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Evaluation of Digital Competencies

Development of an Instrument for Vocational Teacher Training

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Abstract *Approaches to modeling and evaluating teachers' digital competencies are often based on the TPACK model. However, in-depth analyses of the conceptualization of the model show that the specificities of the so-called dual subject matter of vocational education are not sufficiently represented. This article provides insights into the development and testing of an instrument for teachers' self-assessment of digital competencies in vocational education. The instrument is based on the structure of TPACK but is adapted in various ways to reflect the specificities of vocational education. The aim of this article is to transfer a conceptual extension of the TPACK model into an initial instrument and to analyze it as part of an initial exploration.*

Title *Evaluation of Digital Competencies. Development of an Instrument for Vocational Teacher Training*

Keywords *Digital Competencies, Dual Subject Matter, Evaluation, TPACK, Vocational Teacher Training*

1 Introduction

When we talk about digital competencies, it is important to determine the competency requirements for educators, especially with regard to teacher training (Kultusministerkonferenz [KMK], 2021, pp. 23–26). Digital competencies for teachers encompass the use of media for teaching and learning (media didactics), education for responsible media use (media education) and the reflection of digital technologies for the subject matter to be taught. A frequently cited model that structurally depicts these requirements is the TPACK model by Koehler, Mishra and Cain (2013). The TPACK model is used not only for

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conceptualizing the digital competencies of teachers but also as a theoretical framework for developing instruments to evaluate digital competencies (see, among others, Chai, Ng, Li, Hong & Koh, 2013; Kusaini, Mahamod & Mohammad, 2022; Schmidt et al., 2009; Sofyan et al., 2023). The model also provides a theoretical framework in research on digital competencies in the context of vocational education and training (VET) (e.g. Seufert, Guggemos, Tarantini & Schumann, 2019). However, in previous approaches, the transfer of the model to the context of VET (in Germany) did not sufficiently reflect the conceptualization of the model. A specific characteristic of VET that TPACK and similar models do not address is the so-called *dual subject matter* (KMK, 2019, p. 6). This means that the curricula of VET are not primarily structured according to academic disciplines but rather with a focus on the practical work and business processes relevant to specific occupations. Therefore, the learning objectives of VET derive from disciplinary subjects (e.g. methodology, epistemology and theories) as well as from the professional practice (e.g. how certain tasks and problems are handled within the working practice) (Kremer & Sloane, 2014, p. 8). An examination of Shulman's works (1986; 1987), which forms the foundation of the TPACK model, reveals a conceptualization of content rooted in academic disciplines; learning objects that relate to the professional fields of action are not represented. TPACK therefore reflects on how technology influences scientifically structured knowledge, but it does not address the impact of digital transformation on the operational and business processes within these professional domains.

This contribution addresses this research gap by developing and testing an instrument for self-assessment of digital competencies among prospective teachers in vocational education. The instrument is conceptually based on the TPACK model and aims to represent the dual subject matter of vocational education through adaptations of the model or adjustments of existing scales/items. The article begins with a brief introduction to the modeling of digital competencies based on the TPACK model (Chapter 2). Chapter 3 then presents the development and testing of the instrument as part of an initial pretest (n=78) and focuses on how the evaluation of teachers' digital competencies can be mapped using a self-assessment instrument. The objective here is to transfer a conceptual extension of the TPACK model into an instrument and to conduct an initial exploration. Subsequently, Chapter 4 provides insights into the content analysis of the results from the pretest, centering on how vocational teacher trainees assess their digital competencies. Finally, the findings from the pretest are discussed concerning the evaluation of teachers' digital competencies in the context of VET (Chapter 5).

2 Modeling Digital Competencies of Teachers in VET

The requirements discussed for teachers in the context of digital transformation are often summarized under the term *digital competencies*. In discussions about these competencies, various gaps or ambiguities can be identified (for an overview, see e.g. Rubach, 2024). On one hand, the areas of requirements occasionally merge into a conglomerate which is difficult to grasp (e.g. due to different understandings or a lack of disclosure of the specific perspective under consideration). On the other hand, discussions about digital competencies are at times strongly dominated by individual facets, commonly focusing on the application of technology for instructional design (Sloane et al., 2018, p. 12). Additionally, the context of vocational education introduces specific characteristics that significantly differ from general education. Therefore, this chapter focuses on how digitization changes content-related knowledge in the context of VET. Firstly, I introduce the TPACK model and provide an overview of empirical findings. Secondly, I emphasize why a content-related reflection on digital competencies is crucial for teacher training in vocational education.

2.1 The TPACK Model and Empirical Findings

The TPACK model according to Koehler et al. (2013) is frequently used and adapted in teacher training to conceptualize digital competencies. It is a structural model that depicts the relationships between content (*Content Knowledge*, CK), pedagogy (*Pedagogical Knowledge*, PK) and technology[1] (*Technological Knowledge*, TK) in the form of a Venn diagram. The intersections between PK and CK, TK and PK and TK and CK represent the links between the adjacent dimensions: *Pedagogical Content Knowledge* (PCK), *Technological Pedagogical Knowledge* (TPK) and *Technological Content Knowledge* (TCK). *Technological Pedagogical Content Knowledge* (TPACK) is at the center of the model, combining all three base dimensions. A possible interpretation[2] of TPACK encompasses the knowledge, skills, and abilities of a teacher to instruct content by (a) considering the specifics of the subject, (b) guided by basic pedagogical principles, and (c) through the appropriate use of technology (Koehler et al., 2013, p. 16). The model therefore comprises a total of seven dimensions. TPACK is based on previous works by Shulman (1986; 1987), who emphasizes the relevance of subject-specific didactic knowledge, which in his model results from the meaningful combination of content-related knowledge and pedagogical knowledge. The TPACK model incorporates the conceptualization of subject-didactic knowledge from Shulman's original model and introduces the technological dimension, opening avenues for integrating technology into subject-didactic considerations. This model extension serves as a theoretical framework for delineating various perspectives on the digital transformation within teacher training programs, such as examining how digitization influences pedagogical approaches to teaching specific subject content.

The TPACK model is often referred to in both national discourse (in Germany) (e.g. Beißwenger et al., 2021; Brandhofer, 2020; Eickelmann & Drossel, 2020; Knackstedt, Sander & Kolomitchouk, 2022) and in international discourse on digital competencies in teacher education (an international overview is shown by Voogt et al., 2013). Numerous evaluation instruments are conceptually based on the model. Overviews of empirical studies and validated instruments based on the TPACK model can be found in Kadıoğlu-Akbulut, Çetin-Dindar, Küçük and Acar-Şeşen (2020) or Valtonen et al. (2017). The findings demonstrate, among others, that not all seven theoretical TPACK dimensions can be confirmed empirically (Archambault & Barnett, 2010). Voogt et al. (2013) conclude that, from a conceptual perspective, different interpretations arise, especially for the TPACK

1 In this article, digitization is conceptually subsumed under the term *technology*.

2 For a discussion regarding the interpretation of the TPACK dimension, refer to Voogt, Fisser, Pareja Roblin, Tondeur & Braak (2013, p. 119).

dimension (separate knowledge domain versus integration of CK, PK, TK and their intersections). The authors also emphasize that TPACK must be differentiated for specific subject areas (Voogt et al., 2013). Individual studies transfer the TPACK model to specific disciplines, for example for mathematics (Handal et al., 2013). For the VET context in general, only a few studies have transferred the model (e.g. Arifin et al., 2020; Torggler et al., 2023). Additionally, there are even less studies that transfer the TPACK model to the commercial domain and differentiate the individual dimensions (Schlottmann & Gerholz, 2022; Seufert et al., 2019).

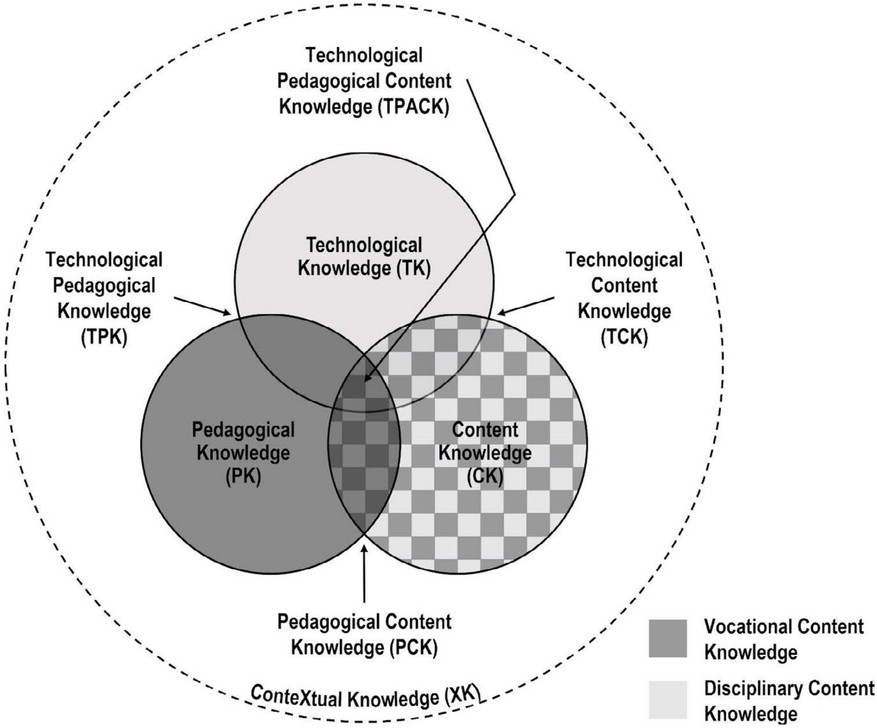
2.2 The Dual Subject Matter in VET

Unlike general education, vocational education curricula are not exclusively based on disciplinary subjects but are structured according to professional fields of action. In the curricula of VET the professional fields of actions of the occupations are converted into so-called *learning fields*; these learning fields represent "didactically elaborated professional fields of action" (Sloane, 2003, p. 4). Accordingly, VET is characterized by a dual subject matter, i.e. the learning objects are determined on the one hand by the subject system of the respective reference discipline(s) and on the other hand by the professional fields of action of the respective occupations (KMK, 2019, p. 6). Following Kremer and Sloane (2014, p. 8), I divide the knowledge from these two content-related reference systems into *disciplinary knowledge* and *vocational knowledge*. From a sociological perspective, the knowledge derived from these two reference systems differs fundamentally. Disciplinary knowledge represents knowledge which is logically structured by a discipline, and which is developed, expanded, and reviewed within a scientific community. Vocational knowledge represents job specific knowledge like workflows or methods which derive from work practices within an occupation (more detailed in Sänger & Jenert, 2023). Teaching according to the idea of learning fields requires the design of authentic work situations (so-called *learning situations*); these learning situations should present the vocational learners with tasks that are typical of a certain field of action in the respective occupation (Sloane, 2003, p. 8). Disciplinary knowledge is therefore not represented in the structure of the reference discipline(s), as is usual for general education. It is used, for example, to assess or solve a problem in an authentic work situation and is thus integrated into the learning situation, i.e. disciplinary knowledge is typically derived inductively in the respective learning situation (Tramm, 2002). Therefore, in instructional practice, disciplinary knowledge is *applied* or *put into practice* in real work situations instead of being strictly confined to its disciplinary framework (Gerholz & Goller, 2021, p. 413). A closer analysis of Shulman's conceptualization reveals that for him, content knowledge is derived exclusively from the structure and knowledge bases of scientific disciplines (Shulman, 1986; 1987). Since the TPACK model is also based on Shulman's conceptualization of content knowledge, the model only reflects disciplinary knowledge. Due to its conceptualization of content, the TPACK model does not sufficiently represent the dual subject matter and therefore falls short when it comes to modelling digital competencies of teachers in VET (Sänger & Jenert, 2023).

The dual subject matter must be considered when modeling digital competencies of teachers in VET. Originally, the TPACK model only considers how the digital transformation affects disciplinary knowledge, e.g. how simulations change the understanding of certain phenomena (Koehler et al., 2013, p. 16). Content-related digital competencies (TCK dimension in the TPACK model) also need to reflect vocational knowledge, i.e. the extent to which occupations, professional fields of action, and ultimately individual occupational activities are affected by digital transformation and how teaching in VET needs to adapt to these transformational processes (Busse et al., 2022). The latter consideration implies that, in addition to general vocational knowledge, teachers must also have knowledge of how the digital transformation affects operational work and business processes (e.g. business cases which could be used as an example) (Windelband, 2021).

In the discourse on digital competencies in vocational teacher training, there are already initial approaches which attempt to take the dual subject matter into account. In the field of business education, Seufert et al. (2019) and Schlottmann and Gerholz (2022) can be mentioned, among others. The contributions locate knowledge about effects of digital transformation on work and business processes at the intersection between content knowledge and technological knowledge (TCK dimension). They consider the digital transformation of work and business processes from a discipline-oriented perspective. In contrast to existing contributions, this article focusses on an occupational perspective, i.e. vocational knowledge is considered as an independent component in the conceptualization of digital competencies. This conceptualization is implemented by including vocational knowledge as component of content knowledge (CK dimension) in the original model (see Figure 1). The conceptualization of vocational knowledge is based on the work of Rauner, who defines vocational knowledge as "knowledge incorporated in practical work" (2007, p. 62); the origin of vocational knowledge thus lies in professional practice (more detailed in Sänger & Jenert, 2023). The expansion of the content dimension also affects the TCK dimension: knowledge about how digitization influences work and business processes is also regarded as an independent component of digital competencies (vocational logic). It is complementary to knowledge about how digitization affects scientifically structured bodies of knowledge (disciplinary logic), as originally reflected by the TCK dimension in the TPACK model. Therefore, I distinguish between *Disciplinary Technological Content Knowledge* and *Vocational Technological Content Knowledge*. In the subject-specific didactic dimension (PCK), the expansion of the model addresses the challenge of combining both types of content knowledge (disciplinary and vocational) with pedagogical considerations (a more detailed explanation of the model extension can be found in Sänger & Jenert, 2023). The next chapter will outline the transfer of the conceptual extension into a first instrument and its initial exploration.

Figure 1: Extended TPACK model



Source: Sänger & Jenert, 2023, p. 446

3 Development and Testing of the Instrument

The development[3] and testing of an instrument for the self-assessment of digital competencies for prospective teachers in VET is presented below. The instrument is conceptually based on the TPACK model but makes additions at individual points to consider the dual subject matter, as outlined in Chapter 2.2. The aim here is to operationalize the model extension and conduct an initial exploration. Since the instrument was designed for testing in business education programs, the instrument is framed by this context, for example by including items relating to professional fields of actions in commercial-administrative occupations.

Firstly, items were collected that had already been used and validated in studies in the context of the TPACK model; this resulted in a total of 164 items. In the second step, the items were assigned to the TPACK dimensions if the assignment did not emerge from the studies themselves. The items were then summarized in the case of multiple responses or completely excluded due to the context-specificity of the studies. Ultimately, 38 items

3 The development of the instrument was supported by teacher training students as part of a teaching-related project in a Master's program, especially by compiling, assigning, and condensing the items. I thank the student group for their assistance.

were included which were distributed across the TPACK dimensions. Two approaches were chosen in order to include both disciplinary and vocational content knowledge: On the one hand, individual items relating to content knowledge were modified. For example, item CK1 ("I have sufficient knowledge about my teaching subject") was adapted to "I have sufficient knowledge (e.g. concepts, models, theories) about my teaching subject as well as its vocational relevance". On the other hand, the scale *Vocational Technological Content Knowledge* (TCK-V[4]) was newly developed. This scale specifically addresses the digitization-related content knowledge for professional fields of action (vocational knowledge). The TCK-V scale is conceptually based on the work of Schlottmann and Gerholz (2022) and Seufert et al. (2019). Schlottmann and Gerholz (2022) locate the knowledge about how digital technologies change business processes in the TCK dimension. Seufert et al. (2019) introduce a new dimension in their model called "Knowledge about the Digitization of the Economy" (p. 320) as part of content knowledge. Based on the model extension presented in Chapter 2.2, I combined both approaches with the extended TCK scale for vocational knowledge. The goal is to address the dual subject matter in all content-related dimensions while maintaining the integrative approach of the TPACK model. In addition, a further scale on media education was included according to the framework of Herzig and Martin (2018). It is dedicated to the responsible use of and education on digital media use (MEDE). There is no genuine connection expected between media education and vocational knowledge; but since TPACK does not address media education explicitly, I added this scale for the first exploration of the instrument. This addition is an attempt to integrate the subdivision into media didactics and media education according to Herzig and Martin (2018) into the TPACK model. In addition to an introductory section containing socio-demographic information, the instrument used in the pretest comprises a total of 46 items. Table 1 shows an overview of the instrument as well as sample items with references.

At the end of each scale, respondents are also asked about the areas or sources from which they acquired their knowledge (e.g. internship semester, university, or apprenticeship). Since the knowledge is not expected to originate from a single source, this question allows multiple answers. The TPACK scales are assessed using a six-point Likert scale (1=not at all true; 6=totally true), as is the origin of the knowledge (1=not at all; 6=everything).

4 To stay within the logic of the TPACK model, I extended the original TCK dimension. In this article, I use *Vocational Technological Content Knowledge* (TCK-V) and *Digitization-Related Vocational Content Knowledge* interchangeably (representing how work and business processes are influenced by digitization).

Table 1: Overview of the instrument

Dimension	Sample item	Reference
Content Knowledge (extended CK)	I have sufficient knowledge (e.g. concepts, models, theories) about my teaching subject as well as its vocational relevance.	Own item extension based on Chai et al. (2013)
Pedagogical Knowledge (PK)	I can adapt my teaching style to the heterogeneity of my students.	Based on Schmidt et al. (2009)
Technological Knowledge (TK)	The high technical complexity discourages me from using digital media.	Based on Vogelsang, Finger, Laumann & Thyssen (2019)
Pedagogical Content Knowledge (PCK)	I can address my students' (general) work-related learning difficulties for my subject without the use of technology.	Based on Chai et al. (2013)
(Disciplinary) Technological Content Knowledge	I can select digital media that can be used to better convey subject content in the classroom.	Based on Endberg & Lorenz (2016)
Vocational Technological Content Knowledge (TCK-V; extended TCK)	I am aware of the digital tools (e.g. enterprise resource planning systems) that play a role for my students.	Own item formulation based on Schlottmann & Gerholz (2022) and Seufert et al. (2019)
Technological Pedagogical Knowledge (TPK)	I can adapt the use of digital media to different activity-oriented teaching activities.	Based on Osterberg, Bleck, Melai, Meier & Lipowsky (2020)
Media education (MEDE; extended TPK)	I am able to sensitize my students to the handling of private data in digital environments.	Based on Rubach & Lazarides (2019)
Technological Pedagogical Content Knowledge (TPACK)	I am able to apply strategies to integrate knowledge of teaching approaches, technologies and content in my teaching.	Based on Schmidt et al. (2009)

The instrument was used in both Bachelor's (n=50) and Master's (n=28) modules in programs in the field of business education at the University of Paderborn to test the developed instrument and gain initial insights into the self-assessment of prospective teachers regarding their digital competencies. The data was analyzed using a principal component analysis (PCA) with Varimax rotation in SPSS to determine the factor structure[5]. In a first step, only the original TPACK scales were considered; in a second step, the two new scales TCK-V and MEDE were also included. The sample suitability according to the KMO criterion (.881) and Bartlett's test (<.001) is fulfilled in the first analysis; the anti-image correlations are greater than .60 (for sample suitability, see Tabachnik &

5 In this article, the term *factor* is used synonymously with *component*. Differences between factor analysis and principal component analysis are discussed, among others, by Tabachnik and Fidell (2013). They point out that despite different underlying assumptions, various extraction methods tend to produce similar results in practice under equivalent conditions (p. 647).

Fidell, 2013, p. 617). The conceptualization of the TPACK model suggests seven factors, i.e. one factor per TPACK dimension (Zelkowski, Gleason, Cox & Bismarck, 2013, p. 183). First, the components were calculated based on the Eigenvalue greater than one; SPSS determined 6 components. The three basic dimensions of the TPACK model (CK, PK and TK) each load uniquely onto one factor, as does the PCK dimension, i.e. the subject-didactic dimension. The dimensions TCK, TPK and TPACK show cross-loadings, while all TPACK items load onto the factor within a closed scale. Hence, I found the TPACK scale to be the best solution for this factor. If the items from the TCK and TPK dimensions are excluded from the PCA, five factors (factor loadings >.60) can be clearly identified, which explain approx. 73 % of the total variance. Hence, five factors appear to be the most suitable for the original TPACK dimensions (CK, PK, TK, PCK and TPACK).

In the second step, the two additional scales TCK-V and MEDE were also included in the PCA. The sample suitability according to the KMO criterion (.871) and Bartlett's test (<.001) is also fulfilled here; the anti-image correlations are greater than .60. However, the items of the MEDE scale load onto the same factor as the PK dimension, i.e. the general pedagogical dimension, in the sample surveyed. For this reason, the MEDE scale is not included in the instrument as the scale could not be identified as an independent factor. The TCK-V scale, which explicitly addresses the digitization-related vocational content knowledge for the occupational fields of action (see Table 2), forms a separate component with the items TCK-V1 to TCK-V3 (factor loadings > .60). The TCK-V scale is included in the instrument due to its statistical suitability and its theoretical relevance for modeling digital competencies in VET.

To ensure that the TCK and TCK-V dimensions differ empirically from one another, cross-factor loadings were examined in a final step. The highest cross-loading between both dimensions is .24. According to Tabachnik & Fidell (2013, p. 654), a factor loading of .32 or below can generally be considered as poor. A cross-loading is observed when an item loads at .30 or higher on two or more factors (Fabrigar, Wegener, MacCallum & Strahan, 1999, p. 287), which is not the case between the two dimensions. Consequently, the analysis indicates that the two scales are independent.

Table 2: Items of the TCK-V scale

Item	Item formulation (original in italics)
TCK-V1	I am aware of the digital tools (e.g. enterprise resource planning systems) that play a role for my students. *Mir ist klar, welche digitalen Werkzeuge (bspw. ERP-Systeme) für meine Schüler*innen eine Rolle spielen.*
TCK-V2	I am well-informed about the role that digitization plays in changing business processes in the daily work routine of students. *Ich bin gut darüber informiert, welche Rolle die Digitalisierung für Veränderungen von Geschäftsprozessen im Arbeitsalltag der Schüler:innen darstellt.*

Item	Item formulation (original in italics)
TCK-V3	I can provide assistance to my students regarding the operational complexity of digital tools (e.g. enterprise resource planning systems). *Ich kann hinsichtlich der Bedienkomplexität von digitalen Werkzeugen (bspw. ERP-Systemen) meinen Schüler:innen Hilfestellung geben.*
TCK-V4 (excluded)	I am capable of informing myself about digitization-related changes in the economy and utilizing them for my teaching. *Ich bin in der Lage, mich über digitalisierungsbezogene Veränderungen in der Wirtschaft zu informieren und diese für meinen Unterricht zu nutzen.*

The final instrument therefore comprises six factors (factor loadings >.60) with 29 items, which explain approx. 75 % of the total variance (see Table 3). The reliability analysis of the identified scales shows good to very good internal consistencies (Cronbach's alpha between .838 and .935); for the gradation of Cronbach's alpha, see Zelkowski et al. (2013, p. 185), among others.

Table 3: Principal Component Analysis

	1	2	3	4	5	6
K1	.640					
CK2	.761					
CK3	.729					
CK4	.668					
PK1		.627				
PK2		.635				
PK3		.664				
PK4		.763				
PK5		.745				
TK1			.756			
TK2			.809			
TK3			.870			
TK4			.776			
TK5			.783			
TK6			-.628			
PCK1				.813		
PCK2				.876		
PCK3				.794		

	1	2	3	4	5	6
TPACK1					.656	
TPACK2					.661	
TPACK3					.720	
TPACK4					.794	
TPACK5					.632	
TPACK6					.640	
TPACK7					.740	
TPACK8					.628	
TCK-V1						.911
TCK-V2						.737
TCK-V3						.770

Note. Extraction: Principal Component Analysis. Rotation: Varimax with Kaiser normalization.

4 Analysis of the Results

The presentation of the results can be divided into three sections: the evaluation of the socio-demographic information, the TPACK scales and the information on the sources of knowledge. In sections two and three, only the items identified in the second PCA are considered (Table 3).

Approximately two thirds of the participants in the present sample (n=78) were Bachelor's students and one third were Master's students in the field of business education at the University of Paderborn. Approx. 62 % of the students in the sample are female, approx. 38 % male. The average age in the sample is approx. 25 years (standard deviation of approx. 4 years). On average, the students are in the third semester of their Bachelor's or Master's degree. Overall, the present sample can be classified as typical of the field of business education (see e.g. survey Goller & Ziegler, 2021). At the beginning of the survey, the areas in which the students had generally already gained experience (aptitude and orientation internship, professional field internship, practical semester, side job or part-time work, apprenticeship and practical experience in the field of work) were also surveyed.

The scales were evaluated for the entire sample on the one hand and separately for Bachelor's and Master's students on the other. The comparative analysis of Bachelor's and Master's students examines the question of whether students tend to rate their competencies higher as they progress through their studies (as examined by Zinn, Brändle, Pletz & Schaal, 2022, for example). On average, Master's students rate their competencies across all dimensions approximately half a scale point higher than their Bachelor's counterparts, as shown in Table 4.

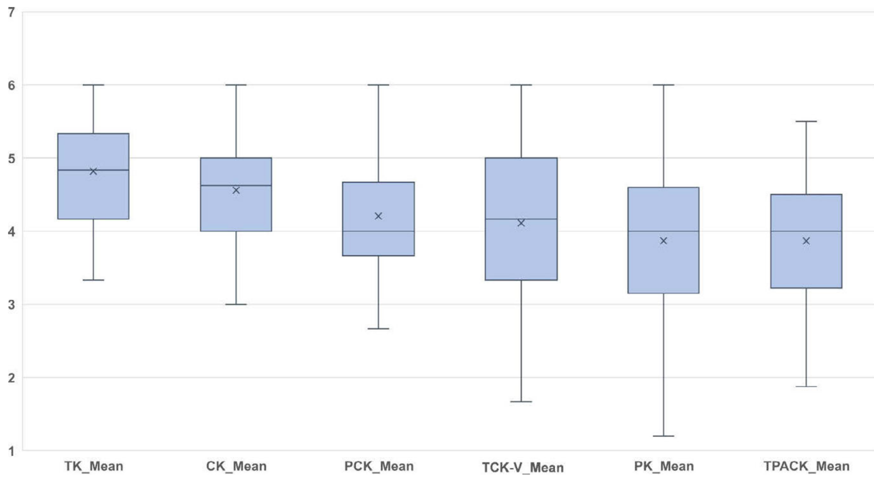
Table 4: Mean comparison of Bachelor's and Master's Students

	BA (n=50)		MA (n=28)					
Variable	M	SD	M	SD	T	df	p	d
CK	4.41	.78	4.84	.59	-2.56	76	.013	.60
PK	3.66	.98	4.25	.67	-2.85	73	.002	.67
TK	4.68	.74	5.10	.72	-2.21	76	.015	.52
PCK	4.20	.77	4.23	.86	-0.17	76	.863	
TPACK	3.66	.96	4.24	.68	-3.13	72	-.003	.67
TCK-V	3.93	1.02	4.43	1.08	-2.01	76	.048	.47

Note. Answer scale six-point Likert scale (1=not at all true; 6=totally true).

When looking at the entire sample, the basic dimensions TK and CK are on average more pronounced than the PK dimension, i.e. students rate their pedagogical competencies lowest with regard to the three basic dimensions CK, PK, and TK (with the lowest values being PK3=PK5=3.76; SD=1.02 and 1.20 respectively). PK3 asks about the ability to assess students' performance; PK5 asks about knowledge of methods and concepts that guide didactic action. The items representing the CK and TK dimensions are the most pronounced of all scales, with the TK dimension achieving the highest mean values of all scales overall. Consequently, students rate their technology-related competency highest of all competencies, led by the item TK3 („I can communicate and cooperate with the help of digital media in my future career"). The PCK dimension, i.e. subject-specific didactic knowledge, is rated slightly better than pedagogical knowledge on average across the entire sample, but worse than content-related knowledge. The TCK-V scale, which assesses digitization-related vocational content knowledge, receives lower average ratings compared to subject-specific didactic knowledge but higher ratings than pedagogical knowledge. The items that represent the TPACK dimension, i.e. teaching of a subject-related content, taking into account both pedagogical principles and the use of technology, are rated lowest on average by the students in the entire sample. The item TPACK6 („I am able to create self-directed learning activities of practical professional content knowledge with the help of ICT tools [e.g. web quests, blogs]") achieved the lowest mean value of all items with a mean value of 3.67 (SD=1.11). The scales are rated on average in descending order as follows: TK, CK, PCK, TCK-V, PK, TPACK (see Figure 2).

Figure 2: Mean comparison of the scales in the total sample



Note. Answer scale six-point Likert scale (1=not at all true; 6=totally true).

Regarding the sources of knowledge, it should first be noted that not all possible sources of knowledge were fulfilled for all students. For example, only 9 out of 78 respondents had already completed the practical semester at the time of the study and only around two thirds of all respondents had completed an apprenticeship; this limits the evaluation. On average, the highest mean values across all scales were found in the categories *apprenticeship/practical experience in the field of work* and *private environment*. For the dual subject matter of VET, the scales CK and TCK-V are particularly interesting. Table 5 shows the mean values and standard deviations of the three most frequent statements for the sources of knowledge in descending order for the CK, TCK-V and TPACK scales.

Table 5: Average responses regarding the sources of knowledge

	CK	TCK-V	TPACK
1	Apprenticeship/Practical experience in the field of work 4.29 (1.12)	Apprenticeship/ Practical experience in the field of work 3.74 (1.56)	Private environment 3.12 (1.49)
2	University 3.63 (1.19)	Private environment 3.26 (1.32)	Apprenticeship/ Practical experience in the field of work 2.92 (1.41)
3	Private environment 3.54 (1.03)	Side job or part-time work 2.78 (1.46)	University 2.89 (1.37)

Note. Answer scale six-point Likert scale (1=not at all; 6=everything).

5 Discussion

The primary objective of the article was to transfer a conceptual extension of the TPACK model into an instrument and to conduct an initial exploration of its applicability. Additionally, it aimed to examine student teachers' self-assessment of their digital competencies. Therefore, the following discussion refers on the one hand to the testing of the instrument and on the other hand to the evaluation of the results from self-assessment. Furthermore, the limitations and possible practical implications of the study are discussed.

5.1 Results from the PCA

In relation to the instrument's testing, I found that the discriminative power of items with a technology reference is not sufficient. This is likely because the dimensions TCK and TPK already contain elements represented by the TPACK items; this finding aligns with the study by Zelkowski et al. (2013). A significant difference from the results of Zelkowski et al. in this study is the identification of the subject-specific didactic dimension (PCK) as an independent factor. In contrast to the technology-related items, this scale is characterized by the item formulation *without the use of technology* (item formulation based on Chai et al., 2013, p. 46). The explicit exclusion of technology reference could explain why the scale loads onto a separate factor, linguistically distinguishing itself from the other scales. From a conceptual standpoint, this study underscores the limitations of employing TPACK as a framework for empirically measuring digital competencies, as not all TPACK dimensions could be identified as measurable factors in the present study. This could be attributed to the limited ability to distinguish between specific dimensions or the idealized nature of these dimensions for modeling, posing challenges in empirical measurement (Archambault & Barnett, 2010). Consequently, it must be critically examined whether TPACK offers a suitable basis for modeling all facets of digital competencies. Brandhofer (2020) compares the TPACK model with established competence catalogs for modeling digital competences, such as the Digital Competence Framework for Educators (DigCompEdu). The recent article by Wilmers et al. (2023) provides an overview of different models of digital competencies for different areas of education. Rubach and Lazarides (2023) present a systematic review that provides a more extensive systematization concerning teachers' competence and competence-related beliefs about ICT use, which is detached from the TPACK model. One advantage of alternative models detached from TPACK is that the individual dimensions can be considered in a more differentiated way than TPACK can achieve. In my opinion, a disadvantage of alternative models is that the interactions between the dimensions are at least partially lost. These considerations of interrelationships are helpful to carry out an integrative modeling of teachers' digital competencies (Schmid & Petko, 2020, p. 136). Due to the proximity of the TPACK model to the usual curricular division of teacher training programs in Germany into subject science, subject didactics and educational science, curricular references can also be derived from the model, e.g. to identify goals for curricular development (Jenert & Kremer, 2021, p. 12).

The TCK-V scale was newly developed for the instrument to specifically capture digitization-related vocational content knowledge. Unlike in the original conceptualization in the TPACK model, this scale does not focus on the impact of technology on disciplinary knowledge but reflects the effects of digital transformation on work and business processes. The scale emerged from a theoretical standpoint and follows the assumption that vocational knowledge is not adequately represented in previous models of digital competencies (Sänger & Jenert, 2023). In the PCA, the scale was identified as an independent factor, providing empirical confirmation that vocational knowledge requires its own scale.

It should be emphasized, regarding the PCA, that the sample (n=78) is relatively small. Depending on the minimum sample size assumed as a condition, the present sample size needs to be considered as a limiting factor. According to Tabachnik and Fidell (2013), a sample size smaller than 100 is acceptable if clear factors can be identified and all factor loadings are greater than 0.6 (p. 618); these criteria are met in the present study. Furthermore, another constraint exists concerning the evaluation of the instrument with student-teachers. Future research should also include testing the instrument with experienced, in-service teachers.

5.2 Analysis of the Self-Assessment

The analysis of the results of the self-assessment suggests that students tend to perceive themselves as tech-savvy, but apparently lack general pedagogical and didactic conceptual knowledge. The rather low average self-assessments in the TPACK dimension could indicate a low development of the required digital competencies for future teaching activities; this assumption should be re-examined in a further study. The comparative examination of the self-assessment of Bachelor's and Master's students suggests that students tend to rate their competencies higher with advancing progress in their studies (see also Zinn et al., 2022). To further investigate whether students tend to assess their competencies higher with progression of their study, this assumption should be retested in a larger sample. It is important to note the limitations of self-assessments for competency measurement, as investigated in the context of TPACK by Max, Lukas and Weitzel (2022). Since a predominant part of studies use self-assessments (Voogt et al., 2013), Max et al. (2022) suggest a combination of self-assessments and performance tests.

Regarding the knowledge sources, the categories *apprenticeship/practical experience in the field of work* and *private environment* are consistently mentioned most frequently across all assessed scales, on average. While acknowledging that information about knowledge sources may be influenced by individual student circumstances, the unexpectedly high relevance of the private environment underscores the importance of this source of knowledge. Concerning the sources of content knowledge, the categories of *apprenticeship/practical experience in the field of work*, *private environment*, *university*, and *side job or part-time work* are mentioned most frequently on average for the CK and TCK-V dimensions. The high relevance of the prospective teacher's own *apprenticeship/practical experience in the field of work*, especially regarding the digitization-related vocational content knowledge (TCK-V), emphasizes the importance of these two categories beyond the university context.

5.3 Key Findings and Future Directions for Instrument Development

Overall, the results of this study empirically support the argument that vocational technological content knowledge (TCK-V) requires its own independent scale. As the TCK-V dimension forms a separate factor, I assume that the distinction between disciplinary and vocational knowledge also applies to content knowledge (CK). My assumption aligns with the theoretical perspective suggesting the consideration of both components of the dual subject matter as separate elements in modeling digital competencies. To test my assumption and to improve dimensionality, for the future development of the presented instrument, both disciplinary and vocational knowledge should be represented as independent components. Consequently, the items addressing content knowledge (CK) will be separated into *disciplinary content knowledge* and *vocational content knowledge*. Since I integrated both reference systems of content knowledge (discipline and profession) into the CK items in this study, I cannot test my assumption with the present data. The revised instrument should then be tested and validated in a larger sample using confirmatory factor analysis in order to assess the suggested adaptions. Moreover, exploring the relationships between variables can contribute to assessing the nomological validity of the instrument, for instance, by investigating whether an apprenticeship positively correlates with self-assessed vocational knowledge or if the semester in the respective program positively correlates with the overall self-assessment of digital competencies. Additionally, the newly developed scale for digitization-related vocational content knowledge (TCK-V) should be reviewed once again.

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