European Journal of Teacher Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cete20

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To cite this article: Joshua Weidlich & Marco Kalz (2023): How well does teacher education prepare for teaching with technology? A TPACK-based investigation at a university of education, European Journal of Teacher Education, DOI: 10.1080/02619768.2023.2243645

To link to this article: https://doi.org/10.1080/02619768.2023.2243645

Published online: 04 Aug 2023.

EUROPEAN JOURNAL OF TEACHER EDUCATION
https://doi.org/10.1080/02619768.2023.2243645

How well does teacher education prepare for teaching with technology? A TPACK-based investigation at a university of education

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ABSTRACT

Past research has identified deficits in knowledge of student teachers regarding integration of technology in teaching leading to a need to investigate the efficacy of teacher training initiatives. There is a gap in understanding of developmental trajectories of these skills, as well as whether other factors moderate this. Using the TPACK-Model, the current study presents an analysis (N = 526) of a teacher training at a University of Education in Germany. Overall, results suggest trajectories where some knowledge domains are positively associated with study progress while others are not. Specifically, technology-related knowledge mostly does not show an association with study progress. However, this phenomenon is moderated by gender, suggesting that women report lower skills in technology-related dimensions and no associations with study progress. Our results illustrate the necessity to improve teacher training so that preservice teachers in general, but especially women, feel better qualified to integrate technology into the classroom.

ARTICLE HISTORY
Received 22 November 2022
Accepted 15 July 2023

KEYWORDS
Teacher training; TPACK; technology integration; educational technology; classroom technology

Introduction

In order to prepare the future generation of teachers for the meaningful use of digital technologies in the classroom, systematic measures are needed to improve the general technological knowledge and skills of prospective teachers, as well as their pedagogical integration. In teacher training programs in Germany, there is currently still an inconsistent picture regarding the integration of competences for the use of digital media in teaching into the curricula (Bertelsmann Stiftung 2018). Due to a large national investment program to update the technical infrastructure of schools in Germany, the topic of teaching competences in the use of digital media will become increasingly important (Scheiter and Lachner 2019). While it is to be expected that the equipment of schools for the use of digital media in the classroom will improve, at least in the short term, there is a danger that the investment, by focusing on technology and infrastructure, will repeat

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the problems of a similar national initiative called 'Schools on the internet', so that technology and infrastructure will be available, but there will be a lack of didactic and methodological concepts for integrating digital media into the classroom (Niegemann 2000; Weinreich and Schulz-Zander 2000). In order to prepare the future generation of teachers for the meaningful use of digital media in the classroom, systematic measures are needed to improve the general media competence of prospective teachers on the one hand, and on the other hand, competences must be taught to use digital media systematically in the subject lessons (Kerres and Kalz 2003).

For these systematic measures, it is helpful to determine how student teachers' knowledge regarding the use of digital technology in the classroom develops throughout their studies and which factors can be associated with this to derive measures from this in turn. In this paper, we present a study that empirically investigated self-assessed knowledge of student teachers using the TPACK model in the first phase of teacher education and related it to variables such as study progress, gender, and curricular cornerstones. To this end, we first present the theoretical background of the model.

Theoretical background

A popular framework model for differentiating between various teaching-related skills is the TPACK model proposed by Mishra and Koehler (2006). TPACK stands for 'technological pedagogical content knowledge' and thus emphasises the integrative character of subject-specific technological-pedagogical knowledge of prospective teachers. Constitutive for the integrated and superordinate TPACK knowledge area are combined sub-areas, which themselves consist of the three basic areas of technological knowledge (TK), content knowledge (CK) and pedagogical knowledge (PK) (Figure 1).

Mishra and Koehler (2006) have extended the work of Shulman (1986, 1987) with the logic of technological knowledge (TK), so that in addition to technological basic knowledge, its content-related, pedagogical and pedagogical content integration was also taken into consideration. Consequently, at the end of their studies, student teachers should ideally have knowledge in the three basic areas, the three connecting areas, but also in the overarching TPACK area. Prospective teachers would then have a comprehensive body of knowledge that enables them to teach content flexibly and with the help of appropriate technological tools in a professional and pedagogically sound manner (Koehler & Mishra 2009).

Since its genesis, the TPACK model has been internationally recognised in research on professional teaching competencies of (prospective) teachers, especially with regard to the use of media and technologies in the classroom (Harris et al. 2017). As such, the promotion of TPACK knowledge assets in both student teachers and in-service teachers has been widely studied (Voogt et al. 2013; Wang, Schmidt-Crawford, and Jin 2018). Although the model is particularly prominent in English-language discourse, the model's areas of application are in principle independent of country-specific school systems. For example, there are TPACK studies from China (Liu, Zhang, and Wang 2015), Belgium (Tondeur et al. 2019), the United Arab Emirates (Khine, Ali, and Afari 2017), Australia (Bate, Day, and Macnish 2013) as well as Germany (Endberg 2019; Lachner, Backfisch, and Stürmer 2019).

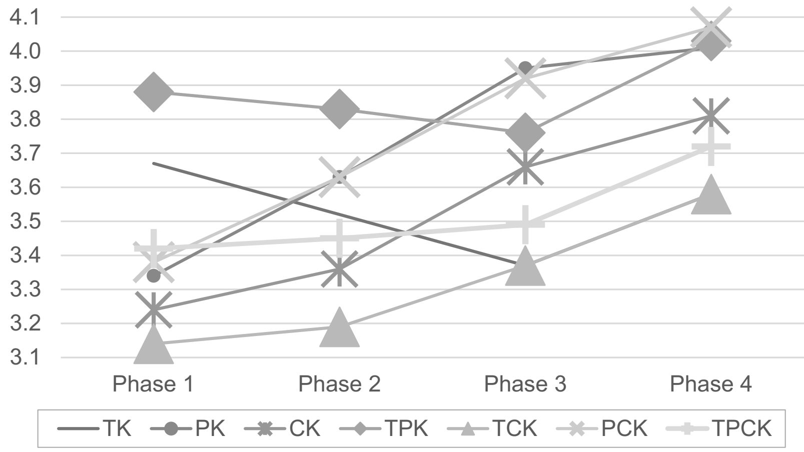

Figure 1. TPACK ratings plotted against study phase.

The main methods used to measure TPACK knowledge are self-assessments (Schmidt et al. 2009), performance-based external assessments (Jen et al. 2016; Yeh et al. 2017) and tests (Baier and Kunter 2020; Lachner, Backfisch, and Stürmer 2019), with self-assessments being the most common (Willermark 2017). In self-assessment studies, (prospective) teachers respond to Likert items from the seven TPACK dimensions. It is well known that validity limitations may exist when individuals assess their own abilities. These may be social, for example in the case of social desirability (Mummendey 1981), or cognitive, as in the case of the Dunning-Kruger effect (Kruger and Dunning 1999). Accordingly, TPACK self-evaluations should be better understood as individual self-efficacy expectations, as is increasingly the case in the recent literature (Scherer et al. 2018). However, attitudes and self-efficacy expectations towards the use of digital technologies in the classroom in particular have been shown in research to be significant determinants of teachers' technology acceptance (Scherer, Siddiq, and Tondeur 2019) as well as the use of technology in the classroom (Drossel, Eickelmann, and Lorenz 2018), so TPACK self-evaluations seem appropriate for an inventory in teacher education.

State of research and research questions

Against the backdrop of current German efforts to implement technology into the K-12 classroom, Scheiter and Lachner (2019) have formulated three conditions for success from the perspective of teaching/learning research. In addition to the necessity of appropriate technological infrastructures and the development of digital materials and concepts that are effective for learning, the third central condition for success is the professional competencies of teachers for the use of technology in the classroom. Likewise, the recently updated national standards in Germany for teacher education emphasise the need for competencies in the use of digital media (KMK 2019). At the same time, however, the current international ICILS study (2018) certifies that Germany's teachers rank behind in international comparisons in many technology-specific matters, for example with regard to technological-pedagogical self-efficacy expectations (Fraillon et al. 2019).

These tendencies seem to be already apparent in the undergraduate studies, as student teachers show the lowest affinity for digital media in the context of teaching and learning compared to other subject groups (Schmid, Goertz, and Behrens 2017).

Internationally, relevant research on the topic can also be identified. Valtonen et al. (2019) found among Finnish student teachers that although all TPACK areas increased over the course of their studies, the trajectories were quite different. For example, subject pedagogical knowledge (PCK) increases the most over the study period, whereas technological knowledge (TK) and subject pedagogical knowledge (TCK) increase less and score the lowest at the last survey time point. On the other hand, Valtonen et al. (2021) find that technological pedagogical knowledge (TPK) and ICT-efficacy significantly increase over time, more than many other important skills outside of the TPACK framework, like critical thinking and self-regulation. Hofer and Grandgenett (2012) found among U.S. students that some domains, including technological knowledge, actually declined briefly and technological content knowledge (TCK) increased the least overall. These studies provide initial indications that the development of some areas of knowledge relevant to the use of digital technologies in the classroom may vary and may not be sufficiently developed through study. However, this area of investigation is still developing and it is important to add to the literature in attempts to resolve these conflicting findings. Further, there has been little research that assesses this association in a German teacher education. To what extent this can also be replicated in Germany is therefore an important question and will be investigated in this study:

FF1. What is the relationship between TPACK assessments and study progress?

In addition to the general investigation of the development at German universities, it is also important to better understand the factors influencing this development. Roussinos and Jimoyiannis (2019) and Scherer et al. (2017) were able to identify gender as an important influencing factor, as both teachers and student teachers rate themselves higher than their female colleagues and fellow students. However, this difference is limited to the technological knowledge domain, whereas pedagogical knowledge was either equally rated or rated higher by females (Cheng and Xie 2018; Lin et al. 2013). Hämäläinen et al. (2021) also find evidence for gender differences in international large scale assessment data, such that women report feeling slightly less able to support students by means of technology, while in Schmid et al. (2021), there were no gender differences with respect to actual technology use in the classroom. This discrepancy may point to potential differences between self-efficacy beliefs and actual ability. On the other hand, findings from a large Germany study by Senkbeil et al. (2019) point to actual gender differences with respect to ICT literacy, although here the sample consists of a cross-section of all university students in Germany and is, thus, not specific to teacher education. Since a German study specifically related to teaching is still pending and K-12 teaching is predominantly studied by women (Stuve and Rieske 2018), it is imperative to replicate the influence of gender on TPACK assessments for the present German sample. In addition, potential gender differences in TPACK assessment in relation to study progress may provide further insights towards modelling these competencies in teacher education. Therefore, the research question for the present study is:

FF2. What influence does the gender of the students have on TPACK assessments and the relationship of these assessments with study progress?

In addition to the gender of the students and their progress in their studies, it is expected that curricular cornerstones of the teacher training course can also be associated with TPACK assessments. A central element of most German teacher training programs is the school internship, which is considered a central means of linking theory and practice in the teacher training program (Arnold et al. 2014), although its effectiveness is not undisputed in German research discourse. For example, Hascher (2012) suggests in a review article that despite the high importance attributed to the internship by all school-based stakeholder groups, the evidence base remains heterogeneous, as both negative developments (e.g. low self-esteem), positive developments (e.g. adoption of practical techniques), and ambivalent effects (e.g. hardly any expanded school-relevant knowledge) can be attributed to the internship. In contrast, empirical work predominantly attests to the effectiveness of school placements, for example, in terms of self-assessed subject and teaching skills (Bach et al. 2010) and self-efficacy in teaching and assessment (Franz & Ophoff 2019). Other relevant evidence showed that longer placements have been shown to be more effective than short placements (Böhnert et al. 2018). Completely lacking at present are studies that specifically examine these practical phases in light of TPACK assessments, particularly with regard to teaching with digital technology. The lack of evidence on how elements of the current state of the teaching curriculum relate to TPACK assessments necessitates an investigation of these relationships in order to assess the effectiveness of existing measures and to derive any need for action and further development. Therefore, the third research question is as follows:

FF3. What is the relationship between curricular cornerstones of the teacher training program and self-assessed TPACK dimensions?

Method

Sample

For this study, we were able to recruit 526 student teachers from the Heidelberg University of Education, which represents 12.7% of the population at this university. Of these participants, 409 (78.4%) indicated being female, with the remaining being male. No student indicated belonging to any other gender. On average, the students are 24.1 years old (median: 23 years). Compared to the population of all first-year students in Germany in 2018, this corresponds to the traditional picture that a teaching degree is primarily targeted by female students (Arbeitsgruppe Bildungsberichterstattung 2020). Compared to the population of student teachers at all universities of teacher education from 2018 (Kastendeich & Fohler 2019), the proportion of male participants in the survey is slightly higher (by about 3.6%). The average age at graduation from teacher training colleges is 27.8 years according to the graduate survey (Kastendeich & Fohler 2018). Bachelor's degree programs (primary, secondary, special education) make up the largest percentage of students in this sample, each at approximately 23%. Students who are an early phase of their studies (<25% of expected total study time) are slightly underrepresented at 13%, whereas students in later phases of study are roughly equally represented at almost 30% each (cf. 4.4 on measuring study progress).

Procedure

Data collection took place entirely online during the summer semester 2019 between July 4th and July 31st of 2019, using Limesurvey, an online survey tool (limesurvey.org). Participants were recruited for the survey through two channels: First, there was an initial call via the 'CampusNews', a regular mail from the Rectorate to the students. Two weeks later, a reminder to participate was sent via the same channel. Furthermore, a call for participation was made on the homepage of the university's campus management system.

Curricular cornerstones

Three learning events have been selected as curricular cornerstones in the first phase of teacher education. The first is the school internship, in which student teachers visit a school for the duration of one semester in order to gain their first longer practical school experience. At the time of the survey, 221 students in the present sample had already completed this, whereas 305 had not yet. In contrast, the four-week field internship is less about everyday teaching and more about dealing with in-depth pedagogical issues such as inclusion or individual support, which can also be completed abroad. At the time of the survey, 127 students had already completed this, 322 students were yet to do so and 77 students indicated 'not applicable', as the BFP is not compulsory in all examination regulations. These two practical phases of the study program were taken into account because students can gain practical competence experience during these periods, which could influence relevant self-assessments. The overarching study profile (Heidelberg University of Education 2019) contains thematic elective modules that can be taken over the course of several semesters. Here, in addition to topics such as counselling skills and research methods, profiles such as media and technology and, building on this, in-depth technological competency can be selected. Here, 352 students stated that they had already taken courses from the study profile, of which 110 students in turn stated that they had chosen profiles with a connection to media/technology. This third cornerstone was chosen because here students acquire dedicated knowledge about the use of technology in teaching if they choose a module with this content focus, which should, in turn, be reflected in the self-assessments.

Measurement methods

TPACK self-assessments

TPACK self-assessments were measured with four to six items per knowledge domain and five response levels ranging from 'strongly disagree' to 'strongly agree'. At the time of data collection, to our knowledge, there was no validated German-language TPACK scale. Thus item formulations were either direct translations from English-language scales or were reformulated. Items were reformulated when the existing scales were not appropriate for the present study context. For example, the most widely used TPACK battery, that of Schmidt et al. (2009), contains items in the content domain (CK) that are specific to particular subjects; mathematics, social science, science, and literature. This distinction was not appropriate for the present study as students in a university of education are not trained according to this subject logic. Other, more recent questionnaires sometimes have a focus on specific pedagogical concepts, such as in Valtonen et al. (2017), where the focus is on 21st-century-skills. This restriction would also not have been appropriate here, because teacher training schools, for example, also train special needs teachers, for whom guiding self-regulated learning in teaching practice plays a lesser role. Thus, this group of students would score lower on the dimension of pedagogical knowledge (PK), without there being any actual deficits here. From these different specifications, it emerged that none of the existing scales fully fit the present context. Thus, suitable items were taken from existing scales and additional items were formulated independently (Table 1). An attempt was made to formulate the items in such a general way that they were valid for all student teachers we aimed to sample. The items were translated by an employee with an English-speaking background and checked for clarity and comprehensibility by two other persons, a professor of educational technology and a lecturer in teacher training. To ensure that our instruments have adequate psychometric properties despite these additions and modifications, we report the results of a confirmatory factor analysis in section 4.6.

Table 1. Overview of TPACK measurement in this study.

TPACK dimension	Sample item	# items	Factor loadings	Cronbach's Alpha	Adapted from	Items added
TK	'I keep up with important new technologies'. (TK2)	6	.79–.96	.93	Schmidt et al. (2009): TK1, TK2, TK4, TK6	TK3, TK5
PK	'I can adapt my teaching style to different learners'. (PK3)	6	.68–.75	.89	Schmidt et al. (2009): PK2, PK3, PK4, PK5	PK1, PK6
CK	'I am familiar with recent research in my subject area'. (CK3)	5	.54–.89	.84	Valtonen et al. (2017):CK1, CK2, CK3):	CK4, CK5
TPK	'I am thinking critically about how to use technology in my classroom'. (TPK4)	4	.62–.80	.87	Schmidt et al. (2009): TPK2, PK3,TPK4	TPK1
PCK	'I know how to select effective teaching approaches for my subject area'. (PCK2)	4	.59–.71	.85		PCK1–4
TCK	'I know how to use technologies that are specific to my subject area'. (TCK2)	5	.84–.95	.92	-	TCK1–5
TPCK	'Depending on the learning goal, I can teach the contents of my subject area through different approaches while using appropriate technology'. (TPCK5)	5	.66–.80	.91	-	TPCK1–5

Study progress

The variable study progress was composed of two items. Students were first asked to state their current semester, then the estimated number of semesters until the start of their thesis. In order to calculate the study progress, these two items were added to a total study duration and divided by the number of previous subject-related semesters, which resulted in the proportional study progress. Based on this, the second temporal variable, study phase, was coded by dividing the interval-scaled study progress into four phases: Phase One 1–25%, Phase Two 26–50%, Phase Three 51–75%, and Phase Four 76–100%. Example: a student who is in her second semester of study at the time of the survey and expects to begin her thesis in seven semesters would thus indicate a study duration of nine semesters prior to her thesis. Her study progress would then be ~ 22%, which would put her in the first study phase.

Analysis steps

To test the psychometric quality of the TPACK measurement model, confirmatory factor analysis (CFA) is conducted (Section 4.6). CFA can be used without prior exploratory procedures if theory building is sufficiently mature to suggest a clear factor structure (Mueller and Hancock 2008; Prudon 2015). This is the case here, as the factor structure of the TPACK model has been tested and mostly confirmed in multiple papers (e.g. Khine, Ali, and Afari 2017; Scherer, Tondeur, and Siddiq 2017). For the CFA, the criteria according to Hu and Bentler (1999), and Schreiber et al. (2006) are applied to test the model goodness of fit; the $\chi 2/df$ ratio (should be between 2 and 3), the Root Square Mean of Approximation (RMSEA, ≤.06), the Standardized Root Mean Square Residual (SRMR, ≤.08), the Tucker-Lewis Index (TLI, ≥.95) and the Comparative Fit Index (CFI, ≥.95). If necessary, improvement of the model fit is achieved by using modification indices to either exclude unclear loading items or to allow selected item pairs to covary. This is done gradually, with an eye on theoretical plausibility, until adequate model goodness of fit is achieved.

To test the association between TPACK assessments and study progress, a simple linear regression is performed with study progress as predictor and the respective TPACK dimension as dependent variable. This results in a total of seven linear regressions, one per TPACK dimension as dependent variable.

To examine any gender differences, the main effect of gender will be used in an Analysis of Variance (ANOVA). Any differential associations between study phase and TPACK dimension by gender will be analysed with the interaction study phase*gender in the ANOVA. Again, since Levene's test for homogeneity of variances is non-significant for all calculations, this statistical assumption for ANOVA is met.

In order to examine the relationship between curricular cornerstones of the teacher training program and TPACK assessments, ANCOVAs and ANOVAs were calculated for each of these events. Since the two internships (ISP and BFP) are firmly anchored in the curriculum, graduates of these internships are on average more advanced than their fellow students who have not yet completed them. Thus, study progress is a confounding variable for these cornerstones and was included as a covariate in the ANCOVA. This is not the case for the overarching study profile cornerstone, because here we do not distinguish between before and after but between different profile choices, so that an ANOVA was calculated here. Levene's test was not significant for all three analyses, so that homogeneity of the variances is given.

Test power was calculated by G*Power (Faul et al. 2007) using sensitivity analysis. As the most complex analysis is the interaction effect study phase*sex with eight groups and df = 3, this test was taken as the basis for calculation, $\alpha = .05$, $\beta = .8$, $N = 526$. This resulted in a sensitivity of f = .145, which corresponds to a partial $\eta 2$ =.017, thus providing sufficient test strength even for small effects.

The data were prepared using IBM SPSS version 25.0. The descriptive and inferential statistical analysis of the data was done with jamovi version 1.0.5.0.

Psychometric quality of the measurement model

The confirmatory factor analysis shows in the first step that the model can still be improved, since the χ2/df-ratio with 2.63 (χ2 = 1509/df = 573) as well as the RMSEA with .056 and the SRMR with .039 are already in the good or very good range. Two criteria, however, do not approach the usual thresholds according to Hu and Bentler (1999) and Schreiber et al. (2006), as CFI and TLI with .93 each are still just below the threshold of .95. To make the improvements, the largest modification indices were sought and items with high loadings on another factor were tested and excluded if necessary. The highest modification index showed a high loading of item TPK5 on factor TPCK. As this did not conform to the model, this item was excluded, which led to an improvement in the model, but was still not quite sufficient with regard to CFI and TLI, as χ2 = 1390/df = 539 = 2.58, RMSEA=. 055, SRMR = .038, CFI = .94, TLI = .93. Other modification indices in the factor loading table were significantly lower, so the covariances of the residuals between items were considered instead. Here, only item pairs within a factor were considered, as this was the only place where covariation could be theoretically justified. Thus, first TK4 and TK5, then TPCK3 and TPCK4, then TK2 and TK3, and finally TPCK4 and TPCK5 were free to covary to arrive at a model with the following fit indices, χ2 = 1245/df = 535 = 2.32, RMSEA=. 050, SRMR = .037, CFI = .95, TLI = .94. All scales of the TPACK dimensions show good internal consistency (α= .84–93). For more information about scales of TPACK dimensions, please refer to Table 1.

Results

Relationship between TPACK assessments and study progress

Linear regressions with study progress as predictor and TPACK dimensions as dependent variables showed statistically significant relationships for pedagogical knowledge (PK), F(1, 524) = 7.52, R2 = .097, $p < .001$; content knowledge (CK), F(1, 524) = 7.51, R2 = .097, $p < .001$; pedagogical content knowledge (PCK), F(1, 524) = 8.53, R2 = 12, $p < .001$; and technological content knowledge (TCK), F(1, 524) = 4.30, R2 = .034, $p < .001$.In contrast, smaller or non-significant relationships were found for technological knowledge (TK), F(1, 524) = .10, R2 = .000, $p = .92$, technological pedagogical knowledge (TPK), F(1, 524) = 2.56, R2 = .012, $p = .011$ and technological pedagogical content knowledge (TPCK), F(1, 524) = 1.84, R2 = .008, $p = .071$. Figure 1 shows the relationship between TPACK assessments and study progress, divided into four study phases.

Table 2. TPACK ratings distinguished by students' gender.

	Women's mean (SD)	Men's mean (SD)	ANOVA	p-value	partial η^2
TK	3.36 (.88)	4.08 (.83)	F(1, 513) = 43.34	<.001	.078
PK	3.82 (.76)	3.72 (.78)	F(1, 513) = 2.66	.104	.005
CK	3.54 (.71)	3.67 (.74)	F(1, 513) = 2.19	.140	.004
TPK	3.83 (.74)	4.06 (.80)	F(1, 513) = 8.34	.007	.016
TCK	3.23 (.91)	3.71 (.94)	F(1, 513) = 24.35	<.001	.045
PCK	3.82 (.71)	3.76 (.69)	F(1, 513) = 0.60	.439	.001
TPCK	3.47 (.76)	3.80 (.88)	F(1, 513) = 2.66	<.001	.030

Influence of gender on TPACK assessments

To investigate gender-specific differences, several ANOVAs were calculated, each with the TPACK dimension as the dependent variable and the factors gender and study phase. Significant main effects of gender emerge for all T-dimensions, with the difference being strongest in technological knowledge (TK) and less strong in technological pedagogical knowledge (TPK). No statistically significant differences were found in any of the non-technological areas (cf. Table 2).

To investigate gender-specific differences between study phases, the interaction effect of study phase*gender was relevant. This is significant for technological knowledge (TK), F(3, 520) = 6.32, partial η2=.036, $p < .001$; technological pedagogical knowledge (TPK), F(3, 520) = 9.86, partial η2=.054 $p < .001$ and technological pedagogical content knowledge (TPCK), F(3, 520) = 5.40, partial η2=.031, $p = .001$.Since effect sizes of .025 and above for interaction effects can be described as large (Kenny 2018), strong correlations between students' gender and self-assessed knowledge of study phases on TPACK dimensions related to technology are identified here. The correlations are such that men rate themselves about the same or somewhat more negatively than women in the first study phase, but men consistently report higher self-assessments in later phases of study, whereas women do not make any higher or even lower self-assessments in later study phases (see Figure 2).

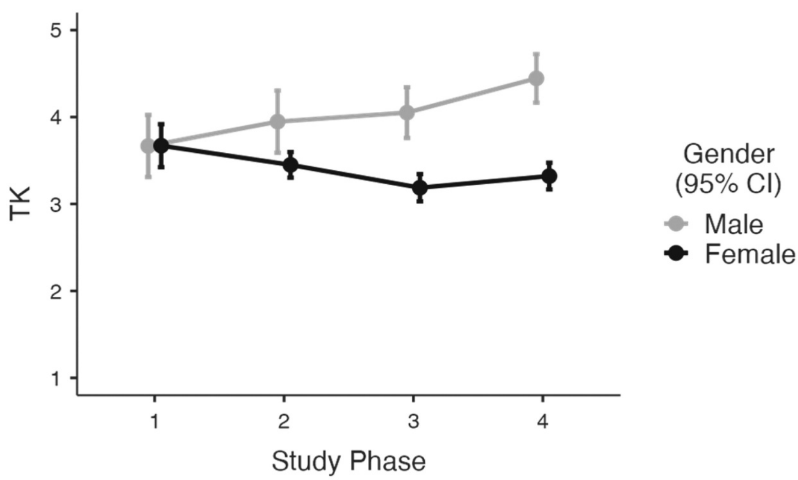

Figure 2. Ratings for TK plotted against study phase, separated by students' gender.

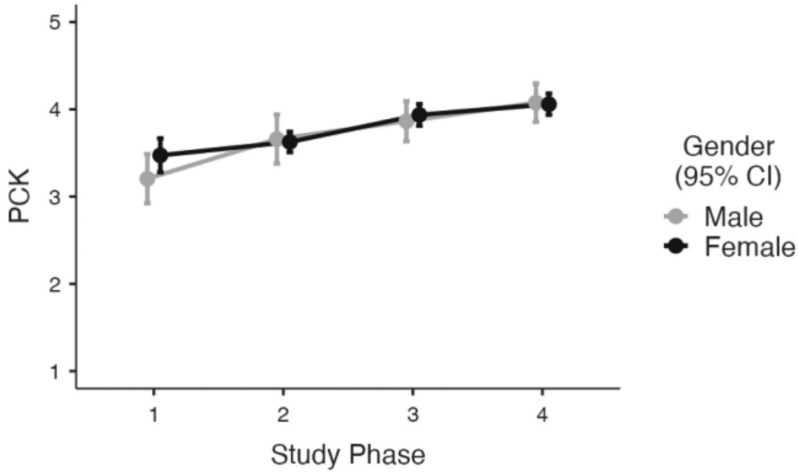

Figure 3. Ratings for PCK plotted against study phase, separated by students' gender.

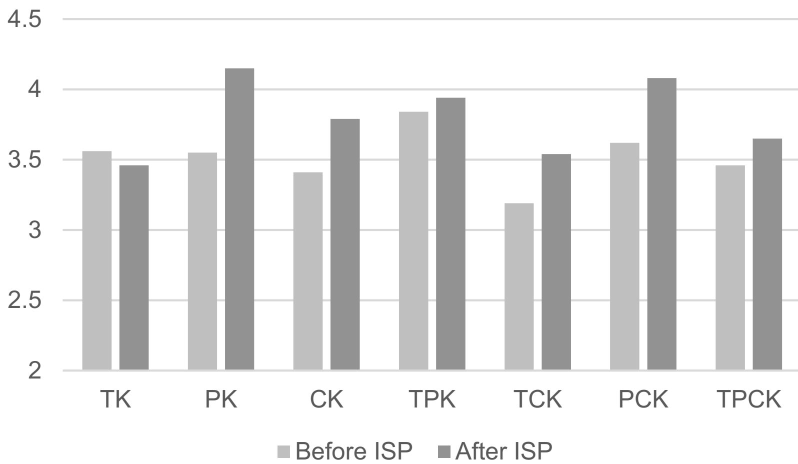

Figure 4. TPACK before and after ISP.

Also statistically significant, but with significantly smaller interaction effects, are the self-assessments of pedagogical knowledge (PK), $F(3, 520) = 3.35$, partial $\eta 2$=.019, $p < .019$, and content knowledge (CK), $F(3, 520) = 3.35$, partial $\eta 2$=.019, $p < .019$.Visual inspection of the assessments across study phases reveals that they diverge only slightly for men and women, however, for pedagogical knowledge (PK) only in the first study phase and for subject knowledge (CK) in the second study phase. For the remaining dimensions, subject-specific technological knowledge (TCK) and subject-pedagogical knowledge (PCK), there are no statistically significant interaction effects, so that similar TPACK ratings can be assumed here for men and women across study phases, (TCK) $F(3, 520) = 2.35$, partial $\eta 2$=.014, $p = .072$, (PCK), $F(3, 520) = .72$, partial $\eta 2$=.004, $p = .54$.For a visual comparison of a large interaction effect for technological knowledge (TC) and no interaction effect for pedagogical content knowledge (PCK), Figures 2 and 3 can be used as examples.

Relationship between curricular cornerstones of the study program and TPACK assessments

In order to investigate the connection between the integrated semester internship (ISP) and TPACK assessments, students before the ISP were compared with students after the ISP, while controlling for study progress (cf. Figure 4). This showed that students predominantly made higher assessments in non-technological knowledge areas after completing the ISP (cf. Figure 5). This association is statistically significant for pedagogical knowledge (PK) $p < .001$, partial η2=.076, content knowledge (CK) $p = .011$, partial η2=.012 and pedagogical content knowledge (PCK) $p < .001$, partial η2=.026, whereas technological knowledge areas show no such association, technological knowledge (TK) $p = .131$, partial η2=.004, technological pedagogical knowledge (TPK), $p = .851$, partial η2=.000, technological pedagogical content knowledge (TPCK) $p = .360$, partial η2=.002. An exception is technological content knowledge (TCK), which is the only T dimension associated with ISP, $p = .017$, partial η2=.011.

The association of the professional field placement (BFP) with TPACK assessments were calculated similarly, while excluding the 77 students who indicated 'not applicable' from the analysis. This showed that assessments in technological knowledge areas were also positively associated with the BFP to some extent, with correlations in technological knowledge (TK) $p < .001$, partial η2=.032, technological pedagogical knowledge (TPK) $p = 0.006$, partial η2=.017 and technological content knowledge (TCK) $p = 0.006$, partial η2=.017. Non-technological knowledge domains do not show these associations, at best with small effects for pedagogical knowledge (PK) $p = 0.183$, partial η2=.004, content knowledge (CK) $p = 0.012$, partial η2=.014 and pedagogical content knowledge (PCK) $p = 0.092$, partial η2=.006. The higher-level TPCK domain shows no correlation with BFP, $p = .059$, partial η2=.008 (cf. Figure 6).

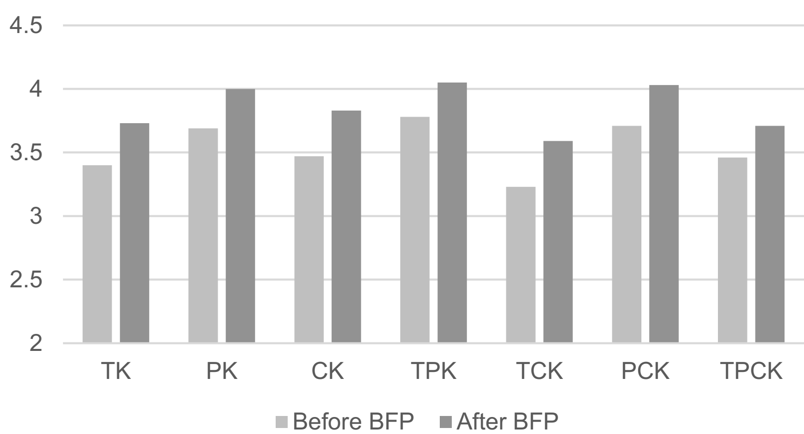

Figure 5. TPACK ratings before and after BFP.

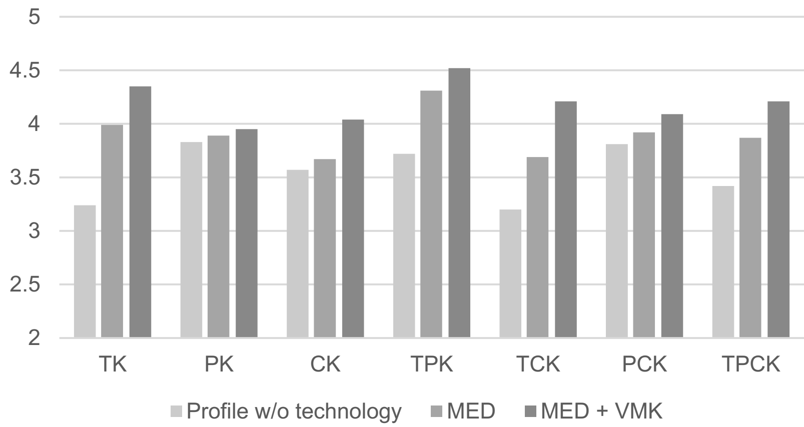

Figure 6. TPACK ratings associated with selected profile.

In order to investigate the correlation between taking an elective profile with technology focus and TPACK assessments, students who had chosen a module with and without technology focus were differentiated. In the BA/MA program, profiles with technology focus are 'media & technology competency' (MED) and 'in-depth technological competency' (VMK), resulting in three groups: no technology-focused profile, MED, MED+VMK. Furthermore, students with additional options due to older examination regulations were excluded from the analysis. The analyses consistently reveal strong statistical correlations between completing modules with technology focus and T-dimensions, as technological knowledge (TK) $p < .001$, partial $\eta2=.188$, technological pedagogical knowledge (TPK) $p < .001$, partial $\eta2=.162$, technological content knowledge (TCK) $p < .001$, partial $\eta2=.122$ and technological pedagogical content knowledge (TPACK) $p < .001$, partial $\eta2=.100$. In contrast, no such correlations were found for non-technological knowledge areas, so that pedagogical knowledge (PK) $p = .823$, partial $\eta2=.002$, content knowledge (CK) $p = .052$, partial $\eta2=.025$ and pedagogical content knowledge (PCK) $p = .414$, partial $\eta2=.008$ could not be related to the choice of a media/technology-related profile (Figure 6).

Discussion

The analysis of TPACK assessments in connection with study progress has shown that there is a connection above all in non-technological areas. The strengthening of content (CK), pedagogical (PK) and pedagogical content (PCK) knowledge of prospective teachers is part of the core business of teacher training schools, so that this connection gives an indication of the fundamental effectiveness of the teacher training. On the other hand, there seems to be a lack of training in general technological knowledge, as with regard to the interlocking with content and pedagogical knowledge, since general technological knowledge (TK), technological pedagogical knowledge (TPK), technological content knowledge (TCK), as well as technological pedagogical content knowledge (TPCK) either cannot be linked to study progress at all or only to a small extent. This is in line with international research findings that attest weaker developmental trajectories for T-dimensions, such as in the studies by Hofer and Grandgenett (2012) and Valtonen et al. (2019). However, it somewhat conflicts with Valtonen et al. (2021). The present results provide evidence that moving through the current curricula of teacher education programs, also in Germany, does not lead to higher self-assessments in these important knowledge areas. In addition to a stronger integration of this content into the curriculum, the use of empirically proven teaching/learning strategies to strengthen these areas, such as those of the so-called SQD model (Tondeur et al. 2012), continues to be recommended. These strategies, which emerge from a synthesis of qualitative evidence (SQD), describe six instructional strategies (e.g. authentic experiences and reflection) that should be considered when teaching technology use skills to prospective teachers. The use of these strategies has been associated with higher self-evaluations in T-dimensions of the TPACK model in follow-up research (Baran et al. 2019; Tondeur et al. 2016).

Confirming the findings of international studies (Roussinos and Jimoyiannis 2019; Scherer, Tondeur, and Siddiq 2017), gender-specific differences were also found in the present group of student teachers, so that especially basic technological knowledge (TK) was assessed significantly lower by women. The assessments for technological pedagogical knowledge (TPK) and technological pedagogical content knowledge (TPCK) were less pronounced but also significantly lower for women. Despite efforts regarding the increase of men in the teaching profession, in the near future, female teachers will probably continue to shape the profession (Stuve and Rieske 2018). Therefore, this self-efficacy bias regarding the use of technology and media for teaching purposes could significantly affect the digital transformation in schools and classrooms, as especially the following generation of teachers are acting as agents of this change. According to Schmid et al. (2017), they are not only unenthusiastic but, depending on their gender, also consider themselves to be less capable, as we were able to show in this study. The fact that men and women arrive at roughly equal assessments in non-technological areas such as pedagogical (PK) or content (CK) knowledge argues against a general interpretation that male students simply assess themselves more optimistically. Instead, there seems to be a real asymmetry with regard to self-efficacy expectations for the use of media and technology for teaching purposes. Thus, this important relationship is replicated for the German context. Since media/technology-related self-efficacy expectations of teachers are central determinants for the actual use of technology in the classroom (Drossel, Eickelmann, and Lorenz 2018), a particular need for action with regard to the support and promotion of student teachers should be noted here.

Gender-specific differences were also found when looking at the TPACK assessments in connection with study progress. Thus, it appears that men and women benefit in different ways from their experiences during their studies, especially with regard to T-dimensions of the TPACK model. Again, the effect was greatest with regard to basic technological knowledge (TK), but was also present with regard to technological pedagogical knowledge (TPK) as well as technological pedagogical content knowledge (TPCK). A visual inspection of these correlations shows that men start with roughly the same or worse assessments than women in the initial phase of their studies, but male students assess themselves more positively than women in later phases of their studies. Again, the explanation that men may assess themselves more optimistically without basis must be rejected, as no differences in the relationship between study progress and TPACK assessments are observed in other, non-technological knowledge areas. Since both groups of students predominantly follow the same curriculum, it is reasonable to interpret that men and women arrive at different self-efficacy expectations in some knowledge areas from the same courses. The phenomenon of gender-specific differences in self-assessments across phases of study is not known in the previous TPACK literature and should therefore be replicated. A deeper understanding of the psychological processes that cause these differences would be a good basis for recommendations to counteract this phenomenon.

The analysis of existing curricular offerings with regard to their effects on TPACK assessments reveals an overall heterogeneous picture. With regard to self-assessed competencies, students in the integrated semester internship (ISP), a 17-week practical phase at a school, benefit primarily in pedagogical (PK), content (CK) and pedagogical content (PCK) knowledge areas. Technological TPACK dimensions remain largely untouched, with the exception of technological content knowledge (TCK). This suggests that students are hardly familiarised with technology and media for teaching purposes in a practical way during this phase, a fact that is hardly surprising considering the state of digitalisation in German schools (Schmid, Goertz, and Behrens 2017). The field internship (BFP), on the other hand, shows somewhat different effects on TPACK assessments. Students report more positive assessments regarding technological (TK), technological pedagogical (TPK), and technological content knowledge (TCK) after this comparatively short internship that is less close to everyday teaching. As the only non-technological area, students after the BFP also report higher assessments in the content knowledge area (CK). Since the BFP can be completed at a wide range of educational institutions, including abroad, students certainly appear to be exposed to technology and media for pedagogical purposes at this stage. The third curricular cornerstone considered was the elective profile of the overarching field of study (OB). As expected, strong correlations between the choice of a technology profile and technological TPACK dimensions emerge here. Non-technological areas, on the other hand, remain unaffected. With regard to this curricular offer, however, a monocausal interpretation must be avoided, since it is quite possible that particularly students with an existing affinity to technology also chose those technology-related profiles. Nevertheless, the possibility that increases in T-areas can be attributed to these technological offerings should be ruled out.

A limitation of the present study is that no longitudinal data are available. Instead, the temporal correlations were inferred from cross-sectional data with the aid of information on individual study progress. Of course, this information is subject to the usual validity limitations, since students could misjudge the upcoming duration of their studies in particular. Furthermore, interpretations of the relationship between study progress and TPACK assessments cannot be made in a strictly causal manner, since characteristics of the present sample, for example, different levels of knowledge at the start of studies or changes in the curriculum could play a confounding role. Finally, aside from a translation into German language, our study context necessitated additions and modifications to well-validated TPACK instruments. It is impossible to rule out that our results may have been affected by this in a substantive way. However, we provide evidence for solid psychometric properties of the instrument, while also arriving at findings in line with those from international work, thus providing evidence for the suitability of our approach to measurement.

This sample consisted of student teachers from a German University of Education, so these results may not be generalisable to students from other teacher training colleges and from other countries. Without question, there may be relevant curricular differences, as well as possibly demographic and/or personality differences from other types of higher education that influence the key variables in these studies. In order to examine the transferability of these findings, similar studies at other teacher education universities would be helpful.

Conclusions

The results of this study suggest that the development of self-efficacy for the use of technology in the classroom is not comprehensively supported in teacher education. On the positive side, there are certainly learning opportunities in the curriculum that are related to improvements in self-efficacy for teaching with technology. However, it is problematic that these do not seem to reach all students equally. In particular, female prospective teachers seem to benefit little from the existing offerings, as female students in later phases of study arrive at either equally high or even lower self-assessments in technology-related areas than their younger peers. There is an urgent need for action to further investigate this imbalance and, if necessary, to remedy it with measures to develop these skills.

Furthermore, the particular importance of general technological knowledge (TK) is also evident in this study. As suggested theoretically by the TPACK model, this area of knowledge has a gatekeeper function, which has also been empirically confirmed in international work (Scherer, Tondeur, and Siddiq 2017). It is foundational knowledge that is a prerequisite for a sound integration of media and technology for instructional purposes. In the present study, the self-assessments in this area in particular show hardly any correlation with academic progress, and at the same time this area of knowledge shows the most serious difference between the genders.

As practical implication of this research we can deduct two areas of action for our institutional embedding of media education in teacher education. These can be differentiated in a didactical adaptation and a curricular adaptation of the current approach. With regards to the didactical adaptation, the existing educational formats at the institution have provided a broad foundation of the media education field including topics which are not primarily relevant for teaching and learning but also take into account the general media system, child protection rules, disinformation and alike in line with national recommendations on media education (KMK 2016). Interestingly, these recommendations have been in the meantime shifted towards the setting of focus areas for media education which calls for a deep approach and not a broad approach (KMK 2021). Accordingly, we have focused in the updated version of our media education module in teacher education on the area of teaching and learning with digital technologies including the improvement of technological knowledge as identified as an area of action in the current study. Future studies will need to show the impact of this change on the (perceived) skill development of students.

The curricula adaptation which followed the current study was based on an assessment of the embedding of media education in teacher education (Bertelsmann-Stiftung 2018). In 2017 only a minority of institutions had a mandatory media education model integrated in their teacher education curricula. Based on an internal discussion, our institution has decided in 2020 to integrate a mandatory media education module in all study programs in teacher education. This decision was also accompanied by a strategic decision to set media education as a strategic profile of the institution. By changing the curricular integration from an elective to a mandatory module, it is expected that also the female students will benefit. If further adaptation on the didactical level are required will be analysed in future studies.

Acknowledgments

The authors would like to thank the pre-service teachers that took time to participate in our research.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The authors received no specific funding for this work.

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Availability of data and material

Data and material for this study will be available upon request to the authors.

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