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Self-reported technological pedagogical content knowledge (TPACK) of pre-service teachers in relation to digital technology use in lesson plans

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ABSTRACT

TPACK is a prominent model of teacher expertise for effectively teaching with digital technologies. While numerous studies have investigated teachers' TPACK by means of self-report surveys, its relation to more objective outcomes like lesson planning has only recently come into focus. The aim of this study was to investigate whether differences in use of digital technologies in lesson plans are related to self-reported TPACK. Lesson plans of 173 pre-service teachers were coded for whether or not they included the use of digital technologies as well as for whether this use was intended for teachers or students. Independent *t* tests and ANOVAs were used to compare individual TPACK components among groups. Subsequently, unique profiles of all TPACK components were identified using cluster analyses and investigated for group differences via cross tabulation. Logistic and multinomial regressions were conducted to investigate the relations between TPACK profiles and technology use controlling for gender, age, and subject group. Overall results showed no significant group differences for either individual TPACK components or for the two- and five-cluster solutions of TPACK profiles. Subject group emerged as the only significant predictor and STEM pre-service teachers showed positive relations of TPACK components and technology use in lesson plans.

1. Introduction

Technological Pedagogical Content Knowledge (TPACK; Koehler & Mishra, 2008; Mishra & Koehler, 2006) is probably the most prominent model of teacher expertise regarding the educational use of digital technologies (Chai, Koh, & Tsai, 2013; Hew, Lan, Tang, Jia, & Lo, 2019; Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013). According to this model, which is an extension of the Pedagogical Content Knowledge framework proposed by Shulman (1986, 1987), teachers need to combine different knowledge dimensions to effectively teach with technology. These include the three core components of pedagogical knowledge (PK), content knowledge (CK), and technological knowledge (TK). In addition, there are three first level hybrid components formed at their intersections, namely pedagogical content knowledge (PCK), technological pedagogical knowledge (TPK), and technological content knowledge (TCK). These combine into the second level hybrid component, technological pedagogical content knowledge (TPCK), which is the most complex type of knowledge. It relies on a creative combination and alignment of all other knowledge domains mentioned previously. Recently, contextual knowledge has also been described as an additional area of knowledge, which needs to be considered to adapt technology use to individual students, specific classrooms, schools, or to the developments of society at large (Mishra, 2019; Porras-Hernández & Salinas-Amescua, 2013; Rosenberg & Koehler, 2015).

According to Chai et al. (2013), the TPACK framework has been primarily used to assess teachers' levels of competence and to design teacher professional development activities that are intended to build up TPACK. The literature presents many institutional case studies or intervention studies addressing these points (Starkey, 2019; Tondeur et al., 2012; Wang, Schmidt-Crawford, & Jin, 2018). In contrast to previous approaches, these professional development activities stressed the importance of content-specific and creative lesson-design activities. The TPACK model avoids a common oversimplification, where digital devices are perceived as mere add-ons to the instructional design process and instead highlights the complex interactions between pedagogy, content, and technology. Although TPACK has been a highly acclaimed and inspiring model, various issues have been identified by recent research. In particular, it has remained disputed how the knowledge dimensions should be defined and how their interplay should be described theoretically (Graham, 2011; Kimmons, 2015), how TPACK

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relates to other aspects of technology integration like teacher beliefs (Krauskopf & Forssell, 2018; Voogt et al., 2013), how TPACK impacts lesson planning (Bilici, Guzey, & Yamak, 2016; Harris & Hofer, 2011) as well as technology use in lessons (Agyei & Voogt, 2011; Chuang, Weng, & Huang, 2015; Heitink, Voogt, Verplanken, van Braak, & Fisser, 2016; Schmidt-Crawford, Tai, Wang, & Jin, 2016) and ultimately student learning (Chai et al., 2013). Studies have struggled to find clear correlations between TPACK constructs and the aforementioned aspects (e.g., Akyuz, 2018; Kopcha, Ottenbreit-Leftwich, Jung, & Baser, 2014; Krauskopf & Forssell, 2018). These issues could be related to how TPACK is currently understood and measured, as will be detailed in the following chapters.

1.1. Teacher's self-reported TPACK

There are various ways for measuring TPACK: standardized self-report rating scales, open-ended questionnaires, interviews, and performance assessments which can take the form of standardized tests, lesson plans, or observations of actual teaching (Abbitt, 2011; Chai, Koh, & Tsai, 2016; Koehler, Shin, & Mishra, 2012; Su & Foulger, 2019; Willermark, 2018). Among these, self-report methods are currently one of the most frequently used approaches, as they are a seemingly straightforward and cost-effective way to collect quantitative data. Various questionnaire scales have been developed to measure the seven areas of TPACK in surveys (e.g., Archambault & Crippen, 2009; Chai, Koh, & Tsai, 2011; Kabakci Yurdakul et al., 2012; Schmid, Brianza, & Petko, 2020; Schmidt et al., 2009; Valtonen et al., 2017). Nevertheless, there are a number of issues surrounding this approach. Existing questionnaires have been criticized regarding the fuzzy, technology-unspecific, and content-agnostic wording of questionnaire items, which ask participants to rate the "appropriateness" of their competencies (Brantley-Dias & Ertmer, 2013; Kimmons, 2015). Furthermore, existing instruments have struggled to show the expected factor structure of seven distinguishable knowledge dimensions (Archambault & Barnett, 2010; Scherer, Tondeur, & Siddiq, 2017).

In addition, self-reports present methodological issues which further threaten their internal validity in more fundamental ways, for example issues of social desirability bias, response bias (e.g., acquiescent, extreme, pattern, random, or inconsistent responding), and subjective or misinterpretations of items (Demetriou, Uzun Özer, & Essau, 2015; Paulhaus & Vazire, 2009). Moreover, the objective value of self-reported knowledge is worth considering, given that self-evaluated knowledge is relative to the extent of a person's knowledge itself. One problem is the issue of tacit knowledge, which assumes that certain types of knowledge are not consciously accessible (Cianciolo & Sternberg, 2018; Polanyi, 1967). Another problem is the so-called Dunning–Kruger Effect, where low-skilled respondents are likely to overestimate their ability (Dunning, 2011; Kruger & Dunning, 1999). This "unskilled and unaware" bias has been recognized in research on TPACK as well: "As with any self-reporting measure, the ability of the instrument to accurately represent knowledge in the TPACK domains is limited by the ability of the respondents to assess their knowledge and respond appropriately to the survey items" (Abbitt, 2011, p. 291). For example, the study by Drummond and Sweeney (2017) showed that self-reported TPACK of pre-service teachers revealed only a weak correlation with a more objective, fact-based knowledge test on TPACK. In another study, Maderick, Zhang, Hartley, and Marchand (2016) came to similar conclusions.

However, this is not just an issue unique to TPACK. Very similar problems have been reported in research on the older and more mature concept of Pedagogical Content Knowledge (see Baxter & Lederman, 1999; Hill, Loewenberg-Ball, Blunk, Goffney, & Rowan, 2007). Low correlations between self-reported and direct assessments of teacher knowledge are common (e.g., recently reported by Copur-Gencturk & Thacker, 2020). Therefore, research on teacher professional knowledge has extended beyond self-reports and focused on performance-oriented measures like actual classroom performance (Blömeke & Delaney, 2014; Hill, Loewenberg-Ball, & Schilling, 2008). With this shift and the inclusion of additional factors like teacher beliefs and context-specific mediators, it was possible to show an impact of teacher competencies on classroom practice and student learning (e.g., Gess-Newsome et al., 2019).

Research on TPACK is taking steps in similar directions to reconsider the value of self-reported data. Given the lack or weak correlations with objective performance measures, Krauskopf and Forssell (2018) propose that self-report questionnaires are more likely to measure confidence and self-efficacy with regard to the TPACK domains rather than actual knowledge (see also Willermark, 2018). Some questionnaire measures have been named accordingly (e.g., the questionnaires of Graham et al., 2009 or Saubern, Urbach, Koehler, & Phillips, 2020 explicitly measure TPACK confidence). Confidence, and more specifically self-efficacy as the ability to overcome challenging tasks, have been core concepts in research on teacher professional competence as they predict future practice (Klassen & Tze, 2014; Zee & Koomen, 2016). Despite the limitations of self-report, considering questionnaire data not strictly as a measure of knowledge but rather as a measure of TPACK confidence or self-efficacy might provide a valuable addition for studying performance and technology uptake in teaching.

1.2. Self-reported TPACK and technology use in lesson plans

While numerous studies have investigated teachers' knowledge by means of self-report surveys, its relation to more objective outcomes like lesson planning and actual teaching practices has only recently come into focus (Archambault, 2016; Chai et al., 2013). Although many studies have found positive relations between self-reported TPACK and self-reported frequency, type, or quality of classroom technology use (e.g., Chuang et al., 2015; Habib, Yusop, & Razak, 2019; Jang & Tsai, 2012; Jung, Cho, & Shin, 2019; Kabakci Yurdakul & Çoklar, 2014; Li, Garza, Keicher, & Popov, 2019), correlations between self-reported TPACK and more objective measures of implementation are less evident. Abbitt (2011) stated that "the degree to which the perceived TPACK contributes to the demonstrated ability of a preservice teacher to effectively plan for instructional uses of technology is largely unclear" (p. 297). However, this connection would be crucial. As Starkey (2019) points out, TPACK needs to be enacted by three different types of competencies: the ability to use particular technologies as a teacher, the ability to decide which technology to use for a specific teaching purpose, and the ability to guide and support students when learning with digital tools.

In recent years, there have been an increasing number of TPACK-related studies that include lesson plans or observations of actual lessons. Most studies try to use lesson plans or recordings of lessons as performance indicators that are analyzed along TPACK rubrics (e.g., Angeli & Valanides, 2005; Archambault, 2016; Harris & Hofer, 2011; Ocak & Baran, 2019; Valtonen et al., 2020). However, these studies seldom relate these performance measures to self-reported levels of TPACK. As one of the few existing studies in this regard, Backfisch, Lachner, Hische, Loose, and Scheiter (2020) did not find direct correlations between self-reported TPACK and technology use in lesson plans. Graham et al. (2009) found that even though self-reported TPACK of teachers increased over the course of a specific professional development program, the extent of their technology use continued to be primarily teacher-centered rather than also having students use technology for learning. In their reviews, Abbitt (2011) and Chai et al. (2016) have pointed out that the exact interplay between self-reported TPACK and technology integration in lesson plans and actual teaching is still unclear. Chai et al. (2016) have put it this way: "pre-service teachers may perceive themselves as efficacious in designing ICT integrated lessons, but their lesson planning performance as assessed by experts may not agree with their self-assessment" (p. 103).

1.3. The present study

This study aims to explore how pre-service teachers' self-reported TPACK reflects on inclusion of digital technology (i.e., digital software and hardware) in their lesson plans. This is investigated on two levels: First, whether individual components of TPACK account for differences in use of technologies in lesson plans; second, whether specific constellations of TPACK's seven components (i.e., TPACK profiles) correspond with planned technology use in lesson plans. Lesson plans are analyzed with regard to a) whether or not they include technology use for teaching or learning purposes, and b) for whom this use is planned (i.e., teachers or students).

In light with our first goal (i.e., to examine TPACK components individually), we expect to find differences only in the technology-related TPACK components (i.e., TK, TCK, TPK, and TPCK) of pre-services teachers in relation to their intended technology use in lesson plans. More specifically, we expect these TPACK components to be higher for those integrating technology in their lesson plans than for those who do not (H1). In addition, we expect higher scores of technology-related TPACK components among pre-service teachers planning students' use of technology compared to those planning only teacher's use or no technology use (H2).

Similarly, for our second goal (i.e., to investigate different constellations of TPACK components underlying planned technology use), we expect distinct TPACK profiles to be associated with technology use in lesson plans. We expect the profiles of those not using technology to be characterized by especially low levels of the technology-related components of TPACK (H3). Whereas for those planning technologies for students, we expect distinguishing levels of pedagogy- and technology-related components (H4).

Given that TPACK is contextually bound (Mishra & Koehler, 2006) teacher's gender (e.g., Ergen, Yanpar Yelken, & Kanadli, 2019; Scherer & Siddiq, 2015; Wright & Akgunduz, 2018) and age (e.g., Koh, Chai, & Tsai, 2010; Lee & Tsai, 2010; Lin, Tsai, Chai, & Lee, 2013) have been regarded as relevant for TPACK and/or use of technology. A further aspect is school subject, although only a few studies take this into account (Voogt et al., 2013). While some studies investigate TPACK in a single subject or subject group (especially the STEM field, see e.g. the reviews by Yigit, 2014 and Young, 2016 on mathematics or by Iswadi, Syukri, Soewarno, Yulisman, & Nurina, 2020 and Setiawan, Phillipson, Sudarmin, & Isnaeni, 2019 on Science), few studies compare TPACK across subjects (e.g., Altun & Akyıldız, 2017; Tokmak, Incikabi, & Ozgelen, 2013). Consequently, clear statements about the relationship between the subject and TPACK are currently lacking. Thus, we included gender, age, and teaching subject as control variables in the analyses and investigated them exploratively.

2. Material and methods

2.1. Sample

This study was conducted amongst pre-service upper secondary teachers enrolled in a teacher training program at a Swiss university. In Switzerland upper secondary school teachers are required to hold at least a Master's degree in their teaching subject. Thus, the pre-service teachers in this study were either completing or already held at least a Master's degree in their subject. Data was collected over three semesters from pre-service teachers attending the same compulsory course on teaching methodology offered every semester. As part of their coursework, participants were required to create a lesson plan in their subject for a topic of their choice. In addition, pre-service teachers responded to a voluntary online questionnaire assessing their demographic data and TPACK measures. Of the 326 pre-service teachers surveyed, 181 completed the questionnaire (55.5%). More than 95% of the questionnaires could be matched to corresponding lesson plans. The final sample consisted of 173 pre-service teachers (age range: 22–56 years, $M = 31.44$, $SD = 8.10$; for one person the age had to be manually imputed based on the mean of the sample), of which 93 could be identified as females and 80 as males. This sample included lesson plans for 17 different subjects. The subjects were grouped into three subject groups: STEM (biology, chemistry, computer sciences, mathematics, physics), social sciences (economics & law, geography, history, pedagogy & psychology, philosophy, religious studies), and languages (German, English, French, Italian, Latin, Spanish).

2.2. Measures

2.2.1. Teacher's self-reported TPACK

Pre-service teachers replied to the questionnaire "TPACK.xs" (Schmid et al., 2020). This questionnaire measures all seven dimensions reliably with four items per subscale (see Table 1).

2.2.2. Intended use of digital technologies in lesson plans

To assess the intended use of digital technologies, 173 lesson plans were analyzed. Pre-service teachers were asked to imagine and describe a specific educational scenario (i.e., class level, size, composition, as well as school resources and curriculum) and design a lesson for a topic of their choice. The assignment did not mention any explicit instruction for including the use of technologies in the lesson plans. All lesson plans included rationales for their topic choice and learning goals, as well as detailed descriptions of the chronological outline of their lesson (i.e., instructional activity, duration of activity, student working form, technologies used over the course of the lesson, etc.). Based on these detailed descriptions, lesson plans were coded in two steps (see Fig. 1). First, these were coded for whether or not they included the planned use of technologies ("planned technology use": *no technology* or *including technology*). Second, among those including the planned to use technologies, a distinction was made based on whom these technologies were to be used by ("user of technology": *only teacher*, e.g., teacher using PowerPoint for presenting a topic to a class; or *students*, e.g., students using Google Maps to model topographies of local communities; lesson plans in the latter category may also include instances of teachers' technology use). Two trained coders independently coded 25% of the lesson plans, revealing high intercoder reliabilities (Cohen's kappa for "planned technology use" = 0.845; Cohen's kappa for "user of technology" = 1.000). Thus, the remaining lesson plans were coded by a single coder (see Wirtz & Caspar, 2002).

2.3. Data analysis

Prior to our main analyses, full and subsamples (i.e., "no technology", "including technology", "only teacher", and "students") are tested with regards to assumptions of distribution normality by means of Q-Q plots, skewness, and kurtosis (with ranges from −2 to +2 indicating normality; Koh, 2014), as well as of homogeneity of variance by means of Levene tests (Field, Miles, & Field, 2012). For investigating group differences in the seven TPACK components (first goal), various group comparisons are conducted. For the two-group comparison ("no technology" vs. "including technology") either parametric independent *t* tests or respective nonparametric tests are applied: nonparametric Mann-Whitney test for the not normally distributed components (Field et al., 2012) or Welch's *t*-test for variance heterogeneity (Corriero, 2017). Analogously, for the three-group comparison ("no technology" vs. "only teacher" vs. "students"), parametric ANOVAs are chosen for the TPACK components meeting the assumptions of normality and homogeneity, whereas Kruskal-Wallis tests are adopted for components with non-normal distributions (Field et al., 2012), and Welch's ANOVA for those with unequal variances (Tomarken & Serlin, 1986).

Addressing our second goal, that is of analyzing the construct of TPACK holistically in relation to differences in technology use, first, k-means cluster analyses are conducted to identify groups with different patterns of TPACK component scores. Cluster analysis is an explorative

Table 1
Descriptive statistics of TPACK.xs items and subscale reliabilities.

Item		M	SD	α
pk1	I can adapt my teaching based upon what students currently understand or do not understand.	3.77	0.76	
pk2	I can adapt my teaching style to different learners.	3.61	0.83	
pk3	I can use a wide range of teaching approaches in a classroom setting.	3.55	0.88	
pk4	I can assess student learning in multiple ways.	3.80	0.81	
PK subscale		**3.68**	**0.66**	**.82**
ck1	I have sufficient knowledge about my teaching subject.	4.25	0.83	
ck2	I can use a subject-specific way of thinking in my teaching subject.	4.38	0.74	
ck3	I know the basic theories and concepts of my teaching subject.	4.35	0.66	
ck4	I know the history and development of important theories in my teaching subject.	3.80	0.93	
CK subscale		**4.20**	**0.60**	**.74**
tk1	I keep up with important new technologies.	3.47	1.13	
tk2	I frequently play around with the technology.	2.98	1.22	
tk3	I know about a lot of different technologies.	3.39	1.07	
tk4	I have the technical skills I need to use technology.	3.75	1.05	
TK subscale		**3.40**	**0.99**	**.90**
pck1	I know how to select effective teaching approaches to guide student thinking and learning in my teaching subject.	3.83	0.75	
pck2	I know how to develop appropriate tasks to promote students complex thinking of my teaching subject.	3.87	0.78	
pck3	I know how to develop exercises with which students can consolidate their knowledge of my teaching subject.	4.01	0.74	
pck4	I know how to evaluate students' performance in my teaching subject.	3.83	0.82	
PCK subscale		**3.88**	**0.62**	**.82**
tpk1	I can choose technologies that enhance the teaching approaches for a lesson.	3.75	0.88	
tpk2	I can choose technologies that enhance students' learning for a lesson.	3.59	0.93	
tpk3	I can adapt the use of the technologies that I am learning about to different teaching activities.	4.19	0.79	
tpk4	I am thinking critically about how to use technology in my classroom.	3.67	0.95	
TPK subscale		**3.80**	**0.70**	**.79**
tck1	I know how technological developments have changed the field of my subject.	3.53	1.08	
tck2	I can explain which technologies have been used in research in my field.	3.45	1.17	
tck3	I know which new technologies are currently being developed in the field of my subject.	2.88	1.20	
tck4	I know how to use technologies to participate in scientific discourse in my field.	3.20	1.10	
TCK subscale		**3.27**	**0.99**	**.89**
tpck1	I can teach lessons that appropriately combine my teaching subject, technologies, and teaching approaches.	3.68	0.83	
tpck2	I can use strategies that combine content, technologies, and teaching approaches that I learned about in my coursework in my classroom.	3.40	0.97	
tpck3	I can choose technologies that enhance the content of a lesson.	3.60	0.94	
tpck4	I can select technologies to use in my classroom that enhance what I teach, how I teach, and what students learn.	3.54	0.85	
TPCK subscale		**3.56**	**0.76**	**.87**

Note. Scale: 1 (*strongly disagree*) to 5 (*strongly agree*); α = Cronbach's alpha; N = 173.

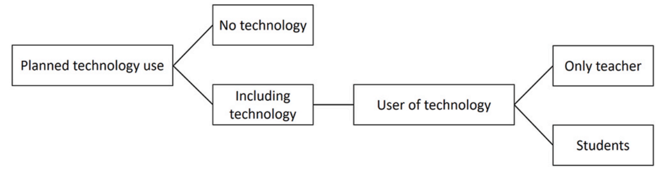

Fig. 1. Coding scheme for classifying technology use in lesson plans.

approach which attempts to identify patterns in data and use these to discover groups with the smallest within group differences and largest between group differences (i.e., groups whose members are more similar in their characteristics to each other than they are to those of other groups; Jain, 2010). Given the explorative nature of this method, models with different numbers of clusters (K) are frequently investigated as to identify the most meaningful solution in the research context (Jain, 2010). In this study, K clusters are selected based on four indices showing high performance in simulation studies (Milligan & Cooper, 1985) and their respective criteria for optimal solutions (Charrad, Ghazzali, Boiteau, & Niknafs, 2014): Caliński-Harabasz (CH) index with the highest value; the Duda index with the smallest K having an index value is greater than its respective critical value; C-index with the lowest value; and Beale index with K such that the critical value is equal or greater than alpha. Subsequently, the relations between the identified clusters and different classifications of technology use in lesson plans are investigated using cross tabulation.

In order to investigate the relations between TPACK profiles and technology use in lesson plans controlling for the effects of gender, age, and teaching subject, the same preliminary analyses described above are applied. Subject group differences in TPACK components are investigated by means of ANOVAs (or for non parametric variables, by means of Kruskal-Wallis tests). Subsequently, hierarchical logistic and multinomial regressions are conducted for the two- and three-way comparison, respectively. In a final step, cross tabulation is used to investigate the relations between technology use and identified TPACK clusters within each subject group.

All analyses are conducted in R (version 3.6.0; R Core Team, 2019) using the packages *psych* (version 1.8.12; Revelle, 2018), *car* (version 3.0–4; Fox, 2019), *NbClust* (version 3.0; Charrad et al., 2014), *sjPlot* (version 2.8.3; Lüdecke, 2020), and *mlogit* (version 1.0–2; Croissant, 2019).

3. Results

3.1. Differences in individual TPACK components and planned technology use

Initial descriptives showed that regardless of group membership, pre-service teachers' highest TPACK ratings were on the CK subscale and lowest ratings were on the TCK subscale (see Table 2). With regards to the use of technology in lesson plans, codings revealed that 37 lesson plans did not include the use of any digital technologies, whereas of the 136 which did, 90 included "only teacher" use and 46 planned "students" use. Investigating the assumptions for statistical comparisons of groups, revealed approximately normal distributions for all the TPACK components except for CK and PCK in all subgroups. Levene tests indicated homogeneity of variances for all components except TPK, $F(1, 171) = 4.77$, $p = .03$ and $F(2, 170) = 3.63$, $p = .03$, respectively for the two-group (no technology vs. including technology) and three-group comparisons (no technology vs. only teacher vs. students).

Thus, for our first goal of investigating differences in individual TPACK components among pre-service teachers planning to use technology compared to those not planning any technology use, parametric independent t tests were adopted for the components PK, $t(171) = -0.03$, $p = .98$; TK, $t(171) = -0.09$, $p = .93$; TCK, $t(171) = -0.30$, $p = .77$; and TPCK, $t(171) = -1.86$, $p = .06$. For TPCK the effect size is d = 0.34, which equals a small to medium effect. For the not normally distributed components the nonparametric Mann-Whitney test was chosen: CK, $W = 2628$, $p = .68$ (median = 4.25); and PCK, $W = 2917$, $p = .14$ (median = 3.75). For TPK, a Welch's t test was applied to account

Table 2
Descriptives of TPACK components for full and subsamples of technology use.

Sample	*n*	*M (SD)*						
		PK	CK	TK	PCK	TPK	TCK	TPCK
Full sample	173	3.68 (0.66)	4.20 (0.60)	3.40 (0.99)	3.88 (0.62)	3.80 (0.70)	3.27 (0.99)	3.56 (0.76)
Planned technology use								
No technology	37	3.68 (0.77)	4.22 (0.66)	3.39 (0.93)	4.03 (0.71)	3.71 (0.84)	3.22 (1.00)	3.35 (0.86)
Including technology	136	3.69 (0.63)	4.19 (0.58)	3.40 (1.00)	3.84 (0.60)	3.83 (0.66)	3.28 (0.99)	3.61 (0.72)
User of technology								
Only teacher	90	3.72 (0.63)	4.13 (0.58)	3.34 (0.98)	3.88 (0.61)	3.82 (0.71)	3.20 (0.96)	3.66 (0.71)
Students	46	3.61 (0.64)	4.29 (0.58)	3.51 (1.04)	3.77 (0.57)	3.84 (0.56)	3.42 (1.03)	3.51 (0.74)

for variance heterogeneity: $t(48.48) = -0.77$, $p = .44$. Analogously, for the three-group comparison parametric ANOVAs were chosen for the TPACK components meeting the assumptions of normality and homogeneity: PK, $F(2, 170) = 0.40$, $p = .67$; TK, $F(2, 170) = 0.44$, $p = .65$; TCK, $F(2, 170) = 0.80$, $p = .45$; and TPCK, $F(2, 170) = 2.29$, $p = .10$. Kruskal-Wallis tests were adopted for the two components with non-normal distributions: CK, $H(2) = 3.05$, $p = .22$; and PCK, $H(2) = 4.10$, $p = .13$. Lastly, a Welch's ANOVA for unequal variances was conducted for TPK: $F(2, 82.92) = 0.32$, $p = .73$. Overall, no significant differences emerged in comparing means of individual TPACK components across either two- or three-group classifications.

3.2. TPACK profiles and planned technology use

For our second goal of considering TPACK from a multidimensional perspective, three of the four indices (i.e., CH, Duda, and Beale) suggested a two-cluster solution, whereas the C-index identified five clusters (see Table 3). Given the explorative nature of this goal, both solutions suggested by the fit indices were considered in the subsequent analyses.

The two-cluster solution resulted in one group with all high and the other with all low TPACK components scores (see Fig. 2). Similarly, the five-cluster model also revealed two groups characterized by all high and all low TPACK components as well as three additional groups each distinguishing itself from the others for lower scores on one core and its related hybrid TPACK components (e.g., low TK reflected in low TPK, TCK, and TPCK; see Fig. 3).

Table 4 describes the means and standard deviations of TPACK components by cluster for both the two- and five-cluster solutions. In both the two- and five-cluster models (with the exception of the cluster characterized by "low C"), pre-service teachers' highest TPACK ratings were on the CK subscale. In contrast, lowest component ratings varied over clusters.

In a second step, two- and five-cluster models were cross tabulated with planned technology use (i.e., "no technology" vs. "including technology") as well as with the user of technology (i.e., "no technology" vs. "only teacher" vs. "students"). Results for the two-cluster solution (Table 5) revealed practically null relations with both planned technology use, X^2 $(1, N = 173) = 0.17$, $p = .68$ ($\phi = 0.05$) as well as with the user of technology, χ^2 $(2, N = 173) = 0.38$, $p = .83$ (Cramer's V = 0.05). Similarly, the five-cluster solution (Table 6) showed only small and nonsignificant effects in relation to planned technology use and user of technology, χ^2 $(4, N = 173) = 2.83$, $p = .57$ (Cramer's V = 0.13) and χ^2 $(8, N = 173) = 10.28$, $p = .26$ (Cramer's V = 0.17), respectively.

Table 3
Indices for identifying the optimal number of clusters.

Number of clusters (*K*)	CH	Duda (critical value)	C	Beale
2	**74.11**	**1.22 (0.72)**	0.35	**−0.82**
3	56.69	1.26 (0.69)	0.32	−0.91
4	49.49	1.63 (0.64)	0.29	−1.71
5	42.69	1.00 (0.66)	**0.28**	−0.02
6	40.47	0.75 (0.66)	0.37	1.50
7	37.71	2.06 (0.57)	0.37	−2.25
8	35.06	1.33 (0.59)	0.32	−1.09
9	32.17	2.11 (0.48)	0.32	−2.22
10	30.91	1.52 (0.53)	0.34	−1.46

Note. The optimal value for each index is bolded.

3.3. Predicting technology use from gender, age, subject, and TPACK profiles

Considering the effects of gender, age, and subject for the relations between TPACK and technology inclusion in lesson plans, Table 7 presents the descriptives of each TPACK component by subject group and technology use type. Comparing the means of TPACK components between subject groups showed STEM pre-service teachers to have the highest scores on CK, TK, PCK, and TCK subscales. In contrast, social science pre-service teachers had the highest score on the TPK subscale, whereas language pre-service teachers showed the highest PK and TPCK. ANOVAs showed that these differences were only significant for the subscales TK and TCK, $F(2, 170) = 3.82$, $p = .02$ and $F(2, 170) = 7.58$, $p < .00$, respectively. On the remaining subscales differences did not reach significance: PK, $F(2, 170) = 1.84$, $p = .16$; CK, $H(2) = 1.14$, $p = .56$; PCK, $F(2, 170) = 0.66$, $p = .52$; TPK, $F(2, 170) = 0.50$, $p = .61$; and TPCK, $F(2, 170) = 0.22$, $p = .81$.

Hierarchical logistic regressions predicting planned technology use from TPACK profiles controlling for gender, age, and subject, found subject to be the only significant predictor in both models based on the two- and the five-cluster solutions of TPACK profiles (see Table 8 and Table 9): Compared to STEM pre-service teachers, social science and language pre-service teachers were more likely to include technology in their lesson plans.

In predicting technology user, similar patterns of significance emerged for the two hierarchical multinomial regressions (see Table 10 and Table 11). Compared to STEM pre-service teachers, social science and language pre-service teachers were significantly more likely to plan technology for their own use (i.e., only teacher) than to not include technology in their lesson plans. In contrast, compared to STEM pre-service teachers, social science and language pre-service teachers were significantly less likely to plan lessons incorporating students' use of technology (i.e., students) than technology used only by teachers. Subject group did not emerge as a significant predictor for distinguishing between teachers not planning the use of technology and those planning lessons including students' use. For the other predictors (i.e., gender, age, and the two- and five-cluster solutions of TPACK profiles) no significant findings emerged from any of the models.

In the final step, given restrictions of sample size, the relations of technology use and TPACK profiles within subject groups were

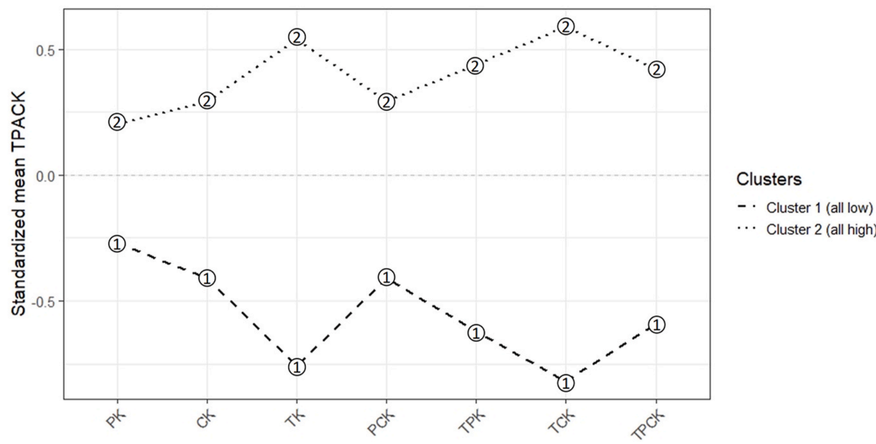

Fig. 2. Two-cluster solution of TPACK presenting standardized mean values as to ease interpretation of clusters with respect to average sample scores per component.

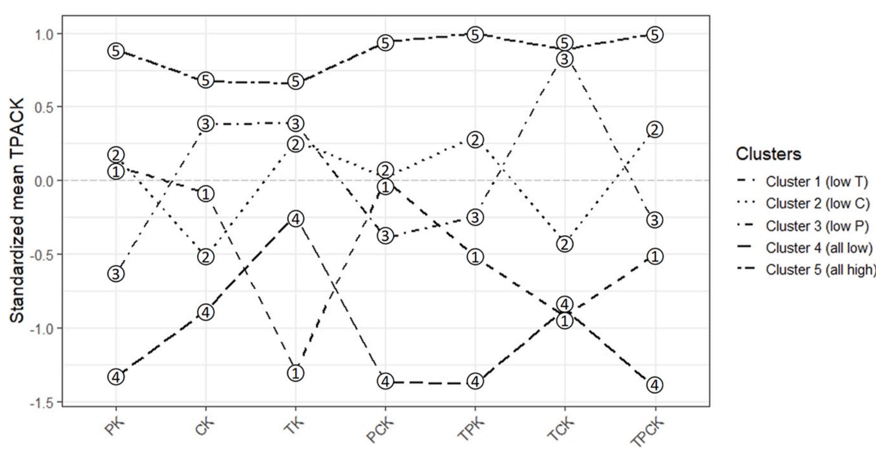

Fig. 3. Five-cluster solution of TPACK presenting standardized mean values as to ease interpretation of clusters with respect to average sample scores per component.

Table 4
Means and standard deviations (in parentheses) for two- and five-cluster TPACK models.

Model	Cluster	PK	CK	TK	PCK	TPK	TCK	TPCK	Description
Two-cluster	1	3.50 (0.54)	3.95 (0.59)	2.65 (0.83)	3.63 (0.60)	3.36 (0.61)	2.45 (0.64)	3.11 (0.66)	*All low*
	2	3.81 (0.65)	4.37 (0.54)	3.93 (0.70)	4.07 (0.58)	4.11 (0.59)	3.85 (0.76)	3.88 (0.66)	*All high*
Five-cluster	1	3.75 (0.46)	4.15 (0.54)	2.13 (0.59)	3.89 (0.42)	3.44 (0.53)	2.36 (0.60)	3.18 (0.55)	*Low T*
	2	3.80 (0.49)	3.89 (0.61)	3.67 (0.59)	3.90 (0.56)	4.01 (0.40)	2.85 (0.50)	3.83 (0.38)	*Low C*
	3	3.27 (0.48)	4.42 (0.47)	3.78 (0.85)	3.64 (0.49)	3.63 (0.54)	4.14 (0.56)	3.32 (0.56)	*Low P*
	4	2.81 (0.52)	3.67 (0.56)	3.17 (0.88)	3.03 (0.44)	2.83 (0.59)	2.40 (0.78)	2.49 (0.62)	*All low*
	5	4.28 (0.52)	4.59 (0.37)	4.04 (0.64)	4.47 (0.44)	4.50 (0.43)	4.14 (0.60)	4.32 (0.53)	*All high*

investigated only for the two-cluster solution of TPACK profiles. Consistent with the results reported above, among STEM pre-service teachers (Table 12) significant relations emerged for the two-cluster TPACK profiles and planned technology use, X^2 (1, N = **43**) = 4.91, p = .02 (ϕ = 0.39) as well as with technology user, X^2 (2, N = **43**) = 7.04, p = .03 (Cramer's V = 0.41). In contrast, no significant relations were found among social science pre-service teachers (Table 13): planned technology use, X^2 (1, N = 55) = 0.00, p = 1.00 (ϕ = 0.04); technology user, X^2 (2, N = 55) = 0.07, p = 1.00 (Cramer's V = 0.04). Similarly, for pre-service language teachers' TPACK profiles no significant relations were found with planned technology use, X^2 (1, N = 75) = 0.27, p = .57 (ϕ = 0.09), nor with technology user, X^2 (2, N = 75) = 1.68, p = .43 (Cramer's V = 0.15) (see Table 14).

4. Discussion and conclusions

Based on the results from the full sample of pre-service teachers, all four hypotheses need to be rejected. However, when looking at STEM teachers in contrast to language and social science teachers, some hypotheses can be confirmed. With regard to the full sample, our findings

Table 5
Two-cluster TPACK solution in relation to technology codings in lesson plans.

Technology coding		Cluster 1 (all low)	Cluster 2 (all high)	Total
Planned technology use	No technology	17	20	37
	Including technology	55	81	136
	Total	72	101	173
User of technology	No technology	17	20	37
	Only teacher	36	54	90
	Students	19	27	46
	Total	72	101	173

suggest that no single component of self-reported TPACK is significantly higher for pre-service teachers that plan to use technology in their lessons when compared to those who do not (H1 rejected). Although the difference in TPCK points in the expected direction, it was only marginally significant. Also, no significant differences were found with regard to whether technology was planned for only teacher's or for students' use (H2 rejected). Here too, self-reported TPCK seems to be slightly higher for those planning only teacher's use but this result is only marginally significant as well. Furthermore, the study was able to distinguish two different ways of clustering pre-service teachers according to their self-reported TPACK: a two-cluster and a five-cluster solution. Neither the two-cluster nor the five-cluster solution showed significant group differences with regard to technology inclusion in lesson plans (H3 rejected) nor with regard to whether technology use was planned for only teachers or students (H4 rejected).

The reasons underlying the lack of relations between TPACK and teachers' planned use of technology could be twofold: First, self-reported TPACK might not be a valid measure of teachers' technology use, whereas more objective TPACK measures might show the expected correlations. This seems plausible as the findings support earlier results showing that self-reported accounts of TPACK do not correlate with other, more objective measures (e.g., Akyuz, 2018; Kopcha et al., 2014; Krauskopf & Forssell, 2018; see also Chapter 1.1). However, it is unlikely that self-reported TPACK is completely useless as it measures TPACK-related confidence and self-efficacy, but for higher levels of predictive value, it needs to be complemented with more rigorous tests (Copur-Gencturk & Thacker, 2020).

Second, the results lead to the question whether self-reported TPACK is the defining aspect of technology integration or whether teacher beliefs, context-related pedagogical reasoning, learner characteristics, or the technological infrastructure need to be taken into account as well (e.g., Brantley-Dias & Ertmer, 2013; Chai et al., 2013; Gil-Flores, Rodríguez-Santero, & Torres-Gordillo, 2017). Similar observations have been made in studies on PCK, where teacher factors and student factors like beliefs and behaviors can be considered as amplifiers and filters (Gess-Newsome et al., 2019). Based on our results, self-reported TPACK measures alone do not suffice for determining differences in teachers' use of technology, but rather require to be considered in combination with additional factors.

With regard to the control variables, no significant differences according to gender or age were found. This result is not surprising. Although certain studies showed significant differences in self-reported TPACK or the use of technology between men and women or regarding the age, the differences were rather small and vary depending on the TPACK component (e.g., Ergen et al., 2019; Lin et al., 2013; Scherer, Siddiq, & Teo, 2015; Tondeur, Valcke, & van Braak, 2008). While there

Table 6
Five-cluster TPACK solution in relation to technology codings in lesson plans.

Technology coding		Cluster 1 (low T)	Cluster 2 (low C)	Cluster 3 (low P)	Cluster 4 (all low)	Cluster 5 (all high)	Total
Planned technology use	No technology	8	6	8	6	9	37
	Including technology	29	36	28	12	31	136
	Total	37	42	36	18	40	173
User of technology	No technology	8	6	8	6	9	37
	Only teacher	20	27	13	7	23	90
	Students	9	9	15	5	8	46
	Total	37	42	36	18	40	173

Table 7
Means and standard deviations of TPACK components in subject subsamples depending on form of technology use in lesson plans.

	n	PK	CK	TK	PCK	TPK	TCK	TPCK
		M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
STEM	43	3.55 (0.70)	4.26 (0.61)	3.72 (0.91)	3.93 (0.67)	3.72 (0.70)	3.76 (0.95)	3.52 (0.85)
Planned technology use								
No technology	16	3.53 (0.74)	4.09 (0.78)	3.55 (0.88)	4.08 (0.74)	3.72 (0.85)	3.14 (0.81)	3.41 (0.95)
Including technology	27	3.56 (0.70)	4.36 (0.47)	3.81 (0.93)	3.84 (0.62)	3.72 (0.61)	4.12 (0.85)	3.58 (0.80)
User of technology								
Only teacher	10	3.75 (0.74)	4.30 (0.55)	3.62 (0.84)	3.98 (0.76)	3.73 (0.53)	4.15 (0.63)	3.75 (0.70)
Students	17	3.46 (0.67)	4.40 (0.43)	3.93 (0.99)	3.76 (0.54)	3.72 (0.67)	4.10 (0.97)	3.49 (0.86)
Social sciences	55	3.65 (0.66)	4.18 (0.59)	3.41 (1.00)	3.80 (0.59)	3.86 (0.70)	3.12 (0.81)	3.53 (0.70)
Planned technology use								
No technology	6	3.50 (0.39)	4.25 (0.50)	3.54 (1.10)	3.71 (0.40)	3.71 (0.29)	3.12 (0.83)	3.17 (0.30)
Including technology	49	3.67 (0.69)	4.17 (0.60)	3.40 (0.99)	3.82 (0.61)	3.88 (0.74)	3.12 (0.82)	3.57 (0.72)
User of technology								
Only teacher	36	3.66 (0.72)	4.15 (0.52)	3.44 (1.02)	3.79 (0.64)	3.81 (0.81)	3.11 (0.84)	3.51 (0.77)
Students	13	3.69 (0.61)	4.25 (0.82)	3.29 (0.95)	3.88 (0.54)	4.10 (0.46)	3.13 (0.78)	3.75 (0.55)
Languages	75	3.79 (0.63)	4.17 (0.60)	3.20 (0.98)	3.92 (0.62)	3.80 (0.70)	3.09 (1.04)	3.60 (0.76)
Planned technology use								
No technology	15	3.92 (0.88)	4.35 (0.57)	3.15 (0.94)	4.12 (0.77)	3.70 (1.02)	3.35 (1.27)	3.37 (0.95)
Including technology	60	3.75 (0.55)	4.12 (0.60)	3.22 (1.00)	3.87 (0.58)	3.83 (0.61)	3.03 (0.98)	3.66 (0.70)
User of technology								
Only teacher	44	3.77 (0.53)	4.09 (0.64)	3.20 (0.98)	3.93 (0.55)	3.85 (0.66)	3.06 (1.01)	3.77 (0.67)
Students	16	3.72 (0.62)	4.22 (0.48)	3.25 (1.07)	3.69 (0.64)	3.75 (0.45)	2.94 (0.92)	3.36 (0.74)

Table 8
Hierarchical logistic regression predicting technology use from gender, age, subject, and 2-cluster model of TPACK profiles.

Predictor		Step 1		Step 2		Step 3	
		β (SE)	e^{β} [95% CI]	β (SE)	e^{β} [95% CI]	β (SE)	eβ [95% CI]
Constant		1.46	4.31	0.56	1.74	0.25	1.28
		(0.75)	[0.97, 18.69]	(0.85)	[0.32, 9.15]	(0.93)	[0.20, 7.83]
Gender (ref.: female)	Male	0.02	1.02	0.01	1.01	−0.03	0.97
		(0.37)	[0.49, 2.15]	(0.41)	[0.45, 2.30]	(0.42)	[0.43, 2.22]
Age		−0.01	1.00	−0.00	1.00	0.00	1.00
		(0.02)	[0.95, 1.04]	(0.54)	[0.95, 1.05]	(0.02)	[0.96, 1.05]
Subject (ref.: STEM)	Social sciences			1.58**	4.83	1.61**	4.99
				(0.54)	[1.76, 14.87]	(0.54)	[1.81,15.44]
	Languages			0.86	2.37	0.92*	2.50
				(0.45)	[0.98, 5.79]	(0.46)	[1.03, 6.22]
TPACK cluster (ref.: all low)	All high					0.33	1.39
						(0.40)	[0.64, 3.06]
R^2	Hosmer-Lemeshow	0.00		0.05		0.06	
	Cox & Snell	0.00		0.06		0.06	
	Nagelkerke	0.00		0.09		0.09	
Overall model evaluation		$X(2) = 0.06$, $p = .97$		$X(2) = 9.80$, $p = .01$		$X(1) = 0.69$, $p = .41$	

Note. ° $p < .06$; *$p < .05$; **$p < .01$; ***$p < .001$.

Table 9
Hierarchical logistic regression predicting technology use from gender, age, subject, and 5-cluster model of TPACK profiles.

Predictor		Step 1		Step 2		Step 3	
		β (SE)	e^{β} [95% CI]	β (SE)	e^{β} [95% CI]	β (SE)	e^{β} [95% CI]
Constant		1.46	4.31	0.56	1.74	−0.31	0.73
		(0.75)	[0.97, 18.69]	(0.85)	[0.32, 9.15]	(1.07)	[0.09, 5.94]
Gender (ref.: female)	Male	0.02	1.02	0.01	1.01	−0.05	0.95
		(0.37)	[0.49, 2.15]	(0.41)	[0.45, 2.30]	(0.43)	[0.41, 2.22]
Age		−0.01	1.00	−0.00	1.00	0.01	1.01
		(0.02)	[0.95, 1.04]	(0.54)	[0.95, 1.05]	(0.03)	[0.96, 1.06]
Subject (ref.: STEM)	Social sciences			1.58**	4.83	1.58**	4.83
				(0.54)	[1.76, 14.87]	(0.56)	[1.69, 15.47]
	Languages			0.86	2.37	0.91*	2.50
				(0.45)	[0.98, 5.79]	(0.48)	[0.99, 6.46]
TPACK cluster (ref.: all low)	All high					0.57	1.77
						(0.66)	[0.48, 6.43]
	Low C					0.91	2.49
						(0.71)	[0.61, 10.32]
	Low P					0.70	2.01
						(0.69)	[0.51, 7.86]
	Low T					0.30	1.35
						(0.67)	[0.35, 5.02]
R^2	Hosmer-Lemeshow	0.00		0.05		0.07	
	Cox & Snell	0.00		0.06		0.07	
	Nagelkerke	0.00		0.09		0.10	
Overall model evaluation		$X(2) = 0.06$, $p = .97$		$X(2) = 9.80$, $p = .01$		$X(4) = 2.04$, $p = .73$	

Note. ° $p < .06$; *$p < .05$; **$p < .01$; ***$p < .001$.

were no differences according to gender and age in our study, differences were found when comparing different subject groups. This is in line with the results of Altun and Akyıldız's (2017) study, in which pre-service science teachers tended to report higher knowledge along TPACK than social science or Turkish language teachers (significant differences in CK, PCK, TCK, and TPCK). However, another study did not find any significant differences in terms of TPACK between science, mathematics, and literacy pre-service teachers before their intervention (Tokmak et al., 2013). In our study, we also observed higher levels of TK and TCK for STEM pre-service teachers. In addition, STEM pre-service teachers with overall high levels of TPACK showed higher levels of technology integration in lesson plans than those with lower ratings on the TPACK scale. In contrast, TPACK ratings and technology integration in lesson plans were unrelated in the subsample of language and social science pre-service teachers. Nevertheless, the overall probability of using technology in languages and social sciences were higher than in STEM subjects.

5. Limitations and future research

There are three main limitations of this study. First and foremost, there are questions regarding the use of lesson plans as a measure of actual pre-service teachers' performance. It is questionable how well a single lesson plan, fictively designed as a part of coursework rather than a direct implementation, represents the future teaching of pre-service teachers and how generalizable this lesson is (see also Backfisch et al., 2020 for differences between "experience levels", namely pre-service, trainee, and in-service). In addition to the validity of relying on a single lesson plan, limitations also result from the ways these lesson plans are analyzed. The codings in this study focused on generic features, namely, whether technologies were planned and by whom they were intended to be used. A finer-grained differentiation considering the quality of technology use and its functions are important factors. In its given form, the dependent variable of technology use might be too broad and too generic for sensing meaningful differences. This point should be

Table 10
Hierarchical multinomial regression predicting technology use from gender, age, subject, and 2-cluster model of TPACK profiles.

Predictor		Step 1		Step 2		Step 3	
		β (SE)	e^{β} [95% CI]	β (SE)	e^{β} [95% CI]	β (SE)	e^{β} [95% CI]
Only teacher use vs. no use							
Constant		1.54	4.69	0.22	10.05	−0.17	0.84
		(0.80)	[0.97, 22.70]	(0.93)	[0.20, 7.73]	(1.01)	[0.11, 6.16]
Gender (ref.: female)	Male	−0.22	0.80	−0.31	0.73	−0.37	0.69
		(0.40)	[0.37, 1.74]	(0.45)	[0.30, 1.76]	(0.45)	[0.28, 1.68]
Age		−0.20	0.98	−0.02	0.98	−0.01	0.99
		(0.02)	[0.94, 1.03]	(0.03)	[0.93, 1.04]	(0.03)	[0.94, 1.04]
Subject (ref.: STEM)	Social sciences			2.31***	10.05	2.36***	10.55
				(0.60)	[3.08, 32.85]	(0.61)	[3.20, 34.78]
	Languages			1.44**	4.24	1.52**	4.57
				(0.52)	[1.54, 11.67]	(0.53)	[1.63, 12.80]
TPACK cluster (ref.: all low)	All high					0.43	1.53
						(0.43)	[0.66, 3.56]
Student use vs. no use							
Constant		−0.54	0.59	−0.68	0.51	−0.86	0.42
		(0.89)	[0.10, 3.30]	(0.97)	[0.08, 3.40]	(1.06)	[0.05, 3.39]
Gender (ref.: female)	Male	0.49	1.64	0.42	1.52	0.39	1.48
		(0.45)	[0.68, 3.94]	(0.48)	[0.59, 3.89]	(0.48)	[0.57, 3.82]
Age		0.02	1.02	0.01	1.01	0.02	1.02
		(0.03)	[0.96, 1.07]	(0.03)	[0.96, 1.07]	(0.03)	[0.96, 1.07]
Subject (ref.: STEM)	Social sciences			2.31	1.97	0.70	2.02
				(0.60)	[0.60, 6.51]	(0.61)	[0.61, 6.69]
	Languages			0.17	1.18	0.20	1.22
				(0.53)	[0.42, 3.31]	(0.53)	[0.43, 3.48]
TPACK cluster (ref.: all low)	All high					0.20	1.23
						(0.47)	[0.49, 3.06]
Student use vs. teacher only use							
Constant		−2.08	0.12	−0.90	0.20	−0.69	0.50
		(0.76)	[0.03, 0.55]	(0.88)	[0.07, 2.29]	(0.96)	[0.08, 3.29]
Gender (ref.: female)	Male	0.71*	2.04	0.73	2.08	0.76	2.14
		(0.37)	[0.99, 4.23]	(0.41)	[0.92, 4.67]	(0.42)	[0.95, 4.86]
Age		0.03	1.03	0.03	1.03	0.03	1.03
		(0.02)	[0.99, 1.08]	(0.02)	[0.99, 1.08]	(0.02)	[0.98, 1.08]
Subject (ref.: STEM)	Social sciences			−1.63**	0.20	−1.65**	0.19
				(0.53)	[0.03, 0.33]	(0.53)	[0.07, 0.54]
	Languages			−1.30*	0.28	−1.32*	0.27
				(0.52)	[0.10, 0.76]	(0.52)	[0.10, 0.74]
TPACK cluster (ref.: all low)	All high					−0.22	0.80
						(0.40)	[0.28, 1.52]
R^2	MacFadden	0.02		0.08		0.08	
Overall model evaluation		$X^2(4) = 6.54$, $p = .16$		$X^2(4) = 20.66$, $p = .00$		$X^2(2) = 1.02$, $p = .60$	

Note. *$p < .05$; **$p < .01$; ***$p < .001$.

Table 11
Third step of the hierarchical multinomial regression predicting technology use from gender, age, subject, and 5-cluster model of TPACK profiles.

Predictor		Only teacher use vs. no use		Student use vs. no use		Student use vs. teacher only use	
		β (SE)	e^{β} [95% CI]	β (SE)	e^{β} [95% CI]	β (SE)	e^{β} [95% CI]
Constant		−0.78	0.46	−1.48	0.23	−0.71	0.49
		(1.18)	[0.05, 4.72]	(1.25)	[0.07, 2.62]	(1.15)	[0.05, 4.68]
Gender (ref.: female)	Male	−0.36	0.70	0.35	1.42	0.71	2.04
		(0.47)	[0.28, 1.73]	(0.50)	[0.54, 3.76]	(0.43)	[0.88, 4.72]
Age		−0.01	0.99	0.03	1.03	0.03	1.03
		(0.03)	[0.94, 1.05]	(0.03)	[0.97, 1.09]	(0.02)	[0.98, 1.08]
Subject (ref.: STEM)	Social sciences	2.30***	9.97	0.67	1.95	−1.63**	0.20
		(0.63)	[2.92, 33.99]	(0.64)	[0.56, 6.79]	(0.55)	[0.07, 0.58]
	Languages	1.48**	4.38	0.23	1.26	−1.24*	0.29
		(0.54)	[1.51, 12.67]	(0.56)	[0.42, 3.76]	(0.54)	[0.10, 0.83]
TPACK cluster (ref.: all low)	All high	0.92	2.50	0.07	1.08	−0.84	0.43
		(0.74)	[0.59, 3.37]	(0.79)	[0.23, 5.08]	(0.76)	[0.10, 1.92]
	Low C	1.07	2.92	0.70	2.02	−0.37	0.69
		(0.78)	[0.64, 13.36]	(0.85)	[0.38, 10.56]	(0.76)	[0.16, 3.04]
	Low P	0.51	1.66	0.88	2.41	0.37	1.44
		(0.78)	[0.36, 7.69]	(0.78)	[0.52, 11.11]	(0.75)	[0.33, 6.32]
	Low T	0.38	1.47	0.24	1.27	−0.14	0.87
		(0.74)	[0.35, 6.22]	(0.82)	[0.26, 6.15]	(0.75)	[0.20, 3.77]
R^2	MacFadden = 0.10						
Overall model evaluation: $X^2(8) = 6.76$, $p = .56$							

Note. *$p < .05$; **$p < .01$; ***$p < .001$.

Table 12
Two-cluster TPACK solution in relation to technology codings in lesson plans for STEM pre-service teachers.

Technology coding		Cluster 1 (all low)	Cluster 2 (all high)	Total
Planned technology use	No technology	9	7	16
	Including technology	5	22	27
	Total	14	29	43
Technology user	No technology	9	7	16
	Only teacher	1	9	10
	Students	4	13	17
	Total	14	29	43

Planned technology use: $\chi^2 = 4.91$, df = 1, $\phi = 0.39$, Fisher's $p = .02$.
Technology user: $\chi^2 = 7.04$, df = 2, Cramer's V = 0.41, Fisher's $p = .03$.

Table 13
Two-cluster TPACK solution in relation to technology codings in lesson plans for social science pre-service teachers.

Technology coding		Cluster 1 (all low)	Cluster 2 (all high)	Total
Planned technology use	No technology	2	4	6
	Including technology	19	30	49
	Total	21	34	55
Technology user	No technology	2	4	6
	Only teacher	14	22	36
	Students	5	8	13
	Total	21	34	55

Planned technology use: $\chi^2 = 0.00$, df = 1, $\phi = 0.04$, Fisher's $p = 1.00$.
Technology user: $\chi^2 = 0.07$, df = 2, Cramer's V = 0.04, Fisher's $p = 1.00$.

Table 14
Two-cluster TPACK solution in relation to technology codings in lesson plans for language pre-service teachers.

Technology coding		Cluster 1 (all low)	Cluster 2 (all high)	Total
Planned technology use	No technology	6	9	15
	Including technology	31	29	60
	Total	37	38	75
Technology user	No technology	6	9	15
	Only teacher	21	23	44
	Students	10	6	16
	Total	37	38	75

Planned technology use: $\chi^2 = 0.27$, df = 1, $\phi = 0.09$, Fisher's $p = .57$.
Technology user: $\chi^2 = 1.68$, df = 2, Cramer's V = 0.15, Fisher's $p = .43$.

addressed by future investigation, as the mere use of technologies is not in itself a quality criterion. Rather, it is important that the use of technologies is aligned with the goals and content of the lessons. Quality could, for example, be rated using the Three Basic Dimensions of teaching quality (see Praetorius, Klieme, Herbert, & Pinger, 2018) or the SAMR model (see Hamilton, Rosenberg, & Akcaoglu, 2016; Puentedura, 2006). Another approach could be to take greater account of teachers' decision-making process regarding the use of technology (see e.g., Kopcha, Neumann, Ottenbreit-Leftwich, & Pitman, 2020) and the reasons why teachers use technology in classrooms (see e.g., Heitink et al., 2016). In future, teacher's technology use should be considered over multiple lessons and in addition to lesson plans, video recorded lessons could also be included to examine the use of technology and help increase external validity.

Second, it is crucial to acknowledge that this study was conducted with pre-service teachers. Pre-service teachers are not completely bare of any professional knowledge but they are likely to be not experienced enough to already have well established schemas and stable structures of TPACK. In other words, pre-service teachers belong to that "in-between" knowledge development phase "… when one acquires some minimal information but evidence for [self-assessed] knowledge adequacy is neither easily available nor convincing, …" (Park, Gardner, & Thukral, 1988, p. 402). In contrast to the not knowledgeable and the highly knowledgeable which appear to have realistic evaluations of their knowledge, this "in-between stage" shows greater discrepancies between their self-perceived and their actual knowledge (Park et al., 1988). Therefore, in the future, it would be interesting to examine not only pre-service but also in-service teachers who teach at different school levels (see e.g., Backfisch et al., 2020).

Third, given the insufficient number of teachers per individual subject, analyses were based on overarching subject groups. Focusing on specific subjects individually could be important, since for example, computer science teachers, given the inherent content of their teaching subject, would be expected to have greater TK as well as to naturally use digital technology more often than other teachers. Future research is required to further investigate this point, as our results show that there are differences between subject groups, yet at present the literature comparing individual subjects is very limited.

To conclude, future research needs to investigate relations between self-reported TPACK, more objective TPACK measures, different kinds of technology integration measures that go beyond self-report data, as well as how these constructs may vary across teaching subjects. Next to the simple question of whether technology is used or not, the quality and ultimately the effectiveness of technology use need to be taken into account. In addition, TPACK needs to be embedded in overarching frameworks of technology integration to assess its predictive value in combination with other measures like teacher beliefs or context variables such as student variables, technological infrastructure, or school culture. There does not seem to be a direct connection between self-reported TPACK and technology use in lesson plans, thus research needs to understand the indirect and mediated connections in order to support teachers in the task of integrating technology in a meaningful way in their lessons.

Credit author statement

Mirjam Schmid: Conceptualization, Methodology, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Project administration. Eliana Brianza: Conceptualization, Methodology, Formal analysis, Data Curation, Writing - Original Draft. Dominik Petko: Conceptualization, Methodology, Writing - Review & Edition, Supervision.

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