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Empowering Future Educators: Tailored Interventions and Digital Competency Development in Teacher Education

Abstract

This study delves into teacher students' self-assessment of their Technological Pedagogical Content Knowledge (TPACK) (pre: n=230, post: n=122), investigating the impact of tailored courses within their teacher education program. The study reveals substantial improvements in students TPACK self-perception after participating in these courses, emphasizing practical application of digital tools. The findings underscore the necessity of aligning theoretical knowledge with real-world usage, crucial for effective teaching practices in the digital world.

Keywords

Teacher Education Programs, Digital Tools, TPK

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Lehrkräfte der Zukunft stärken: Maßgeschneiderte Interventionen und Entwicklung digitaler Kompetenzen im Lehramtsstudium

Zusammenfassung

Diese Studie untersucht die Selbsteinschätzung von Lehramtsstudierenden hinsichtlich ihres Technologisch-Pädagogischen-Fach-Wissens (TPACK) sowie der Auswirkungen maßgeschneiderter Kurse innerhalb ihres Lehramtsstudiums auf diese Einschätzung (pre: n=230, post: n=122). Die Studie zeigt wesentliche Verbesserungen in der Wahrnehmung des TPACK der Studierenden nach der Teilnahme an diesen Kursen auf und betont die praktische Anwendung digitaler Medien im Studium. Die Ergebnisse unterstreichen die Notwendigkeit, theoretisches Wissen mit der Anwendung in der realen Welt in Einklang zu bringen, was für effektive Lehrpraktiken in der digitalen Welt entscheidend ist.

Schlüsselwörter

Lehramt, digitale Medien, TPK

1 Background

The Standing Conference of the Ministers of Education and Cultural Affairs (KMK) in Germany calls for increased support for education in the digital world (KMK, 2016; 2021). Teachers and their digital competence play a central role in this context (Lockton & Fargason, 2019; Wohlfart & Wagner, 2022a). Despite a significant increase in the use of digital tools by teachers in the last ten years – in 2013, only 34.4% of surveyed teachers reported using digital tools weekly, in 2018 it was 60.2% – Germany's educational landscape still ranks in the middle at best internationally regarding digital transformation (Eickelmann et al., 2019). The preparedness of students for the digital world is therefore questionable if digital technology plays no significant role in the classroom. Thus, there is an urgent need to promote and sustainably convey teachers' competencies for education in a digital world (Ternès & Schäfer, 2020; Tondeur et al., 2012).

The first phase of teacher education acts as a crucial lever in this process, introducing prospective teachers to teaching fundamentals and subject content, imparting essential pedagogical, didactic, and subject-specific knowledge to prepare them for their future profession (KMK, 2004). It is a mainly theoretical phase of education, supplemented with internships and pedagogical seminars. Given the ongoing digital transformation in society and schools, it is essential for future teachers to have the necessary skills to effectively use digital technologies in teaching and prepare students for the demands of the digital world (Döbeli Honegger, 2016; Eickelmann et al., 2016; European Council, 2010; Starkey, 2020). Moreover: besides the subject-specific application of digital tools, there is a need for adapted pedagogical competence to facilitate the transfer into the classroom. Therefore, during the first phase of teacher education, an increasing number of courses is offered, focusing on digital teaching and learning methods (Bertelsmann Stiftung et al., 2018; Kerres, 2020). The goal is to teach teacher students how to integrate digital tools and technologies into their future teaching to enhance the educational process and teach their future students' relevant digital skills (KMK, 2016; 2021).

As institutions responsible for teacher education, universities face the challenge of keeping pace with the ongoing digital transformation (Petri & Krempkow, in press). Besides imparting subject-specific knowledge, they have an educational mandate that includes digital competencies (see also Aktionsrat Bildung et al., 2018). Analyzing the demands across diverse university departments and disciplines, as well as among students, is essential for crafting modern curricula and fostering vital digital proficiencies, particularly for aspiring educators. Given this challenge, investigating the existing digital competencies among teacher education students, and identifying potential gaps becomes necessary.

Thus, the present study responds to the call of the thematic issue and utilizes the theoretical frameworks of the Technological Pedagogical Content Knowledge (TPACK) model by Mishra and Koehler (2006) to evaluate the effectiveness of tailored courses for education in the digital world during the first phase of teacher education. The TPACK model is particularly suitable because it emphasizes the interaction between technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK). It takes the specific requirements of teachers in the digital world into account by integrating not only technological competence but also pedagogical and subject knowledge.

2 Conceptual Framework: TPACK

Digital competence has been explored in various ways in political documents and scholarly works. Ferrari (2013) defines digital competence as a comprehensive set of skills, knowledge, attitudes, and values necessary to effectively and ethically use information and communication technologies (ICT) and digital tools in different contexts. For our study, digital competence encompasses skills in handling ICT, knowledge, creativity, and attitudes towards these. To understand the complexity of integrating ICT into subject-specific teaching, we employ the TPACK model, which combines pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), and technological content knowledge (TCK) (Mishra & Koehler, 2006). The model is based on Shulman's (1986) assumption that teaching is successful only when teachers integrate subject matter knowledge (CK) and PK into PCK. Mishra and Koehler (2006) extended the complex interplay of CK and PK by adding the level of technological knowledge (TK) through a series of "Learning-by-Design" seminars and examined it further.

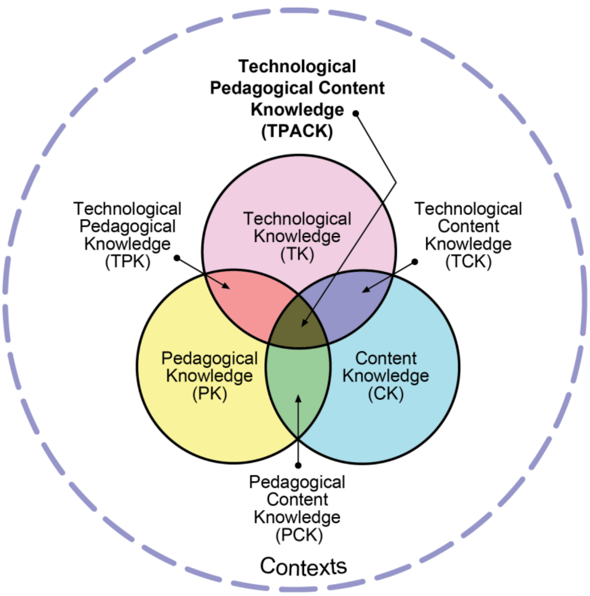

Fig. 1: The TPACK model (reproduced with permission from http://tpack.org).

Since its introduction, the TPACK model has become a cornerstone of digital education research, with over 1200 journal articles and book chapters and 315 dissertations (Harris & Wildman, 2019). In this context, Wohlfart und Wagner (2022a, 2022b) analyze eight systematic reviews focusing on the TPACK framework and highlight the diversity in interpretations of the framework. While some reviews draw clear boundaries between the knowledge domains, others find it challenging to do so

(Archambault & Barnett, 2010; Kopcha et al., 2014). In addition, the importance of specific context (e.g. school culture, class size, teachers etc.) and the need to adapt research methodologies have been highlighted by critics (Rosenberg & Koehler, 2015). Despite these challenges, there exists widespread practical acceptance of the TPACK framework in the educational science community. In the German educational discourse, a significant shift is noticeable, indicating a growing acceptance of the TPACK model (Delere, 2020; Endberg, 2019; Schmid & Petko, 2020; Tiede, 2020; Wohlfart & Wagner, 2022b). This evolving perspective aligns with the notion introduced by Willermark (2018) that conceptualizes TPACK as a competency.

Transitioning from the evolving acceptance of the TPACK model in the German educational discourse, this study aims to fill the gap in understanding the initial knowledge dimensions within the TPACK framework among teacher students. In addition, there is a need for insights into how students' self-perception regarding these knowledge dimensions develops with the attendance of tailored courses. Based on this, the following three research questions are explored in this article:

1. How do student teachers assess themselves regarding the knowledge domains within the context of the TPACK model?
2. What changes occur in students' self-perception regarding these knowledge domains after attending tailored teacher education courses related to education in the digital world?
3. How are the self-assessments of student teachers across different knowledge domains within the TPACK model interrelated?

3 Method

In the present study, the research questions were investigated through an online survey as part of an intervention study with a pre-post-test design. Teacher education students at a German university were surveyed at the beginning of the semester (t=1) and after successfully completing teacher education courses related to education in the digital world (t=2).

3.1 Instrument

To evaluate the conveyed digital competence, a questionnaire based on teacher students' self-assessment was utilized. The different knowledge dimensions of the TPACK model were employed as suitable variables for the evaluation (Wohlfart & Wagner, 2022b). The operationalization was conducted using a quantitative questionnaire based on the work of Schmidt et al. (2009) and its translation into German by Endberg (2019). The pre-test consisted of 46 items, including 8 questions regarding sociodemographic information and 34 content-related questions regarding the TPACK model (rated as self-assessment on a 5-point Likert scale). Additionally, three open-ended questions were asked, exploring students' expectations concerning the courses and the delivery of digital competence. The post-test included the same 34 TPACK items.

3.2 Data Collection, Sample and Tailored Courses

The data collection spanned four semesters (Summer Semester 2021, Winter Semester 2021/2022, Summer Semester 2022, Winter Semester 2022/2023) and included students who participated in one of 12 tailored courses related to digital education (see Table 1). These courses, part of the "digiMINT – digital learning in STEM teacher education" and "digiLAB – digital learning in teacher education" projects at Karlsruhe Institute of Technology (KIT), were specifically designed for students of teacher education to enhance their digital teaching competencies across different subject areas. Funded by the Federal Ministry of Education and Research and the

Ministry of Science, Research, and the Arts of Baden-Württemberg, both projects systematically implemented an interdisciplinary concept based on continuous communication and networking between subject disciplines, subject didactics, and educational sciences (KIT, 2022). The main goal of the projects was to develop, test and evaluate tailored courses towards digital learning contexts in STEM subjects, Physical Education (PE) and accompanying studies of the teacher education program (a.k.a. *Bildungswissenschaftliches Begleitstudium*), drawing upon the unified theoretical background of the TPACK framework (KIT, 2024). A total of 230 students took part in the pre-survey, while 122 students participated in the post-survey. Figure 3 depicts the gender and age distribution of the respondents.

Table 1: Overview of Participants by Course-Area

Course Area	**Pre-Survey Participants**	**Post-Survey Participants**	**Total Number of Responses**
Mathematics	73	45	118
Physical Education (PE)	35	6	41
Information Technology (IT)	6	5	11
Interdisciplinary STEM-Courses	47	31	78
Media Competency	61	35	96
Summary	**230**	**122**	**352**

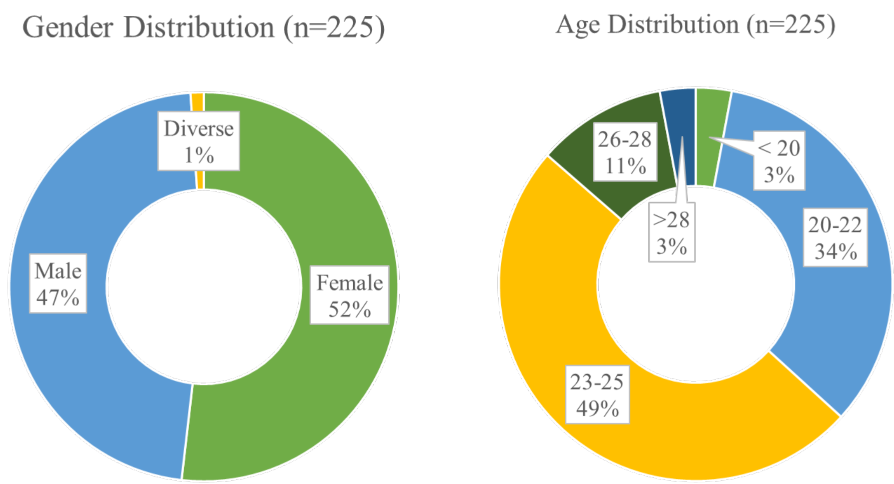

Figure 3: Gender and Age Distribution of Respondents

3.3 Data Analysis

The data analysis was conducted using SPSS version 25. The evaluation results were aggregated for the entire sample, including the pre-post comparison. Ordinal scale data based on the Likert scale ("strongly agree" – "strongly disagree") were transformed into quasi-metric data ("5" – "1") for analysis purposes. In addition to a descriptive analysis of the data, t-tests for independent samples and several correlation analyses were performed to identify intra-domain differences and relationships between individual knowledge domains and the two data collection points. We also performed several one-way ANOVAs to examine group differences based on gender, age and the attended course groups.

4 Results

4.1 TPACK Self-Assessment

In addressing the first research question, we examined how student teachers assessed their knowledge domains within the TPACK model. Table 2 provides a comprehensive overview of self-assessment results for the TPACK knowledge domains during both survey periods. In the pre-survey, the highest mean value is observed in CK with 3.84, while the TPK domain has the lowest mean value of 3.32. In the post-survey, CK continued to be rated the highest ($m = 4.15$). However, TK is rated the lowest in self-assessment (and thus has the smallest difference indicating development) with a mean value of 3.56.

As for the second research question, exploring changes in students' self-assessment regarding these knowledge domains after attending tailored teacher education courses, we analyzed variations based on course areas. All mean values show a positive difference between pre- and post-survey assessments. Except for TK, all these positive developments in self-assessment between the two measurement points are significant, with Cohen's d indicating moderate to strong effects (Table 2). According to self-assessment, TPK has developed the most significantly with a mean difference of 0.59 ($t(338) = 7.39$, $p < 0.01$).

Table 2: Results of Technological Pedagogical Content Knowledge (TPACK) Knowledge Domains based on Students' Self-Assessment

Knowledge Domain	Pre-Survey			Post-Survey			Difference	t	Cohen's d
	m	SD	n	m	SD	n			
Content Knowledge	3.84	0.62	214	4.15	0.59	114	0.31	4.45**	0.508
Pedagogical Knowledge	3.48	0.55	228	3.79	0.51	119	0.31	5.17**	0.578
Technological Knowledge	3.55	0.82	224	3.56	0.67	119	0.02	0.20	0.013
Technological Content Knowledge	3.55	0.81	215	3.93	0.76	118	0.38	4.20**	0.479
Technological Pedagogical Knowledge	3.32	0.75	220	3.91	0.61	120	0.59	7.39**	0.838
Technological Pedagogical Content Knowledge	3.43	0.62	217	3.91	0.58	115	0.49	7.08**	0.791

*$p < 0.05$
**$p < 0.01$

Note: Means are based on a five-point scale with 1 = strongly disagree, 2 = tend to not agree, 3 = Neither agreement nor disagreement, 4 = tend to agree, 5 = strongly agree.

In a second step, we analyzed the differences in self-assessment between pre- and post-survey based on course areas and found the same significant improvement ($p < 0.01$) for the mathematics-courses (CK, PK, TPK, TCK, TPACK) and the interdisciplinary STEM courses (CK, PK, TPK, TPACK). For the media competency courses, TPK and TPACK significantly improved based on the self-assessment. The differences for the other courses (PE and IT) were not significant.

We then examined whether we could identify differences in self-assessment of the students based on gender, age and the course area they attended. For this purpose, we performed several one-way ANOVAs of the pre- and post-survey data. There were no significant differences in the data related to gender or age in either cohort.

Furthermore, while there were no significant differences based on the attended course area in the pre-survey (n = 217), we did identify significant differences between at least two course areas in the post-survey (n = 114). Table 3 shows results from the following post-hoc analysis which revealed that post-coursework, students attending seminars with a focus on general media-competency (n = 33), or PE (n = 6) assessed their technology-specific knowledge domains significantly lower in comparison to those attending a course with a mathematical focus (n = 45).

Table 3: Significant results for Tukey's HSD Test for Multiple Comparisons for Technological Pedagogical Content Knowledge (TPACK) Domains based on Course Area (homogeneity of variances $p > 0.05$; significance of one-way ANOVAs $p < 0.05$)

Dependent Variables	(I) Course	(J) Course	Mean Difference (I-J)	Std. Error	Sig.	95%- Confidence Interval	
						Lower Bound	Upper Bound
Technological Pedagogical Knowledge	Mathematics	Media Competency	0.387*	0.13	0.03	0.02	0.75
		Physical Education	0.8867*	0.25	0.01	0.19	1.58
Technological Knowledge	Mathematics	Media Competency	0.4167*	0.15	0.04	0.01	0.83
Technological Content Knowledge	Mathematics	Media Competency	0.5717*	0.16	0.01	0.11	1.03
Technological Pedagogical Content Knowledge	Mathematics	Media Competency	0.4040*	0.13	0.02	0.05	0.76

4.2 TPACK Associations

To address the research question on the interrelation of student teachers' self-assessments across different knowledge domains within the TPACK model, Pearson correlation analysis was conducted. This analysis aimed to unveil the connections between the various dimensions of TPACK. This was first done separately for the two survey periods (pre- and post-test) and then combined into a single dataset. The presented results reflect the individual correlation analyses apart from the relationship between TK and PK, which was not significant in the pre-survey. Table 4 displays the correlations of the merged dataset (n = 329).

Table 4: Correlation matrix of Technological Pedagogical Content Knowledge (TPACK) domains according to Pearson (n=329)

	TK	CK	PK	TCK	TPK	TPACK
TK	1					
CK	0.311**	1				
PK	0.120*	0.354**	1			
TCK	0.465**	0.542**	0.347**	1		
TPK	0.541**	0.508**	0.460**	0.565**	1	
TPACK	0.477**	0.583**	0.493**	0.758**	0.689**	1

* The correlation is significant at the 0.05 level (2-tailed).
** The correlation is significant at the 0.01 level (2-tailed).
CK = Content Knowledge, PK = Pedagogical Knowledge, TK = Technological Knowledge, TCK = Technological Content Knowledge, TPK = Technological Pedagogical Knowledge, TPACK = Technological Pedagogical Content Knowledge

The correlation analyses revealed significant relationships between the knowledge domains with moderate to large effects for all variables (Cohen, 1988). TK has the strongest positive correlations with TCK and TPACK. CK shows a moderate positive correlation with PK and a strong positive correlation with TCK and TPACK respectively. TCK demonstrates moderate to strong positive correlations with all individual knowledge domains: TK, CK, and PK. Further, TCK has the strongest positive correlation with TPACK at 0.758 ($p < 0.01$), indicating its central position in the overall TPACK framework. TPK shows moderate positive correlations with all individual knowledge domains: TK, CK, and PK, indicating the balanced integration of technology with pedagogical and content knowledge. The correlation matrix also reveals a strong positive correlation between TPK and TCK as well as with the overall TPACK score.

5 Tailored Interventions: Shaping Digital Competencies in Teacher Education

5.1 Understanding Pre-Course Self-Assessment

Before attending specific courses, students rated their specific CK highest with a mean score of 3.84, indicating a reasonably confident understanding of the subject matter. This echoes the principles of Shulman's PCK model (1986), emphasizing the significance of content-specific expertise in effective teaching practices. Conversely, TPK was perceived as the weakest domain pre-coursework, with a mean score of 3.32, suggesting the need for improvement in integrating pedagogy and technology. These findings align with previous research examining TPACK dimensions in varying samples (Wohlfart et al., 2023; Wang et al., 2018).

Additionally, the correlation analysis (Table 3) unveiled significant relationships between various TPACK knowledge domains. Particularly noteworthy is the strong correlation between TPK and other domains, indicating its central role in the integration of technology and pedagogy (Chai et al., 2013; Lachner et al., 2019;

Mödinger et al., 2023; Wang et al., 2018). Specifically, it highlights that teachers with a strong grasp of TK also tend to excel in integrating pedagogy with technology and content, showcasing the importance of a comprehensive understanding of these dimensions for effective teaching practices that incorporate digital tools. The correlation between TPACK and its individual components highlights the interconnectedness of these dimensions, emphasizing the need for a holistic approach to digital competency development as illustrated by the designers (Mishra & Koehler, 2006).

5.2 Impact of Tailored Courses

Post-coursework, there was a significant improvement in students' self-assessment across all TPACK domains, substantiated by the significant differences in mean values between pre-survey and post-survey scores. The effect sizes, indicated by Cohen's d, were moderately strong for all knowledge dimensions, underlining the substantial impact of the specific courses on students' perceptions of their digital competencies. CK continued to be the most positively rated domain, with a mean score of 4.15, signifying a substantial enhancement in subject-specific knowledge. The substantial improvement of TPK, with Cohen's d at 0.838 ($p < 0.01$), emphasizes the significant impact of tailored interventions on enhancing TPK and, consequently, fostering comprehensive digital competencies among student teachers (Lachner et al., 2019).

Furthermore, the results demonstrated notable differences based on the course areas attended. While the pre-survey data revealed no significant differences, students attending courses focusing on general media competency or PE assessed their technology-specific knowledge domains post-coursework lower compared to those in mathematical courses. This finding underscores the need to consider context in measuring and interpreting TPACK (Mishra, 2019; Wohlfart & Wagner, 2022a). Variations in course content, teaching methods, availability of technological solutions, prior exposure to technology, instructor expertise, course design, student engagement levels, and peer influence might contribute to this difference in post-coursework self-assessment (Chai et al., 2013; Rosenberg & Koehler, 2015). For our study, we lack information on the focus on specific technologies or the percentage of content related to digital competence within individual tailored courses, as this was in the responsibility of the respective teachers. Our findings highlight the importance of considering university teachers as role models to enhance students' confidence and skills in technology integration (Wohlfart et al., 2023). Tailoring courses to address these aspects could lead to more balanced and confident self-assessments across diverse educational contexts (Chai et al., 2013; Wang et al., 2018), having significant implications for shaping future teacher education programs and guiding the seamless integration of technology into educational practices.

5.3 Practical Application and Implications for Teacher Education

Overall, our results highlight that the tailored courses played a pivotal role in shaping students' confidence and expertise in utilizing technology for educational purposes. Focusing on TPACK domains, these enhanced student teachers' digital skills and confidence. Considering the robust effect sizes observed, the courses not only show their effectiveness but also underscore the need for incorporating similar customized interventions in teacher education curricula to empower future educators adequately. In this context, our results provide valuable implications for teacher education programs: First, we recommend implementing a holistic approach to digital competency development. This includes designing courses that address the gap between subject-specific expertise (CK) and the integration of pedagogy and technology (TPK). Second, teacher education programs should implement targeted courses tailored to enhancing specific TPACK knowledge domains. For this purpose, it is prudent to provide additional support and resources for higher education teachers who are made responsible for the implementation of these courses to ensure a balanced development across all course areas. Lastly, our results emphasize the imperative of taking into account contextual factors, a principle highlighted in the TPACK-Upgrade proposed by Mishra (2019), when designing teacher education programs.

5.4 Limitations

In this study, it's crucial to acknowledge limitations that might impact the robustness of the findings. Firstly, the instrument used to measure the students' self-assessment of TPACK knowledge domains relied on self-reported data. While self-assessment provides valuable insights into students' perceptions, it might be influenced by various subjective factors, potentially introducing bias into the results (Schmid et al., 2020). Future research endeavors might explore alternative methods or employ triangulation techniques to enhance the reliability and validity of the results.

Additionally, the absence of a causal inference due to the lack of an experimental control group design, alongside a significant dropout rate from pre-survey to post-survey, underscores the need for cautious interpretation. These factors, combined with the pre-post design without a control group, warrant careful consideration when assessing the implications of our findings.

Finally, it is important to acknowledge the critical discourse surrounding the TPACK framework within the German-speaking academic community (Wohlfart & Wagner, 2022b). Despite the theoretical foundation of various adaptations and advancements such as DPaCK (Huwer et al., 2019), DPACK (Döbeli Honegger, 2020), and SEPACK (Frederking, 2022), their practical differentiation continues presenting challenges in contemporary research. While the theoretical groundwork for these concepts exists, their empirical differentiation remains a challenge in current research. This limitation underscores the evolving nature of pedagogical frameworks in educational technology and emphasizes the necessity for further refinement and exploration, especially in the context of empirical studies.

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