digital skill*" AND "vocation teacher* OR "VET teacher" and "vocational education" OR "vocational training" provided 145 publications when duplicates were removed. 48 publications were eligible for full-text reviews after a screening of abstracts and a tentative adherence to our inclusion criteria: Publications in English, German, and Scandinavian languages based on empirical studies. The core literature presented in Appendix 1 comprehends a subset of fully reviewed publications (n=15) that use TPACK, DigCompEdu, or similar frameworks as models or templates for survey development. A contrasting set of publications (n=14) without any references to such frameworks is not included in Appendix 1. We have analyzed both sets for relevance based on the coding scheme (Table 1).

In line with the principles of integrative literature reviews, we made supplemental and targeted searches that would provide a deeper understanding of our research themes after our descriptive analysis of the core literature and the contrasting set. These added references are included in our

synthesis of both the theoretical framework, the descriptive analysis, and the key themes of this article (VET issues in Table 1). Our goal is to let this exploration be a step towards the identification of basic elements in a model of vocational teachers' digital competence. The synthesis follows the basic tenets of "comparative analysis" when the categories and the structure of the descriptive analysis and the theoretical framework are refined in a systematic comparison of similarities and differences (Wolfswinkel et al., 2013).

Descriptive analysis of core and supplementary literature

Descriptive analysis

The purpose of our descriptive analysis is to identify relevant patterns in the publications summarized in Appendix 1 and the contrastive set of publications. As shown half of the records are published in 2021 and 2022, and several articles refer to the Covid lockdown and to international observations that this incident struck the VET sector especially hard (UNESCO-UNEVOC, 2022). According to our review, it also had a strong impact on the variables that we have highlighted in the coding scheme. In several publications, the emphasis was on technologies for distance teaching and a concern for vocational teachers' low intention to use digital tools. Regarding the teacher profiles that were focused on (see Table 1), a clear majority of the publications dated 2021 and 2022 underlined technological proficiency. Such competencies were self-assessed as low or average, but only in three records (Agrati, 2019; Alhonkoski et al., 2022; Gustavsson et al., 2020) do the authors provide a differentiation of specific digital resources and refer to contexts. Although the TPACK model advocates the integration of professional pedagogical competence and technological skills, some of the papers departing from this model did not address the pedagogical aspects. Another feature that may be attributed to the COVID-19 lockdown was the methodological preference for online surveys. The TPACK framework inspired nearly all the records in the appendix overview with only a few using the validated questionnaires in full. More often, a subset of items was selected and combined with items derived from other instruments, such as the Spanish national framework INTEF (Sanchez-Prieto et al., 2020). In five articles, the authors claimed that the scales were adapted to VET, but only in one case was this revision made explicit (Roll & Ifenthaler, 2021). Still, these articles concluded that their validation of the measurement tools' factorial structure for the selected group of in-service VET teachers was successful. The overview in Appendix 1 shows that in several publications the TPACK framework served as a model for the construction of ad-hoc questionnaires or as a methodological

platform for categorization of observation and interview data from a qualitative research perspective.

Cattaneo et al. (2022) developed the Digital Competence Scale for VET by adding seven VET-specific items to the DigCompEdu. 2.0 self-assessment instrument (Lucas et al., 2021) to measure competence beliefs about technology use that supports connectivity between learning locations in school and work. The latter was explicitly included in subscales in terms of (1) teachers' technology use for communicating and collaborating with colleagues, trainers, and external partners, and (2) teachers' ability to integrate technology in the learning process that fosters connectivity between theory and practice. The authors refer to the Erfahrungsraum model (Schwendimann et al., 2015) that we below present and discuss. Their study confirmed the importance of VET teachers' attitudes toward technology use, an issue that is likewise highlighted in several of our listed publications. In their differential analysis of VET teachers' digital competencies, Cattaneo et al. (2022) do not include potential differences between vocational domains.

The school/work connectivity theme was addressed in three publications that referred to the TPACK, often combined with the issue of subject-specific integration of technology and pedagogy. Roll and Ifenthaler (2021) refer to multidisciplinary skills as the new pedagogical content for VET teachers in the Industry 4.0 context. Their study of pre-service VET teachers in business administration indicated that the dimension "application of digital security" had the strongest relationship with self-assessed and demonstrated multidisciplinary digital competence. The authors do not discuss to which extent this result may be specific for VET teachers in this domain. With ethnographic data from a very different field, forestry, and agriculture, Gustavsson et al. (2020) problematize notions of "boundary crossing" between school and work. In their study of simulation-based training of students learning to drive forestry and harvesting vehicles, the authors show how the drivers conceive the use of high-fidelity simulators as play and not real work. The teachers had to invent support structures that amplified and clarified to the students the differences between driving in a simulated context and an authentic one. The study of Alhonkoski et al. (2022) on the use of 3D simulation in the training of healthcare workers identifies attitudes and emotions among vocational teachers in this field that may prevent them from engaging with this type of technology. To sum up this section on connectivity, this issue is conceived differently in the vocational domains referred to above, but in a couple of cases, the digitalization of tools for work and learning becomes the subject content for pedagogical reflection.

Connectivity to vocational domains relates to our second main issue of digitalized vocational didactics – its integration into the specific VET subjects. Despite the acclaimed insistence of the

TPACK model on the importance of pedagogical content knowledge, the publications in our list do not make comparisons across subjects of the digital competence profile of VET teachers. Similar findings are reported for general education teachers (Starkey, 2020), with the reservation that the latter are often pre-service teachers. Addressing the theme of pedagogical integration of technology in specific subjects. Rahmawati et al. (2021) identified a clear discrepancy between the self-assessed competencies of Indonesian vocational teachers in pedagogical technology integration and their practice in lesson plans. Hobley (2022) made similar observations among vocational teachers, who during the Covid-lockdown explored new online communication tools but did not demonstrate “digital wisdom” according to the author. They lacked a transformative capacity to use digital resources for quality improvement of their teaching and learning. Innovative pedagogy is illustrated by Agrati (2019) who describes how four vocational teachers in Mechanical Technology adapt subject-specific content, millimeter measurement, into digital subject-specific content with the use of interactive power-points for students with dyslexia. In the concluding discussion, the author identifies a “sub-track” competence that goes beyond the TPACK model in adapting the pedagogical content knowledge to the students’ specific needs. Adaptive pedagogy, one of the issues we included as key elements in vocational didactics, is only addressed in this article besides being integrated as one of the subscales in the Digital Competence Scale for VET (Cattaneo et al., 2022).

To summarize, it was no surprise that most articles were not addressing our key issues such as connectivity between school/work, subject specificity, and adaptive pedagogy. As mentioned above, the urgency of updating VET teachers facing the Covid lockdown seemed to have narrowed the thematic and methodological focus in our sample. The articles tended to leave out contextual issues, for example, the changing professional work of vocational teachers. Thus, we found no publications that used the teachers’ PDC Framework (Ottestad et al., 2014) in understanding the digital competence of VET teachers. Often background information about the national VET systems was lacking in the selected articles. The context of Indonesian vocational teachers and their UK counterparts not only represent contrasting cultural ecologies but also structural poles – the first a school-based variant (UNESCO-UNEVOC, 2020) and the second a market-based variant. Given the diversity of VET structures, literature reviews with an ambition to perform an international comparative study face the challenge of having to compare “apples and oranges”. One solution is to compare only versions of dual-VET (Pilz, 2016).

The non-listed publications echoed the listed in terms of publication years (8 out of 12 in 2021 or 2022), the use of self-assessment instruments, and an even stronger focus on technological proficiency or “maturity”. In both sets, a couple of articles surveyed age and gender differences in

VET-teacher's digital competencies and technological acceptance with mixed results and without relating these figures to vocational domains (Sanchez-Prieto et al., 2020; Saripudin et al., 2021). Three articles based on research from VET systems with duality (Enochsson et al., 2021; Havreberg & Sylte, 2021; Vilppola et al., 2022) address the challenges for VET teachers with integrating competencies when technologies in workplaces require different digital skills compared with technologies in vocational schools. Havreberg and Sylte (2021) describe the context of VET teachers in health care with students that must deal with welfare technologies such as Smart Houses etc. when they are outplaced in-home care units. The teachers report a lack of competence when it comes to such digital resources.

Since the systematic review only provided a limited view of the specific aspects of VET teachers' digital competence development, we made supplemental literature searches guided by our tenets of vocational didactics and selective results from our first review.

A complementary perspective on the development of VET-teachers' digital competence profiles

An alternative and possibly complementary research strategy to the one reviewed above could be to study VET teachers' professional digital competencies in a more explorative and casuistic way. Two articles in our selected literature illustrate this approach. Villalba et al. (2018) studied the digital competence requirements for vocational teachers who wanted to implement a "flipped classroom" in a successful way. Kämäräinen et al. (2019) reported on transnational research and innovation projects in VET that were to generate new digital learning resources for VET teachers' professional development in several occupational domains. The authors conclude that the DigCompEdu framework is not context-sensitive to "...the multiple learning venues and different contributing partners in the field of VET..." (p. 193). However, Cattaneo et al. (2022) indicated that their revision of this framework is consistent with research efforts that deepen our understanding of technology integration in different vocational domains. As pointed out above, the authors referred to the Erfahrungsraum pedagogical model (Schwendimann et al., 2015) that has served as a conceptual platform for the DUAL-T project engaging several studies in Swiss VET over 15 years (2007-2021 according to Dillenbourg et al., 2022). Their focus has been on new technology-enhanced instructional strategies that support effective alternation of learners' experience across the learning sites in dual VET, for example digital "learning documentation" and ePortfolios (Caruso et al., 2016). This approach adds to the relevance of searching the literature on the DUAL-T project and similar studies of technology integration in VET (Kyndt et al., 2021). However, our main rationale for this extension is to outline an alternative approach to the development of VET teachers' digital

competence profiles that takes into account the above diversity of VET. We will make a cursory visit to the research inspired by the Erfahrungsraum model, which is well-documented in several reviews (Cattaneo et al., 2021; Dillenbourg et al., 2022).

The basic idea of the Erfahrungsraum model is to illustrate connectivity between work and school in VET as basically an iterative process facilitated by digital artifacts, for example, mobile devices (Dillenbourg et al., 2022). These are functional in capturing “traces of experience” from authentic or simulated work contexts as a first step of externalization that facilitates a review of such events as raw digital artifacts in a context for reflection. This activity needs to be stimulated and scaffolded in terms of relevant experience that may be enriched through video annotations. In analyzing routine and rare experiences, a process of comparison and categorization generates generalizable knowledge grounded in authentic or simulated data. This externalized knowledge is recontextualized (Guile, 2019) when validated in the context of work after this process of augmented reflection. Reviewers of the DUAL-T research have concluded that the implementation of the Erfahrungsraum model in several demonstration projects across vocational domains and a variety of digital resources provides solid evidence for enhanced effects on learning outcomes across the school and work boundary (Hesse et al., 2022). They added that one of the most promising avenues for pursuing its legacy is in research on VET education and professional development (p. 109). However, the design-based studies did not explicitly address VET teachers' digital competence profiles or competence development. Cattaneo et al. (2019) acknowledge that the differential effects of implementing the Erfahrungsraum model across vocational domains and digital resources need further clarification. In addition, they are explicit about the limitations due to VET structures that deviate from the Swiss dual model with frequent alterations every week. If these are organized partly sequential with school attendance followed by apprenticeship, such as the Norwegian variant, connectivity across such time scales is enhanced by implementing through-going ePortfolios (Lahn & Nore, 2018).

Synthesis: A middle-range framework of VET teachers' digital competence

A synthesis based on the review analysis and supplementary searches

Our first research question was about the fruitfulness of the selected three digital competence models as templates for the development of technology-enhanced competence and professional development programs for VET teachers. Given the meager results of our literature review, we are not in a position to pass strong judgment on this matter. However, we agree with some of the selected articles on digital competence frameworks for teachers that the underlying model is too

general (Caena & Redecker, 2019) – at least, for the purpose formulated in our research question. If such a conclusion is valid for educators in general, it seems even more appropriate for VET teachers given the complexity of the latter professional roles and teaching context. Among the three main frameworks reviewed above the PDC Framework includes dimensions that align well with Schulman’s “signature pedagogies” such as a contextual understanding of pedagogical content knowledge, a focus on teachers’ transformative professional roles, and attitudinal aspects. Still, the PCDF was never used in the studies of VET teachers that we have reviewed, and except for the recent Swiss slightly revised version of DigCompEdu (Cataneo et al., 2022), this literature did not discuss how the two main frameworks, TPACK and DigCompEdu, could be modified to take into account the specific nature of VET. Thus, concerning our second research question about the need for such a modified model, our literature review has strengthened the relevance of this option. In the next sections, our synthesizing discussion aims to lay a couple of cornerstones for such a proposal.

We have defined four key issues that a conceptual model for VET teachers’ digital competence should address: Connectivity between school/work, vocational subject specificity, adaptive pedagogy, and digital self-efficacy. The first theme is closely connected to the second as demonstrated by the DUAL-T research. In terms of connectivity, this project focused mainly on digital tools for bridging learning processes and less on a curriculum integration perspective (Tynjälä et al., 2022). The digital pedagogy for boundary-crossing in VET represented by the Erfahrungsraum model provides rich empirical material for understanding effective vocational teacher performance, but it is less explicit about how digitalization restructures VET teachers’ professional roles and these aspects of competence profiles. In addition, subject specificity and contingencies related to vocational domains are not clearly addressed, although Cattaneo and Aprea (2018) admit that the design principles of DUAL-T fit with a visual culture typical of occupations that handle physical material. In a review of mainly simulation-based methods (Virtual Reality, Augmented Reality, Serious Games, etc.) Aarkrog (2021) refers to technology integration frameworks implemented in Australian VET (Reich et al., 2021). These tools are less pretentious in terms of bridging connectivity between school/work than the Erfahrungsraum model but could be heuristic methods for mapping levels of integration and teacher competence requirements in structured VET-teaching environments.

As pointed out above, our review of the TPACK model and its incorporation of Shulman’s pedagogical content knowledge did not contribute to a deeper understanding of competencies needed by VET teachers when integrating technology and pedagogy in specific subjects. Agrati (2019, p. 7) referred to DigCompEdu when describing “sub-track” competence which includes the teachers’ ability to select/modify/manage existing digital resources in a vocational subject and transform and adapt

them to students' achievement levels. Except for this article, the issue of digital competencies supporting adaptive pedagogy in terms of personalized teaching was not addressed in our review. A supplementary search in the literature guided by these topics provided a map of challenges and technology-enhanced instructional strategies. Recent literature has increasingly addressed the teachers' digital competencies needed when facing the downsides of digitalization (Hatlevik et al., 2021) in terms of students' distractions from learning tasks, copying of content, fragmented group work, etc. We may assume that these aspects are of special importance in VET given the serious motivational issues in terms of high dropout rates and a large variation in students' abilities (Krötz & Deutscher, 2022). However, the potential negative impacts of digitalization on VET students' learning are an under-researched area (Wuttke et al. 2020). Still, an adaptive pedagogy could include the use of digital media as pedagogical resources to establish differentiated learning trajectories (Hansen & Karim, 2020), compensatory teaching with assistive communication modes (Douse & Uys, 2019), scaffolding techniques, innovative assessment supporting self-regulation and personalized learning and empowering strategies with the development of personal learning environments, PLEs (Korhonen et al., 2020). The digital competencies that are identified for the implementation of such an adaptive approach concur slightly with sub-scale descriptions of the DigCompEdu, notably Empowering learners, area 5 as indicated by Amenduni et al. (2022, p. 55). VET teachers with high digital competence tended to have positive views on personalized teaching strategies. However, the digital implementation of differentiated learning trajectories is also dependent on connectivity between school/work in terms of curricular integration, which is a major focus of the HELDAL project. Again, the competencies to meet changing professional roles are crucial for VET teachers in the era of digitalization.

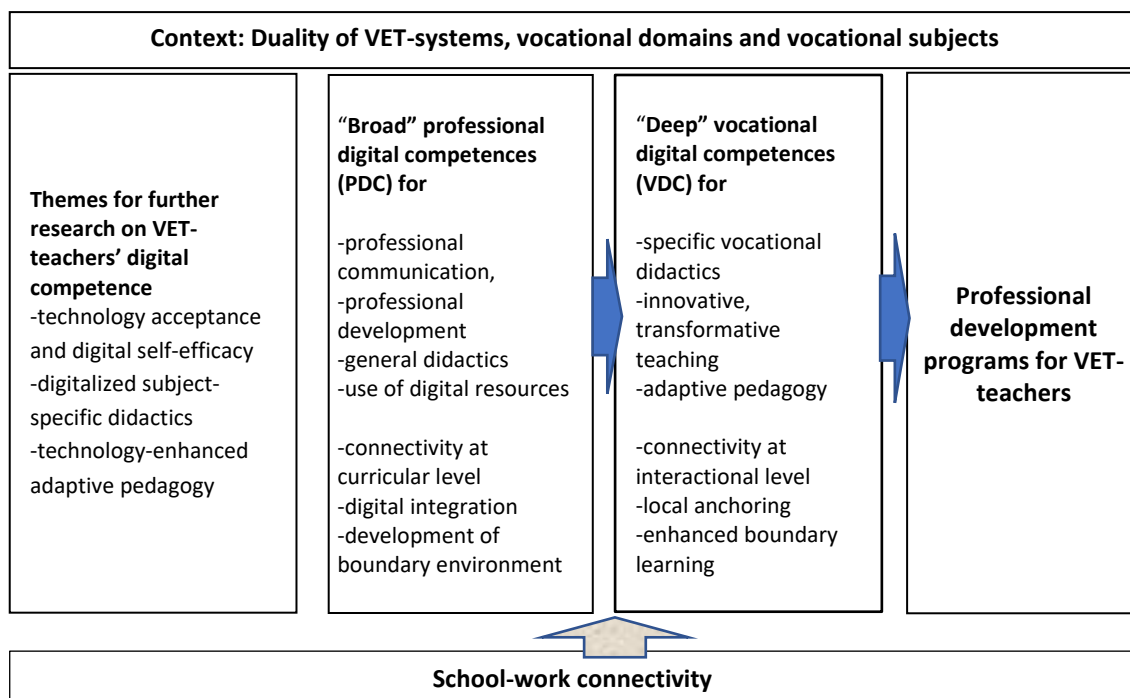
Several articles in our core literature addressed the interaction between digital self-efficacy and VET teachers' attitudes toward the use of technology. In line with research on general education teachers (Backfisch et al., 2021). Antonietti et al. (2022) underline the importance of VET teachers' beliefs in their digital competencies for integrating technology into their teaching. In our introduction above, we referred to VET teachers being exposed to technological innovation in their subject area and to the challenges of redesigning such tools for learning activities. In addition, digital teaching tools are introduced such as learning analytics using students' and apprentices' online behavior as traces of their learning strategies and progress (Niegemann, 2020). How the aggregate effects of these trends affect VET teachers' perceived utility of the technology, and their digital self-efficiency is a topic in need of research.

A middle-range framework for research on vocational teachers' professional development

Below we will weave together the different threads of our review and synthesis into a conceptual model of VET teachers' digital competence that may provide a template for studies on VET teachers' digital competence profile and professional development for this occupational category (Figure 1). The lesson from our exploration of the literature is that research on these issues needs a higher priority – tentatively along the following tracks:

(1) Although we were no able to assess in full the fruitfulness of the reviewed models, we agree with Cattaneo et al. (2022) that a product-oriented framework such as the TPACK should be replaced with a more process- and action-based. In our case, we highlight themes for further research, and a combination of the PDCFramework and DigCompEdu seems fit for such a purpose. The former would put a stronger emphasis on the changing nature of VET teachers' professional roles.

Figure 1. A conceptual model for frameworking research on VET teachers' digital competence



(2) With reference to the sociologist Robert Merton (in Hedström & Udehn, 2009) we outline a middle-range conceptual framework that provides leads for research grounded in specific empirical domains. By combining research methods, exploratory studies could be subject to systematic

validation and aggregation (Guetterman et al., 2019). Such a strategy is defensible given the complexity of VET and the deficit in terms of research efforts.

(3) This grounded approach implies that international comparisons need to consider the national contexts of VET. As a starting point, we presume that our framework is primarily valid for VET systems that have variants of duality school/-work.

In the discourse on teachers' digital competence frameworks, a returning theme has been the relation between contextual factors such as access to digital resources, support, etc., and personal factors such as attitudes to technology, age, etc. Although this distinction is more blurred for VET teachers (Alhonkoski et al., 2022; Roll & Ifenthaler, 2021), we will differentiate between "broad" professional digital competencies (PDC) and "deep" vocational digital competencies for VET teachers (VDC). The former is comparatively more generic and linked to professional roles and engagement as VET teachers, whereas the latter refers to technology-enhanced subject-specific didactics that often need to be personalized to the learners' proficiency levels and innovated on the spot, which we above have referred to as adaptive pedagogy (Agrati, 2019). In Figure 1 we indicate that these two categories also relate somewhat differently to connectivity between school and work: PDC to the curricular level and the sustainability /development of a boundary environment (Tynjälä et al., 2022; Bouw et al., 2019) and VDC to the interactive level where learning enhancement may be supported by effective boundary objects (Akkerman & Bakker, 2012). A rationale for this distinction is indirectly provided by The Norwegian National Curriculum Frame Plan for Vocational Teacher Education (National Council of Teacher Education, 2018) and European guidelines for integrating digital competencies in vocational subjects (Cedefop, 2020). Whereas the "broad" professional level is amenable to formalized quality criteria, the "deep" vocational level should resist very detailed descriptions of digital competencies and provide a scope for vocational teachers' autonomy in practice and personalized teaching (Tondeur et al., 2021). The digital competence frameworks have been criticized for stifling teachers' innovative practices (McDonagh et al., 2021). As guidelines for VET teachers' professional development, "stand-alone" courses should provide adequate learning in "broad" themes such as basic skills in algorithmic thinking that may support technology acceptance and usability beliefs. On the other hand, the "deep" track for digital competence development is more personalized and integrated with innovations in instructional practices (Lyckander, 2021).

Figure 1 indicates that the profile of VET teachers PDC and VDC could serve as a template for further research on the three themes that our review has highlighted as important. The school/work connectivity issues run through these themes. The frameworking aspect of the model is enhanced by its strategic importance to the construction of programs for VET teachers' professional development.

A middle-range approach could also use models or platforms for digital pedagogy such as the Erfahrraum or ePortfolio / through-going documentary tools as templates for research activities on the targeted issues. However, as shown, the different elements are dependent on contextual factors such as the duality of VET systems and vocational domains/subject specificity.

We have commented above on the dominating use of self-assessment scales in the validation and development of the digital competence frameworks – both for VET teachers and teachers in general. The DUAL-T research differed in this respect since efforts were made to get evidence of proficiency in practical situations combined with self-reports (Dillenbourg et al., 2022). Video-based studies have proven to generate rich empirical support for the development of VET teachers' professional vision (Evi-Colombo et al., 2020) and could be developed into instruments for digital competence assessment. An alternative measurement approach would be to use problem-solving tests, but valid instruments of this kind need to be developed for VET teachers (Zhao et al., 2017). To summarize, there is a need to do more explorative research such as multi-case studies, to identify phenomena and patterns with high ecological validity. For example, the exposure of VET teachers in the different vocational domains to digitalization. This type of qualitative research could be integrated with comparative and systematic research that has a stronger confirmatory aim. Such multi-phase mixed method research (Schrauf, 2018) is likely to improve the empirical basis for a more nuanced common language about VET teachers' digital competence that could be a conceptual model for their professional development in an era of digitalization.

Conclusions

We expected that the 15 years long discourse on conceptual frameworks of teachers' competence would have yielded more relevant research for our focus on VET teachers' professional development. Moreover, the large number of articles published in 2022 was quite uniform reflecting the need to upskill VET teachers in distance teaching strategies during the Covid shutdown. Our review should contribute to the field by identifying what is lacking in the literature, and we think that reporting "null sum" findings is in principle an important research task (Franco et al., 2014). However, our strategy of pursuing fruitful paths in the review by doing supplemental searches strengthened the adequacy of the literature sources for our frameworking. Intertwined with the theoretical platform our synthesis provided a richer basis for further studies on VET-teachers' digital competence profile and arguments for a priority of three main themes to fill the identified knowledge gap. Of the four themes that we framed as key VET issues; school-work connectivity, digital self-efficacy, digital

integration of vocational subjects, and adaptive/personalized pedagogy, the last two were nearly absent in the literature.

Our ambition to construct a conceptual model of VET teachers' professional development and digitalization was transformed into a framework for research that advocates a middle-range approach more sensitive to the diversity of VET and its national contingencies (dualities, Fischer, 2020). The stepwise character of such a research strategy also includes a priority of multi-phase mixed methods design. We think this frameworking would provide a richer basis for constructing professional development programs. It aligns with the conclusions of Aarkrog (2021, p. 15) that the relevant competencies described in the reviewed literature are primarily generic didactic principles transferred to a blended teaching context and that we lack a deeper understanding of how vocational-specific digital competencies are transformed in such processes. We would add that both contextual and individual perspectives are needed when designing research that may fill this gap.

A limitation that our study shares with the research on teachers' digital competence are the burden of having to work with vague concepts (Blikstad-Balas, 2014) such as "competence", "skills", and "qualifications" in a discourse that often weaves together research-based and policy-oriented definitions (Cattaneo et al., 2022). We planned to include a conceptual analysis, but this is a huge task without clear scientific guidelines (Collier & Gerring, 2008). We then expected that an explorative literature review would bring some clarity to this issue. However, it provided no clear answers to our inquiry, and further research on teachers' digital competence should give priority to establishing a better nomenclature in this field (Antera, 2021).

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Appendix 1

First author. Year. Title. Peer-reviewed article / other	Country	Teacher category / vocational domain	Dig. Comp. framework	Research design / Data collect. / n=	Teacher profile / Proficiency level	Specific VET-issues	Authors' main conclusions	Relevance for our study
Agrati, L.S. (2019) Digitizing disciplinary contents. A case-study on sub-track competence. Proceedings.	Italy	In-service / Industry and energy (Mechanical technology)	TPACK-model	Multi-case QUAL./ Observation and interviews / n=4 + n=52	Adaptive. Subject-specific. / More adaptive approach needed.	Digital integration of vocational subjects.	Overcoming the TPCK-framework. Favors an adaptive model	Highly relevant. Addresses subject-specificity etc.
Alhokonkoski M. (2022) The Perspectives of Healthcare Teachers on Their TPCK of Three-Dimensional Technology. Peer-rev.	Finland	In-service / Health, social care and education. (Health care)	TPACK-survey	Survey n=55 and interview n=17 MMR	Subject-specific. Technological 3D / TPCK quite good (self-report)	Digital integration of vocational subjects.	Emphasis on motivation, attitudes and acceptance	Relevant focus on attitudes and motivation.
Antonietti, C. (2022) Can teachers' digital competence influence technology acceptance in vocational education? Peer rev.	Switzerland	In-service / No data on vocational domains	DigCompEdu revised TeacherDigital Competence Beliefs	On-line survey QUAN / n=2011	Technological / Belief in own dig. competence likely to use dig. tools	Motivation and attitudes.	Relationship between beliefs about and use of dig tools in VET teaching	Relevant focus on technology acceptance and attitudes, motivation.
Cattaneo, A.L. (2022) How digitalised are vocational teachers? Assessing digital competence in vocational education and looking at its underlying factors. Peer rev.	Switzerland	In-service / No data on vocational domains	DigCompEdu revised for VET	On-line survey QUAN / n=1692	Contextual / Digital resource selection highest	School-work connectivity	Pos. attitudes and digital tool use affect teacher digital competence	Highly relevant on personal vs contextual variables
Chua, J.H. (2014) The Effect of Field Specialization Variation on Technological Pedagogical Content Knowledge Among Malaysian TVET Instructors. / Peer-rev	Malaysia	In-service instructors / Industry and energy ICT and media	TPACK-survey items	Survey =230 and interview n=3	Subject-specific / medium professional competence (TPCK)	Digital integration of vocational subjects	Satisfactory level of instructors professional competence	Moderately relevant. Country-specific data.
Gustavsson, S. (2020) Digital driving simulators in vocational education: Challenges and opportunities (Swedish) / Peer rev.	Sweden	In-service. Agriculture, nutrition, food.	TPACK-model	Multi-case QUAL. Multiple methods action research / n=?	Contextual. Subject-specific / More TPCK required	School - work connectivity. Digital integration	Important with TPCK in simulator-based teaching	Relevant on subject-specific integration and connectivity
Hobley, J. (2022) Will computers blow up the school: or is our digital wisdom evolving? / Peer rev.	UK	In-service / Continuous VET. No data on vocational domains	TPACK-model (digital wisdom)	Case-study. On-line observations, self-assessment logs MMR/ n=?	Technological / Adequate teaching on-line assessment	Motivation and attitudes (digital wisdom)	Adequate uptake but digital wisdom is missing	Relevant about digital wisdom and critical agency
O'Brien, T (2013). Pipe dreams or digital dreams: Technology, pedagogy and content knowledge in the vocational educational and training sector. / Proceedings	Australia	In-service / No data on vocational domains	TPACK-survey	Case. Survey n=25 interview n=14 epistemic beliefs MMR	Subject specific / Low scores on integrating TPCK pedagogy, technology, content	Digital integration of voc. subjects	Low reported TPCK linked to traditional epistemic beliefs	Relevant explorations about the role of epistemic beliefs
Prasojo, L.D. (2020). Factors Influencing Intention to Use Web 2.0 in Indonesian Vocational High Schools / Peer rev.	Indonesia	In-service / Mostly Industry and energy Business and adm. Agriculture Tourism and travel	TPACK-survey items integrated with Technology acceptance	On-line survey / n = 630 QUAN	Adaptive / TPCK, social norms, facilitating conditions effect on intention to use	Digital self-efficacy (intention to use Web2.0)	TPCK and supporting factors facilitate intention to use Web2.0	Relevant combination of TPCK and Technology acceptance
Rahmawati, A. (2021) Vocational teachers' perspective toward Technological Pedagogical Vocational Knowledge. / Peer rev.	Indonesia	In-service / Industry and energy	TPACK-survey items + vocational ped knowledge	Survey n=65, lesson plans n=19, field-observations n=3 MMR	Subject specific / high on PK but low on integration with technology	Digital integration of voc. subjects	Low integration of technology into learning processes.	Relevant mix TPCK and vocational ped. knowledge
Rahmawati, S. (2022) The Distributions of Vocational High School Teachers' Advanced Digital Competence (ADC). / Peer rev.	Indonesia	In-service / Industry, energy, ICT versus Business and administration, Culinary, Design.	DigCompEdu adapted	On-line survey n=392 Industry n=145 Non-industry n=55 QUAN	Technological / Slightly higher for industry domain compared with non-industry	Digital integration of voc. subjects	High scores for both groups but improvement on specific dimensions.	Relevant comparative data vocational domains
Roll, M.J.J. (2021). Multidisciplinary digital competencies of pre-service vocational teachers. / Peer rev.	Germany	Pre-service / Business and administration	TPACKmodel	Survey n= 210 QUAN	Technological / Multidisciplinary model fit, self-assessed attitudes	School-work connectivity / Transformative competence	Specific addition to the TK in the TPCK model	Highly relevant on multi-disciplinary school work
Salleh, M.H. (2022) Factors Influencing TVET Teacher's TPCK Competencies. / Peer rev	Malaysia	In-service / No data on vocational domains	TPACK-survey	Survey n=400 QUAN	Technological / Higher scores on PK, CK than TK.	No specific VET-issue	mentoring and school context effect TPCK	Moderately rel. context on TPCK
Sanchez-Prieto, J. (2020) The generational digital gap within dual vocational education and training teachers. / Peer rev.	Spain	In-service / No data on vocational domains	DigComp for Citizens and Spanish ITET Framework	On-line survey n = 1568 QUAN	Technological / Low scores, age-difference on dig. problem-solving	Adaptive pedagogy	the necessity of improvement through life - long education	Moderately Age-differences in PDC
Şimşek, Ö. (2019) Investigation of the Self-efficacy of the Teachers in TPCK and Their Use of ICT / Peer rev.	Turkey	In-service / No data on voc. domains. VET versus general education teachers	TPACK-survey+ISTE survey	On-line survey n = 387 VET n = 31	Technological / VET higher in self-sufficiency and ICT-use	Digital self-efficacy	Higher TPK for VET-teachers more relevant in their teaching	Moderately rel. comparison of self teacher categories