Challenges in developing a TPACK survey for preservice mathematics teachers in the Norwegian context

RAMESH GAUTAM AND ARNE JAKOBSEN

This study explores challenges when adapting and further developing a subject-specific survey based on the *Technological pedagogical content knowledge* (TPACK) framework in the Norwegian context. Two hundred forty-four preservice teachers from eight institutions across Norway participated in the survey. The most prominent challenges during the adaptation and further development of the survey were related to survey item composition and factor validation due to contextual differences and unclear boundaries between different TPACK domains. After evaluating the reliability and validity, a six-factor survey with 30 items is developed. The implications of this study and direction for further improvement are suggested.

The notion of digital competence has gained significant attention both in school curricula and research internationally for more than a decade (Ferrari, 2012; Krumsvik, 2011; Marín-Suelves et al., 2020). The current Norwegian national curriculum, the *Knowledge promotion reform* (LK20), emphasizes the importance of students' digital competence (Ministry of Education and Research, 2019) and assumes that teachers possess sound digital knowledge to integrate technology effectively in teaching to support students to achieve this competence. However, existing studies reveal that Norwegian preservice teachers (PSTs), who are future teachers, do not acquire sufficient knowledge to integrate technology effectively into their teaching practices through initial teacher education (ITE) programs (Guđmundsdóttir & Hatlevik, 2018; Instefjord & Munthe, 2016; Martinovic & Zhang, 2012).

Many researchers have adopted the technological, pedagogical content knowledge (TPACK) framework to assess and understand tea-chers' and PSTs' self-perceived knowledge in integrating technology in different subject domains, including mathematics (Niess, 2005; Rashid

Ramesh Gautam, *University of Stavanger*
Arne Jakobsen, *University of Stavanger*

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& Asghar, 2016; Valtonen et al., 2017; Verloop et al., 2001; Voogt & McKenney, 2017). The framework, grounded on the principles of situated learning, emphasizes the importance of understanding the interplay between technological, pedagogical and content knowledge. It acknowledges the crucial role of contextual factors and self-efficacy beliefs in effectively integrating technology into teaching practices (Kelly et al., 2020; Mishra & Koehler, 2006). Given the dynamic nature of learning contexts, researchers emphasize the need to contextualize the TPACK framework to understand better how the TPACK domains emerge and interact across diverse contexts and backgrounds (Jang & Tsai, 2013).

While TPACK-based surveys are commonly used to contextualize TPACK domains, a subject-specific survey contextualized for Norwegian settings is currently unavailable. Nonetheless, adapting and contextualizing the framework to different contexts and backgrounds can be challenging, especially when translating and validating surveys to assess PSTs' TPACK (Jang & Tsai, 2013, Sang et al., 2016, Zelkowski et al., 2013).

Thus, this study aims to explore challenges in developing a TPACK survey to assess Norwegian primary and lower-secondary PSTs' self-perceived knowledge in integrating technology into mathematics teaching. More specifically, we will answer the following research question:

> What challenges arise when adapting and further developing an existing TPACK survey for mathematics PSTs to the Norwegian context?

Identifying the challenges involved in survey development within the Norwegian context can be beneficial in further refining and developing contextual aspects of the framework. Furthermore, insights gained from PSTs' self-efficacy perceptions related to TPACK domains will offer valuable information to teacher educators. This information can guide them in making relevant adjustments to ITE program curricula and pedagogical practices ultimately enhancing PSTs' knowledge in integrating technology into teaching mathematics.

Theoretical background

Assessing teachers' mathematical knowledge

Several frameworks have been proposed to assess teachers' mathematical knowledge (Petrou & Goulding, 2011), but no unanimously accepted framework exists (Tirosh & Even, 2007). Consequently, researchers often rely on multiple frameworks. Regarding mathematics teaching, researchers differ widely about the type of knowledge considered relevant and in categorizing these knowledge domains.

In the 1980s, educational psychologist Lee Shulman argued that teachers must possess not only knowledge of the content but also what he referred to as curricular knowledge and pedagogical content knowledge (PCK) (Shulman, 1986; Shulman, 1987). Curricular knowledge refers to an understanding of the curriculum or the prescribed content that teachers are expected to teach, while PCK represents the knowledge teachers possess about how to best teach specific content to their students. The concept of PCK is considered as one of the most significant contributions to research on teachers' knowledge. Nevertheless, some researchers have criticized Shulman's ideas for not sufficiently describing all the aspects of teacher knowledge (Petrou & Goulding, 2011). These critiques have led to further advancements in the concept of PCK. For example, in an extended conceptualization, Fennema and Franke (1992) suggested that the knowledge needed in teaching is interactive and dynamic and that mathematical knowledge for teaching constitutes four elements: knowledge of the content, knowledge of pedagogy, knowledge of students' cognition and teachers' beliefs.

Another framework proposed by Ball et al. (2008) expands Shulman's PCK by clarifying the distinction between subject matter knowledge (SMK) and PCK. It also identifies a specific type of content knowledge unique to teaching mathematics. Similarly, building on Shulman's work, Mishra and Koehler (2006) developed the TPACK framework. This framework further extends Shulman's PCK component by incorporating technology as an important knowledge component and emphasising the interconnectedness of content, pedagogy and technology.

TPACK was introduced as both a knowledge base and a conceptual framework for teachers to integrate technology into their teaching practices (Koehler & Mishra, 2009; Koehler et al., 2007; Mishra & Koehler, 2006). Initially, the framework was not developed as subject-specific, but it was later extended to various subject areas (Baser et al., 2016; Schmidt et al., 2009; Voogt & McKenney, 2017; Zelkowski et al., 2013). Several studies have explored TPACK from subject domain perspectives like science, mathematics and social studies (Schmidt et al., 2009), mathematics (Landry, 2010; Zelkowski et al., 2013) and foreign languages (Baser et al., 2016) among others. Self-report surveys based on the TPACK framework are widely used to assess PSTs' TPACK (Koehler et al., 2012), including their TPACK self-efficacy.

The TPACK framework

Mishra and Koehler (2006) proposed TPACK as a theoretical framework for understanding teacher knowledge required for effectively integrating technology into their teaching practices. The TPACK framework, illustrated in figure 1, represents complex interactions among the types of essential knowledge for successful teaching with technology. Teachers with a sound TPACK know how technological knowledge can be integrated with pedagogical strategies and content representations for teaching specific topics (Koehler et al., 2007).

Figure 1 shows that the intersections of (a) *Technological knowledge*, (b) *Pedagogical knowledge* and (c) C*ontent knowledge* give rise to four different forms of knowledge, namely: (d) *Technological content knowledge*; (e) *Technological pedagogical knowledge*; (f) P*edagogical content knowledge* and (g) *Technological pedagogical content knowledge*. These seven domains are briefly explained in table 1.

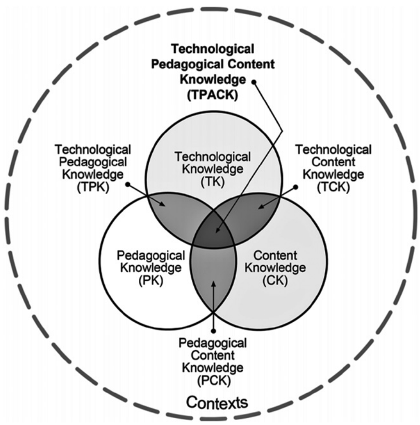

Figure 1. *The TPACK Framework (reproduced by permission of the publisher, © 2012 by* tpack.org*)*

Norwegian initial teacher education

Norwegian ITE consists of four program types: (1) primary ITE (1st–7th grade), (2) lower-secondary ITE (5th–10th grade), (3) teacher education program (8th–13th grade) and (4) post-graduate certificate in education (PGCE). The teacher education program specifically prepares PSTs for teaching mathematics at higher levels (8th–13th grade) and involves different mathematics coursework compared to primary and lower-secondary ITE. Similarly, PGCE participants have diverse educational backgrounds (e.g. engineering), and their mathematics coursework is not comparable to ITE programs.

This study focuses on PSTs enrolled in the primary and lower-secondary Norwegian ITE programs. These five-year master programs educate most teachers eligible to teach at primary and lower-secondary schools. All

Table 1. *Brief descriptions of the knowledge domains represented in the TPACK framework (Chai et al., 2011, p. 1185)*

Knowledge Domain	Description
Technological Knowledge (TK)	Knowledge of how to operate computers and relevant software.
Pedagogical Knowledge (PK)	Knowledge of planning instruction, delivering lessons, managing students, and addressing individual differences.
Content Knowledge (CK)	Subject matter knowledge such as knowledge about languages, mathematics, sciences etc.
Technological Content Knowledge (TCK)	Knowledge of how content can be researched or represented by technology, such as using computer simulation to characterize and study sine function.
Pedagogical Content Knowledge (PCK)	Knowledge of "the ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986, p. 9).
Technological Pedagogical Knowledge (TPK)	Knowledge of how technology can facilitate pedagogical approaches, such as using asynchronous discussion forums to support the social construction of knowledge.
Technological Pedagogical Content Knowledge (TPACK)	Knowledge of facilitating students' learning of a specific content through appropriate pedagogy and technology

Norwegian institutions offering these programs must follow the national regulations for teacher education. The National Council for Teacher Education has developed comprehensive national guidelines for each program, including subject-specific guidelines. These guidelines are academic guidelines specifying subjects and the content of all subjects, but the institutions have autonomy in how subjects and content are taught. Consequently, the course descriptions for mathematics and other subjects may vary across institutions offering the programs. However, all institutions must integrate teaching practices into the subjects, with a minimum of 110 days of supervised and assessed practice over five years (Jakobsen & Munthe, 2020).

Methodology

This study aimed to investigate the challenges that arise when we adapt and further develop an existing TPACK survey for mathematics PSTs in the Norwegian context. Following the survey development process outlined by Creswell and Clark (2017), the study encompassed two distinct phases: development and validation. The development phase involved conducting a literature and document review and adopting and revising a survey initially developed in the US context. Subsequently, the validation encompassed the collection and analysis of quantitative data.

Development phase

The development phase consisted of five different stages, as described below:

i) *Qualitative literature and document review*: The first stage started with a qualitative review of mathematics curriculum documents of ITE programs and documents of school mathematics curricula relevant to this study in Norway. The ITE documents included course descriptions of different mathematics courses offered by ITE programs in Norway. The purpose was to identify general topics in mathematics, technology and other TPACK domains covered by those mathematics courses.

The review of school mathematics content is based on the competence goals in mathematics mentioned in LK20. This review aimed to identify and match the mathematics content with the survey items (and, thus, the key constructs of the TPACK knowledge domain). This review identified five primary areas in mathematics: *numbers*, *probability and statistics*, *algebra*, *geometry* and *functions*. The concept of *functions* is included only from 8th grade in Norwegian schools (see The Norwegian Directorate for Education and Training, 2020, p. 12), but since *functions* is a part of both primary ITE program (e.g. UiS, 2021a) and lower secondary ITE program (e.g. UiS, 2021b), it is included in the survey.

Then, the literature on existing TPACK surveys were reviewed to identify a survey that could be adopted for this study. Many existing studies focus on TPACK survey analysis (e.g. Abbitt, 2011; Chai et al., 2016; Wang et al., 2018). Some surveys focus on general preservice teachers (Chai et al., 2011; Koh et al., 2010; Sang et al., 2016; Schmidt et al., 2009; Yurdakul et al., 2012), while others focus on general in-service teachers (Archambault & Barnett, 2010; Lee & Tsai, 2010). The survey prepared by Jang and Tsai (2012, 2013) focuses on in-service mathematics and/or science teachers, while that by Bilici et al. (2013) targets science PSTs. The survey by Zelkowski et al. (2013) focuses on mathematics PSTs.

ii) *Adoption of the survey*: In the second stage, the research team of four researchers adopted the survey by Zelkowski et al. (2013) for four specific reasons: (i) the survey focuses explicitly on preservice mathematics teachers, (ii) it has a diverse sample from 15 different institutions across the USA, (iii) it includes all seven interrelated domains that TPACK encompasses and (iv) it is based on previously validated TPACK survey (Schmidt et al., 2009) for elementary preservice teachers.

iii) *Translation and content and cross-cultural adaptation*: In the third stage, the adopted survey was thoroughly reviewed for translation and content and cross-cultural adaptation aiming to develop a conceptually equivalent Norwegian version of the survey. One researcher translated the survey into Norwegian; the other three reviewed the translated document and provided feedback. Both translation and content of the survey were reviewed and revised many times during the process. The four researchers had three subsequent meetings to discuss and further modify the translated document. All the items were thoroughly examined, and those that did not pertain to teaching mathematics in Norwegian primary and lower-secondary schools were deleted, and a final synthesis was produced. After the final review, the TPACK survey with 61 items was generated.

iv) *Experts' review*: Similar to the procedure conducted by Zelkowski et al. (2013), the fourth stage involved an expert review of the survey by five external researchers specializing in TPACK and/or the mathematics curriculum of initial teacher education (ITE). The review aimed to evaluate the content validity (Lawshe, 1975). The researchers were asked to rate to what extent each survey items measured one of the seven TPACK knowledge domains using a 10-point scale (with one being to the least extent and ten being to the greatest extent). The researchers were also requested to provide comments and suggestions for each item. Three items were deleted after receiving the experts' review.

v) *Pre-administration revision*: The final stage was the pre-administration revision. The final pre-administration version of the survey consisted of 58 items in different TPACK domains (appendix 4). The number of items per domain varied from 6 to 12: 6 (TCK), 6 (PCK), 7 (TK), 7 (PK), 10 (CK), 11 (TPK) and 11(TPACK). One of the alternatives could be to choose the six highest-rated items from each domain, which would produce a rather shorter and balanced survey, but since it is unclear which (and how many) items we would be able to retain after the validation phase, we kept all 58 items for the validation phase. We have presented the more specific result of the development phase under the *analysis and results* section.

Validation phase

The validation phase consists of three stages: (i) quantitative data collection, (ii) quantitative data analysis and (iii) post-administration revision.

To analyze the psychometric properties of the Norwegian version of the survey, an online survey was developed using SurveyXact (appendix 4). Though paper surveys are considered to have better completion rates (Norris & Conn, 2005), administering them was difficult during the COVID-19 pandemic. To ensure an easy comparison of the result, the participants answered each question using a five-point Likert scale in line with Zelkowski et al. (2013) as 1: strongly disagree, 2: disagree, 3: neither agree nor disagree, 4: agree and 5: strongly agree.

The whole survey was prepared on nine different pages (screens). A brief description of the TPACK domain was included before the items in seven subsequent pages allocated for each TPACK domain.

The sample consisted of PSTs from primary and lower-secondary ITE programs at different Norwegian universities and/or colleges that had completed at least 30 ECTS mathematics courses. Participants' demographic data like age, gender, education type and other relevant information were also collected to provide a profile of the participants as presented in table 2.

Table 2. *Distribution of the demographic data of the respondents*

Age			
19–22	23–26	27–30	30+
36.9 %	45.5 %	9.0 %	8.6 %

Education type	
Primary ITE	Lower-secondary ITE
36.5 %	63.5 %

Level				
1st year	2nd year	3rd year	4th year	5th year
2.5 %	8.6 %	35.7 %	40.6 %	12.7 %

Practicum			
1–6 weeks	7–13 weeks	14–20 weeks	20+ weeks
25.4 %	29.1 %	26.2 %	19.3 %

Gender		
Male	Female	I don't want to answer
25.8 %	73.4 %	0.8 %

To ensure a diverse national participation, participants were selected using convenience sampling from eight different Norwegian institutions offering two ITE programs (Etikan et al., 2016). The selection process considered institution size, type and geographic location. As the target respondents were specific groups of PSTs, the correspondence was made by contacting either the head of the department, ITE program coordinator(s) or course coordinators.

Data collection was done during two semesters, fall 2021 and spring 2022. The participants received a link (that would, when clicked, create a key unique to the user) to the online survey either through an e-mail sent by the program coordinator or put on the specific institution's *Learning management system* (LMS). At the end of the second semester, we had received responses from 244 participants in total. Since the survey was sent to the participants through the program and course coordinators, it was difficult to know the exact response rate.

In the second stage, we determined the final sample for data analysis. Survey research is prone to a lack of engagement from the respondents (Guin et al., 2012). To account for this, we used three criteria for removing cases from the sample that demonstrated a lack of engagement. First was the completeness criterion (that all 58 items were answered). We examined the survey responses and found 52 incomplete responses, which we deleted from the final sample. Our survey design was structured in a way that respondents were required to answer all items before proceeding. Therefore, these incomplete surveys were not due to missing data in the traditional sense but rather incomplete surveys, where participants had submitted their responses without completing the entire questionnaire. Specifically, many items at the end of the survey were left unanswered in these incomplete surveys. We removed these incomplete surveys from the dataset, carefully considering the potential impact on the validity of our findings.

Secondly, we determined the responses' variance and deleted those with less than 10 % variance. We found two responses with 0 variance and deleted them. Thirdly, in line with Zelkowski et al. (2013), we manually examined specific answering patterns like 1, 2, 3, 4, 5, 4, 3, 2, 1 that could demonstrate a lack of respondents' engagement, but no such pattern was seen. Thus, we deleted 54 responses resulting in a sample of 190 surveys with complete responses.

Data analysis was done using SPSS 28. We assessed whether the scores obtained via the scale had a normal distribution. The analysis (n = 190) indicates normally distributed data, with skewness ranging from -1.05 to 0.28 and kurtosis ranging from -1.00 to 2.71, meeting the recommended values (Kline, 2015).

We took three steps to reduce the number of items that might affect the validity of the survey. Firstly, we investigated the item score mean and standard deviation (SD). Secondly, we examined item communalities and conducted exploratory factor analysis (EFA). Thirdly, we evaluated internal consistency reliability in terms of item-total correlation and Cronbach's alpha (Tavakol & Dennick, 2011).

Analysis and results

In this section, we analyze and present the results of the developmental and validation phases.

Survey development

While adopting the US-administered survey, we carefully considered the alignment with the Norwegian education system and made necessary adjustments. We determined that the ethnicity question, included in the US version, was unnecessary and thus chose to remove it from our survey. One significant problem that emerged during the initial survey translation was the presumed inclusion of mathematical topics. Four items related to teaching *calculus* were replaced by items on teaching *functions*, since *functions* is a core topic in Norwegian primary and lower-secondary school and *calculus* is only introduced in upper-secondary school. The PSTs in this study are not eligible to teach upper-secondary level mathematics. Similarly, three items for *numbers and algebra* were added. The *trigonometry* items were also removed since *trigonometry* is not a part of the school mathematics syllabus for primary and lower-secondary schools in Norway.

In addition to adding and deleting some items, we focused on reformulating and/or redefining the item texts to make them more compatible with the Norwegian system and use. One such example is the concept of "teaching with technology." In the Norwegian context, the term *technology* is rarely used, but the term *digital tools* is used to imply modern technology used in classroom teaching (This is the case for the survey translated into Norwegian. In this article, to remain consistent with other international studies, we have adopted both the terms *technology* and *digital tools*).

The external researchers who conducted the review in stage iv) of the development phase offered various suggestions on item wording, ambiguity, concept repetition and measurement accuracy. They rated items on a 10-point scale (1–10), with three items receiving a score of zero from one researcher. The mean ratings for items in seven knowledge domains were 6.58 (TK), 9.30 (CK), 9.08 (PK), 9.63 (PCK), 7.27 (TCK), 8.18 (TPK) and 8.49 (TPACK). When evaluated individually, a TK and a TPK item achieved an average of 3.8 and 3.6 points, respectively. The research team discussed the ratings and suggestions and made the final pre-administration revision. The two items receiving an average of less than 5 points were deleted from the final survey. As no consensus was established in the research team regarding one of the CK items after the experts' review, we decided to remove the item.

Validity and reliability

We examined the scale validity with item-level tests and exploratory factor analysis (EFA), while the scale reliability was examined in terms of item-total correlation and Cronbach's alpha.

Item level tests

We investigated *item score means* and *item score standard deviation* (SD) to identify items that are unclear, ambiguous, or difficult for the respondents to answer. Despite the potential concerns surrounding the calculation of means and SDs on ordinal data, it is a common practice in analyzing Likert scale items. Item means and SDs provide an "initial indication of the item's ability to discriminate along the Likert scale" (Lester et al., 2014, p. 51). There are no standard criteria for the item-level test using mean and standard deviation (Jin et al., 2018). We used the lowest score option plus 20 % of the score range and the highest score option minus 20 % of the score range to define the cut point of the exclusion criterion in terms of item score mean (Lester et al., 2014). In a 5-point Likert scale survey, the lowest score option for an item is 1, the highest is 5, and the score range for each item is 4. Thus, the items with a mean score lower than 1.8 or higher than 4.2 were regarded as candidates for deletion. Similarly, the exclusion criterion for the item score SD was smaller than one-sixth of the score range ($1/6 \cdot 4$), i.e., 0.67 (Jin et al., 2018). Item score means for the data set ranged from 2.78 to 4.17, and item score SDs ranged from 0.67 to 1.17, which suggests that no item met the exclusion criteria.

Exploratory factor analysis

To conduct EFA, we first performed Bartlett's test of sphericity (Bartlett, 1950) and Kaiser-Meyer-Olkin's (KMO) measure to examine sampling adequacy (Kaiser, 1970). In particular, the KMO index is recommended when the case/variable ratio is less than 5:1 (Williams et al., 2010). The KMO value can be between zero and one and considered to be normal if it is between 0.5 and 0.7, good between 0.7 and 0.8, very good between 0.8 and 0.9 and excellent if it is above 0.9 (Field, 2013). Bartlett's test of sphericity should be significant ($p < .05$) for factor analysis to be suitable (Hair, 2014).

The KMO measure of sampling adequacy was 0.87 and Bartlett's test of sphericity was significant (χ^2 (1596) = 2263.964, $p < 0.000$) for this sample. The KMO value of 0.87 indicated that component or factor analysis would be useful for the variables in our survey. First, we calculated communalities and following the recommendations of Russell (2002), eleven items with communality scores of less than 0.5 were removed. (TPK10 (0.16), TPK6 (0.19), TPK11 (0.20), TK7 (0.29), TCK6 (0.37), PK6 (0.40), PCK5 (0.42), TPK4 (0.42), CK3 (0.43), PK8 (0.44) and TPACK1 (0.44))

Then, we employed EFA with Principal axis factoring on the remaining items of the whole sample to analyze the underlying factor structure and to reduce a set of variables into factors. We used Promax rotation with Kaiser normalization because correlations between the factors were considered (Brown, 2009). Following recommendations by Costello and

Osborne (2005), we retained the factors with eigenvalues exceeding one and factor loading exceeding 0.4. The first round of EFA yielded nine factors with different number of items, but only the factors for TPACK (factor 1), CK (factor 2), PK (factor 3), TK (factor 4), TCK (factor 5) and PCK (factor 8) showed distinct and interpretable factor pattern with at least three items each. Factor 6 comprised three items (TCK1, TCK3 and TPK3), factor 7 comprised three items (CK5, PCK3 and TPACK8), while factor 9 had one item (TK6), which also loaded on factor 4. Four TPK items (TPK1, TPK2, TPK5 and TPK9) loaded into the TPACK factor, while one PCK item (PCK1) loaded into the PK factor, and one TPK item (TPK7) loaded into the TK factor. TCK3 cross-loaded on factors 5 and 6, while TPACK8 cross-loaded on factors 1 and 7. We removed these items from further analysis. Furthermore, we removed the items with initial loading below 0.4 (CK1, CK2 and TPK8). This round of EFA resulted in the loss of the TPK factor because all TPK items either had an initial loading below 0.4 or loaded into other factors (appendix 1).

After removing these items, we performed EFA on the remaining items trying to explore the possibility of six factors generated from the first round of EFA. The second round of EFA produced a distinct six-factor model with TPACK (factor 1), TK (factor 2), PK (factor 3), TK (factor 4), TCK (factor 5) and PCK (factor 6) as presented in table 3. After the EFA, we established a final survey comprising 30 items in six domains: 1) TK (5 items), 2) CK (5 items), 3) PK (5 items), 4) TCK (3 items), 5) PCK (3 items) and 6) TPACK (9 items). The finalized items of each component after EFA are presented in appendix 5.

The cumulative variance, percentage of variance and eigenvalues for each of the six validated factors after EFA is presented in table 3. The total variance explained (table 4) by six factors (62.25 %) lies within the acceptable range as variance between 40 % and 60 % is sufficient for social science research (Netemeyer et al., 2003).

Internal consistency reliability

We evaluated internal consistency reliability regarding item-total correlation and Cronbach's alpha (Tavakol & Dennick, 2011). These tests, performed at the factor level, were based on survey items retained after performing the exploratory factor analysis. A higher value of item-total correlation coefficient signifies better internal consistency reliability. Total item correlation, considering a minimum value of 0.3, is used to improve Cronbach's alpha score (Cristobal et al., 2007). Thus, the items with item-total correlation coefficient values smaller than 0.3 were the candidates for deletion, as the correlation coefficient values between 0 and 0.3 indicate a weak positive linear relationship (Ratner, 2009). No item satisfied this criterion for deletion in our study (see appendix 3).

Table 3. *Factor Loadings for EFA employing Principal axis factoring on the whole sample with Promax rotation* *

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
TK1				.720		
TK2				.729		
TK3				.710		
TK4				.641		
TK5				.647		
CK4		.693				
CK6		.798				
CK7		.830				
CK8		.692				
CK9		.598				
PK1			.721			
PK2			.754			
PK3			.722			
PK4			.632			
PK5			.516			
PCK2						.495
PCK4						.817
PCK6						.669
TCK2					.562	
TCK4					.912	
TCK5					.591	
TPACK2	.660					
TPACK3	.721					
TPACK4	.653					
TPACK5	.686					
TPACK6	.700					
TPACK7	.867					
TPACK9	.731					
TPACK10	.448					
TPACK11	.545					

Notes. * Factor loadings < 0.40 are removed
Extraction Method: Principal axis factoring.
Rotation Method: Promax with Kaiser normalization.
Rotation converged in 6 iterations.

Table 4. *Total variance explained by the validated factors*

Factor	Eigenvalues	Percentage of Variance (%)	Cumulative Variance (%)
1	9.10	30.35	30.35
2	3.49	11.63	41.98
3	2.60	8.68	50.66
4	2.06	6.86	57.52
5	1.32	4.39	61.91
6	1.00	3.39	65.25

The six-factor model yielded after EFA had all factors with high Cronbach alphas (appendix 3), TK = .82, CK = .85, PK = .84, PCK = .83, TCK = .79, TPACK = .89). Cronbach's alpha reliability coefficient normally ranges between 0 and 1, where Cronbach's alpha's value closer to 1 signifies the greater internal consistency of the items in the scale (Gliem & Gliem, 2003). A maximum alpha value of 0.90 is recommended (Streiner, 2003). Similarly, the value of alpha could be low due to a sparse number of questions, a weak correlation between items, or a heterogeneous structure. For example, if low alpha is due to a low correlation between items, then some items should be modified or removed (Tavakol & Dennick, 2011). The exclusion criterion based on Cronbach's alpha was an increase of Cronbach's alpha of a factor after removing an item (Gliem & Gliem, 2003). Deleting one item (TCK2, see appendix 3) could increase the TCK sub-domains alpha value from 0.79 to 0.8, which is not a significant increase. Therefore, we retained TCK2. Since the values of Cronbach's alpha for each of the five subscales is above 0.79 for each domain, the internal reliability is high at the group level (Taber, 2018), signifying that the finalized survey (appendix 5) is reliable.

Correlation

Correlation analysis (table 5) shows that significant positive correlations were established between different validated TPACK domains at ($p < 0.01$), except for an insignificant correlation between TK–CK and between TK–TCK. There exist low positive correlations between the following domains: TK–PK, TK–PCK, TK–TPACK, CK–PK, CK–TCK, CK–TPACK and PK–TCK, while the correlations are moderately positive for CK–PCK, PK–PCK, PK–TPACK and TCK–TPACK (Schober et al., 2018).

Table 5. *Correlation between different validated factors*

	TK	CK	PK	PCK	TCK	TPACK
TK	1					
CK	.08	1				
PK	.25*	.26*	1			
PCK	.11	.55*	.50*	1		
TCK	.05	.39*	.34*	.47*	1	
TPACK	.25*	.33*	.49*	.54*	.55*	1

Notes. $n = 190$, $^{*}p < 0.01$ (2-tailed)

Discussion and conclusion

TPACK framework has been widely accepted for effective technology integration in terms of both theoretical and practical aspects (Pamuk et al., 2015, Rosenberg & Koehler, 2015, Yeh et al., 2021). However, researchers recommend contextualizing the framework to better understand how TPACK domains emerge and interact across various contexts and backgrounds (Agyei & Voogt, 2011; Jang & Tsai, 2013). This study aimed to investigate challenges arising when adapting and further developing an existing TPACK survey in the Norwegian context.

Survey development

The differences in the mathematics curricula of the USA and Norway make it evident that some items in the survey were irrelevant in the Norwegian context, while some essential topics were missing. To address this, we removed the irrelevant items and added other necessary items. A noteworthy contextual adaptation involved the terminology shift from *students* and *learners* (used interchangeably in the adopted survey) to *elever*, the Norwegian term for school students (Mosvold et al., 2009). Additionally, we improved translations based on expert suggestions. For instance, *effective teaching approaches* (PCK1) was initially translated to *effektive undervisningsmetoder*. However, an expert proposed *gode undervisningsmetoder*, which we adopted. *Deep and broad understanding* was translated to *god forståelse* (as in many CK items) in Norwegian, based on a suggestion from an expert team member, instead of translating it literally to *dyp og bred forståelse*. These modifications were essential to ensure alignment with the Norwegian context.

Experts' feedback helped us reformulate difficult and ambiguous terms, decide on item inclusion and refine the translations of certain terms to ensure better alignment with the Norwegian context. One TK item (*I know about a lot of different technologies*) was removed based on an expert's suggestion that it may not measure much, as most respondents would likely answer "totally agree". Moreover, the item received a low average rating of 3.8 points from the experts. An expert team member questioned if it was possible to specify *thinking* on a CK item (*I can use mathematical ways of thinking*). As no consensus was established in the research team, we removed the item though it received a higher average rating (7.6 points) from the experts. We removed one TPK item (*Different technologies require different teaching approaches*) as an expert team member suggested that it was similar to TPK6.

Survey validation

Our results indicated that we were able to identify six factors of knowledge (TK, CK, PK, PCK, TCK and TPACK) from the Norwegian mathematics PSTs while concepts related to the TPK domain were not clearly identified. This result adds a finding to the literature that differs from the survey we adapted (Zelkowski et al., 2013) as they identified four factors (TK, CK, PK and TPACK). This expansion reflects the recognition of additional knowledge domains and the interplay between technology, pedagogy and content knowledge in the Norwegian context. Though we were able to validate a 6-factor TPACK survey for Norwegian mathematics PSTs, several challenges arose during the process. The most prominent challenge we encountered, as also reported by other TPACK survey designers (e.g. Archambault & Barnett, 2010; Chai et al., 2011), was that the items of overlapping TPACK domains, such as PCK, TCK and TPK, tended to merge with other factors. In this study, TPK items were more problematic than PCK and TCK items, with four out of 11 TPK items merging into the TPACK factor, while one item merged into the TK factor. This could be because the PSTs might have misinterpreted the TPK items. Since TPK emerges from a close interplay between technological and pedagogical aspects (Mishra & Koehler, 2006), it might be difficult for PSTs to distinguish between TPK and TPACK.

Though three PCK items were validated in our study, we encountered a similar challenge with the PCK domain. PCK1 loaded into the PK factor, while PCK3 loaded into the non-interpretable factor 7. PCK1 (*I know how to select effective teaching approaches to guide student thinking and learning in mathematics*) was formulated differently from other items. The words *effective teaching approaches* might have misled the PSTs to answer as if this was a PK item. The expert rating was high for PCK1 (9.8 points, appendix 2), signifying that it was not reasonable to consider it as a PK item. Therefore, we removed the item from further analysis.

Factor 6, with three items from two different domains (TCK1, TCK3 and TPK3) could be considered a separate factor, but TCK3 cross-loaded into TCK factor and factor 6 (with lower factor loading value), making it inappropriate. The experts' ratings for these items were also high, signifying that they ought to measure what they were intended for. Therefore, we removed these items.

The correlation analysis shows that basic knowledge domains (TK, CK and PK) positively influence TPACK. Similarly, a weak positive relationship between PK and TCK and a moderately positive relationship between CK and TCK could be considered as obvious, assuming that the next-level knowledge domains (TCK and TPACK) might be positively influenced by the basic knowledge domains like TK, CK and PK

(Chai et al., 2011). While a positive relationship exists between TK and TPACK domains, as expected, the weak TK – TPACK correlation could signify that the PSTs do not consider TK important for TPACK, revealing nuances in their perceptions and TPACK self-efficacy. An insignificant correlation between TK and TCK suggests that PSTs do not consider TK important for TCK at all. While a moderately positive correlation between CK and PCK domains and PK and PCK domains are expected (Sang et al., 2016), the similar correlation between PCK and TCK supports the argument for unclear boundaries between these knowledge domains.

The removal of some items associated with specific mathematical topics was another challenging aspect. After finalizing the survey through discussions and experts' feedback, we employed statistical measures for survey validation. Preparing for EFA, we deleted 11 items with low communality scores. Most items focused on accessing PSTs' general knowledge about content, pedagogy and technology, but PCK5 (included below) was specifically designed to evaluate PSTs' knowledge of geometry.

> PCK5: I know different strategies/approaches for teaching geometry concepts.

Similarly, some other items deleted during EFA (included below) also aimed to assess specific mathematical concepts.

> PCK3: I know different strategies/approaches for teaching probability and statistics concepts.

> TCK1: I know about technologies that I can use to work with and develop understanding about numbers.

> TCK3: I know about technologies that I can use for understanding and doing algebra.

> TPACK8: I can teach lessons that appropriately combine probability and statistics, technologies and teaching approaches.

Removing these items, which was statistically meaningful, also led to the exclusion of important mathematical topics from the survey. The exclusion of important mathematical topics from the survey may limit its ability to comprehensively assess PSTs' knowledge in those specific areas. This could result in an incomplete understanding of their knowledge to integrate technology into teaching mathematics. Future studies should try supplementing the survey data with qualitative interviews and classroom observations to overcome this constraint and acquire deeper insights. A more comprehensive view of PSTs' knowledge linked to the excluded mathematical areas would be possible with such an approach.

The researchers determined the intended knowledge domain for each item based on their expertise and understanding of the TPACK framework. The decision-making process for item inclusion, formulation and refinement also involved expert team members who provided feedback and suggestions. The researchers considered the expert opinions and based on their expertise and consensus within the research team, they made decisions on item modifications or removal to ensure the validity and relevance of the survey in the Norwegian context. The interpretation of the survey items by the PSTs may have influenced their responses. They seemed to emphasize TK, CK and PK as separate and independent domains, which aligns with our intention to assess distinct knowledge domains. However, there is evidence, as observed in appendix 1, that suggests the PSTs may have misunderstood certain PCK, TCK and TPK items. They responded to these items as if they belonged to the PK, CK, or TPACK domains, as indicated by their cross-loading onto other domains.

It is worth noting that the survey items and their categorization into the seven domains underwent a thorough review process by external experts for their content validity, alongside the researchers' assessments. Additionally, the adopted items had undergone similar rigorous procedure as part of Zelkowski's survey development process (Zelkowski et al., 2013). Therefore, the challenges faced by the PSTs in distinguishing these items might be attributed, among other factors, to their limited experience and the knowledge acquired during their ITE programs.

Moreover, the TPACK framework is also criticized for its lack of conceptual clarity and specificity (Angeli & Valanides, 2009; Brantley-Dias & Ertmer, 2013) and for having "fuzzy boundaries" in knowledge areas (Chai et al., 2011; Graham, 2011; Kimmons, 2015). Researchers and respondents find it difficult to distinguish boundaries and establish relationships between and amongst knowledge domains in both the assessment and development of TPACK (Nilsson, 2022).

Knowing the unclear boundaries between TPACK domains, we included a brief description of each domain in our survey, unlike Zelkowski et al. (2013), who did not. We assumed that the brief descriptions would help the respondents distinguish the differences and interconnections between various domains. Though we were able to validate six factors in contrast to Zelkowski's four, we still could not validate all seven factors. The deleted items in our study (appendix 2) need further revisions and refinements to generate an interpretable factor pattern.

Limitations

Like many other TPACK survey studies, one of our study's limitations is that we could not establish a TPACK survey with all seven valid domains. Future research could possibly further revise and refine the TPK items to develop a survey that can identify all seven valid TPACK domains. Another limitation is that we could not perform a confirmatory factor analysis to confirm the six-factor structure due to the small sample size. Future research should further refine the survey obtaining a larger sample size for running factor analyses. Self-reported survey data from Norwegian PSTs may be subject to overestimation or underestimation, resulting in inaccurate TPACK measures. Supplementing the survey data with classroom observations and /or interviews would enhance the findings and interpretation of the results.

Implications

This research exhibits how an existing survey can be adapted and contextualized to provide a reliable six-factor TPACK survey for assessing Norwegian PSTs' self-perceived knowledge to integrate technology in teaching mathematics. Though we could not develop a survey with all seven valid TPACK knowledge domains, our 30-item survey serves some important purposes. Firstly, it can provide teacher educators with an overview of PSTs' perception of the knowledge they consider necessary for technology integration. Our findings reveal that while Norwegian PSTs could distinguish and self-report six of the TPACK domains, they encountered difficulties in distinguishing the TPK domain. These findings urge teacher educators to provide PSTs with a comprehensive TPACK model. Such a model should enable PSTs to distinguish the significance of each knowledge domain while concurrently emphasizing the interconnectedness among content, pedagogy and technology. This holistic approach is essential for equipping PSTs with their own perceived TPACK knowledge necessary to effectively integrate technology into their teaching practices. Secondly, it can be a valid tool to understand what knowledge domains PSTs deem necessary for technology integration and build on their assumptions to develop other knowledge domains further to support their professional development. Thirdly, our survey can be used by researchers for carrying out further TPACK research with different methodologies to refine further and develop contextual aspects of the TPACK framework. Notably, this is the first domain-specific survey contextualized for Norwegian settings.

Concluding remarks

We validated a six-factor structure of the seven-factor TPACK model with Norwegian mathematics PSTs. The most prominent challenges that arose during the adaptation and further development of the survey were related to survey item composition and factor validation due to contextual differences and unclear boundaries between different TPACK domains. As we failed to validate TPK factors in the Norwegian context, we emphasize the importance of validating all seven factors to interpret Norwegian PSTs' perceived TPACK precisely. Adopting a quantitative research design, the present study explored the challenges of contextual survey development and developed a TPACK survey tailored to assess Norwegian mathematics PSTs' perceived TPACK competencies. The validated survey items from this study serve as valuable resources for future qualitative inquiries, allowing for in-depth investigations into these challenges, including the concept of self-efficacy, within the Norwegian mathematics education context.

References

Abbitt, J. T. (2011). Measuring technological pedagogical content knowledge in preservice teacher education: a review of current methods and instruments. *Journal of Research on Technology in Education*, 43 (4), 281–300.

Agyei, D. D. & Voogt, J. M. (2011). Exploring the potential of the will, skill, tool model in Ghana: predicting prospective and practicing teachers' use of technology. *Computers & Education*, 56 (1), 91–100. doi: 10.1016/j.compedu.2010.08.017

Angeli, C. & Valanides, N. (2009). Epistemological and methodological issues for the conceptualisation, development, and assessment of ICT–TPCK: advances in technological pedagogical content knowledge (TPCK). *Computers & Education*, 52 (1), 154–168. doi: 10.1016/j.compedu.2008.07.006

Archambault, L. M. & Barnett, J. H. (2010). Revisiting technological pedagogical content knowledge: exploring the TPACK framework. *Computers & Education*, 55 (4), 1656–1662.

Ball, D. L., Thames, M. H. & Phelps, G. (2008). Content knowledge for teaching: what makes it special. *Journal of Teacher Education*, 59 (5), 389–407.

Bartlett, M. S. (1950). Tests of significance in factor analysis. *British Journal of Psychology*, 3, 77–85.

Baser, D., Kopcha, T. J. & Ozden, M. Y. (2016). Developing a technological pedagogical content knowledge (TPACK) assessment for preservice teachers learning to teach English as a foreign language. *Computer Assisted Language Learning*, 29 (4), 749–764.

Bilici, S. C., Yamak, H., Kavak, N. & Guzey, S. S. (2013). Technological pedagogical content knowledge self–efficacy scale (TPACK–SeS) for pre–service science teachers: construction, validation, and reliability. *Eurasian Journal of Educational Research*, 52, 37–60.

Brantley–Dias, L. & Ertmer, P. A. (2013). Goldilocks and TPACK: Is the construct "just right?". *Journal of Research on Technology in Education*, 46 (2), 103–128.

Brown, J. D. (2009). Choosing the right type of rotation in PCA and EFA. *Shiken: JALT Testing & Evaluation SIG Newsletter*, 13 (3), 20–25.

Chai, C. S., Koh, J. H. L. & Tsai, C. C. (2011). Exploring the factor structure of the constructs of technological, pedagogical, content knowledge (TPACK). *The Asia–Pacific Education Researcher*, 20 (3), 607–615.

Chai, C. S., Koh, J. H. L. & Tsai, C. C. (2013). A review of technological pedagogical content knowledge. *Educational Technology & Society*, 16 (2), 31–51.

Chai, C. S., Koh, J. H. L. & Tsai, C.–C. (2016). Review of the quantitative measures of technological pedagogical content knowledge (TPACK). In M. C. Herring, M. J. Koehler & P. Mishra (Eds.), *Handbook of technological pedagogical content knowledge (TPACK) for educators* (pp. 97–116). Routledge.

Chai, C. S., Koh, J. H. L., Tsai, C.–C. & Tan, L. L. W. (2011). Modeling primary school pre–service teachers' technological pedagogical content knowledge (TPACK) for meaningful learning with information and communication technology (ICT). *Computers & Education*, 57 (1), 1184–1193.

Chai, C. S., Ng, E. M., Li, W., Hong, H.–Y. & Koh, J. H. (2013). Validating and modelling technological pedagogical content knowledge framework among Asian preservice teachers. *Australasian Journal of Educational Technology*, 29 (1), 41–53.

Costello, A. B. & Osborne, J. (2005). Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. *Practical Assessment*, *Research*, *and Evaluation*, 10 (1), 1–7.

Creswell, J. W. & Clark, V. L. P. (2017). *Designing and conducting mixed methods research*. Sage.

Cristobal, E., Flavian, C. & Guinaliu, M. (2007). Perceived e-service quality (PeSQ): measurement validation and effects on consumer satisfaction and web site loyalty. *Managing Service Quality: An International Journal*, 17 (3), 317–340.

Etikan, I., Musa, S. A. & Alkassim, R. S. (2016). Comparison of convenience sampling and purposive sampling. *American Journal of Theoretical and Applied Sttatistics*, 5 (1), 1–4.

Fennema, E. & Franke, M. L. (1992). Teachers' knowledge and its impact. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning* (pp. 147–164). Macmillan.

Ferrari, A. (2012). *Digital competence in practice: an analysis of frameworks*. Publications Office. https://data.europa.eu/doi/10.2791/82116

Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. Sage.

Gliem, J. A. & Gliem, R. R. (2003). *Calculating, interpreting, and reporting Cronbach's alpha reliability coefficient for Likert–type scales*. Midwest Research–to–Practice Conference in Adult, Continuing, and Community Education. The Ohio State University.
Graham, C. R. (2011). Theoretical considerations for understanding technological pedagogical content knowledge (TPACK). *Computers & Education*, 57 (3), 1953–1960.
Guđmundsdóttir, G. B. & Hatlevik, O. E. (2018). Newly qualified teachers' professional digital competence: implications for teacher education. *European Journal of Teacher Education*, 41 (2), 214–231. doi: 10.1080/02619768.2017.1416085
Guin, T. D.–L., Baker, R., Mechling, J. & Ruyle, E. (2012). Myths and realities of respondent engagement in online surveys. *International Journal of Market Research*, 54 (5), 613–633.
Hair, J. F. (2014). *Multivariate data analysis* (7th ed.). Pearson.
Instefjord, E. & Munthe, E. (2016). Preparing pre–service teachers to integrate technology: an analysis of the emphasis on digital competence in teacher education curricula. *European Journal of Teacher Education*, 39 (1), 77–93. doi: 10.1080/02619768.2015.1100602
Jakobsen, A. & Munthe, E. (2020). Education of Norwegian mathematics teachers. In H. D. G. Lacerda, D. S. C. Cabanha & M. V. Maltempi (Eds.), *Formação inicial de professores de matemática em diversos países* (pp. 185–199). Editoria Livraria da Física.
Jang, S.-J. & Tsai, M.-F. (2012). Exploring the TPACK of Taiwanese elementary mathematics and science teachers with respect to use of interactive whiteboards. *Computers & Education*, 59 (2), 327–338.
Jang, S.-J. & Tsai, M.-F. (2013). Exploring the TPACK of Taiwanese secondary school science teachers using a new contextualised TPACK model. *Australasian Journal of Educational Technology*, 29 (4). doi: 10.14742/ajet.282
Jin, X., Liu, G. G., Gerstein, H. C., Levine, M. A., Steeves, K. et al. (2018). Item reduction and validation of the Chinese version of diabetes quality–of–life measure (DQOL). *Health and Quality of Life Outcomes*, 16 (1), 1–11.
Kaiser, H. F. (1970). A second generation little jiffy. *Psychometrika*, 35 (4), 401–415. doi: https://doi.org/10.1007/BF02291817
Kelley, T. R., Knowles, J. G., Holland, J. D. & Han, J. (2020). Increasing high school teachers self-efficacy for integrated STEM instruction through a collaborative community of practice. *International Journal of STEM Education*, 7, 1–13.
Kimmons, R. (2015). Examining TPACK's theoretical future. *Journal of Technology and Teacher Education*, 23 (1), 53–77.
Kline, R. B. (2015). *Principles and practice of structural equation modeling.* Guilford.

Koehler, M. & Mishra, P. (2009). What is technological pedagogical content knowledge (TPACK)? *Contemporary Issues in Technology and Teacher Education*, 9 (1), 60–70.
Koehler, M. J., Mishra, P. & Yahya, K. (2007). Tracing the development of teacher knowledge in a design seminar: integrating content, pedagogy and technology. *Computers & Education*, 49 (3), 740–762. doi: 10.1016/j.compedu.2005.11.012
Koehler, M. J., Shin, T. S. & Mishra, P. (2012). How do we measure TPACK? Let me count the ways. In Ronau, R. N., Rakes, C. R. & Niess, M. L. (Eds.), *Educational technology, teacher knowledge, and classroom impact: a research handbook on frameworks and approaches* (pp. 16–31). IGI Global.
Koh, J. H. L., Chai, C. S. & Tsai, C.–C. (2010). Examining the technological pedagogical content knowledge of Singapore preservice teachers with a large-scale survey. *Journal of Computer Assisted Learning*, 26 (6), 563–573.
Krumsvik, R. J. (2011). Digital competence in the Norwegian teacher education and schools. *Högre Utbildning*, 1 (1), 39–51.
Ministry of Education and Research (2019). *Core curriculum – values and principles for primary and secondary education*. Author. https://www.regjeringen.no/contentassets/53d21ea2bc3a4202b86b83cfe82da93e/core-curriculum.pdf
Landry, G. A. (2010). *Creating and validating an instrument to measure middle school mathematics teachers' technological pedagogical content knowledge (TPACK)* [PhD thesis]. University of Tennessee.
Lawshe, C. H. (1975). A quantitative approach to content validity. *Personnel Psychology*, 28 (4), 563–575.
Lee, M.–H. & Tsai, C.–C. (2010). Exploring teachers' perceived self efficacy and technological pedagogical content knowledge with respect to educational use of the World wide web. *Instructional Science*, 38 (1), 1–21.
Lester, P. E., Inman, D. & Bishop, L. K. (2014). *Handbook of tests and measurement in education and the social sciences*. Rowman & Littlefield.
Marín–Suelves, D., López–Gómez, S., Castro–Rodríguez, M. M. & Rodríguez–Rodríguez, J. (2020). Digital competence in schools: a bibliometric study. *IEEE Revista Iberoamericana de Tecnologias del Aprendizaje*, 15 (4), 381–388.
Martinovic, D. & Zhang, Z. (2012). Situating ICT in the teacher education program: overcoming challenges, fulfilling expectations. *Teaching and Teacher Education*, 28 (3), 461–469. doi: 10.1016/j.tate.2011.12.001
Ministry of Education and Research (2019). *Core curriculum – values and principles for primary and secondary education*. Author. https://www.regjeringen.no/contentassets/53d21ea2bc3a4202b86b83cfe82da93e/core-curriculum.pdf
Mishra, P. & Koehler, M. J. (2006). Technological pedagogical content knowledge: a framework for teacher knowledge. *Teachers College Record*, 108 (6), 1017–1054.

Mosvold, R., Fauskanger, J., Jakobsen, A. & Melhus, K. (2009). Translating test items into Norwegian–without getting lost in translation. *Nordic Studies in Mathematics Education*, 14 (4), 101–123.
Netemeyer, R., Bearden, W. & Sharma, S. (2003). *Scaling procedures*. Sage.
Niess, M. L. (2005). Preparing teachers to teach science and mathematics with technology: developing a technology pedagogical content knowledge. *Teaching and Teacher Education*, 21 (5), 509–523.
Nilsson, P. (2022). From PCK to TPACK – supporting student teachers' reflections and use of digital technologies in science teaching. *Research in Science & Technological Education*, 1–25. doi: 10.1080/02635143.2022.2131759
Norris, J. & Conn, C. (2005). Investigating strategies for increasing student response rates to online-delivered course evaluations. *Quarterly Review of Distance Education*, 6 (1), 13–29.
Pamuk, S., Ergun, M., Cakir, R., Yilmaz, H. B. & Ayas, C. (2015). Exploring relationships among TPACK components and development of the TPACK instrument. *Education and Information Technologies*, 20, 241–263.
Petrou, M. & Goulding, M. (2011). Conceptualising teachers' mathematical knowledge in teaching. In T. Rowland & K. Ruthven (Eds.), *Mathematical knowledge in teaching* (pp. 9–25). Springer.
Rashid, T. & Asghar, H. M. (2016). Technology use, self-directed learning, student engagement and academic performance: examining the interrelations. *Computers in Human Behavior*, 63, 604–612. doi: 10.1016/j.chb.2016.05.084
Ratner, B. (2009). The correlation coefficient: its values range between +1/-1, or do they? *Journal of Targeting, Measurement and Analysis for Marketing*, 17 (2), 139–142.
Rosenberg, J. M. & Koehler, M. J. (2015). Context and technological pedagogical content knowledge (TPACK): a systematic review. *Journal of Research on Technology in Education*, 47 (3), 186–210.
Russell, D. W. (2002). In search of underlying dimensions: the use (and abuse) of factor analysis in Personality and social psychology bulletin. *Personality and Social Psychology Bulletin*, 28 (12), 1629–1646.
Sang, G., Tondeur, J., Chai, C. S. & Dong, Y. (2016). Validation and profile of Chinese pre–service teachers' technological pedagogical content knowledge scale. *Asia–Pacific Journal of Teacher Education*, 44 (1), 49–65.
Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J. & Shin, T. S. (2009). Technological pedagogical content knowledge (TPACK) – the development and validation of an assessment instrument for preservice teachers. *Journal of research on Technology in Education*, 42 (2), 123–149.
Schober, P., Boer, C. & Schwarte, L. A. (2018). Correlation coefficients: appropriate use and interpretation. *Anesthesia & Analgesia*, 126(5), 1763–1768.

Shulman, L. S. (1986). Those who understand: knowledge growth in teaching. *Educational Researcher*, 15 (2), 4–14.
Shulman, L. S. (1987). Knowledge and teaching: foundations of the new reform. *Harvard Educational Review*, 57 (1), 1–23.
Streiner, D. L. (2003). Starting at the beginning: an introduction to coefficient alpha and internal consistency. *Journal of Personality Assessment*, 80 (1), 99–103.
Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education*, 48 (6), 1273–1296.
Tavakol, M. & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, 2 (53), 53–55.
Tirosh, D. & Even, R. (2007). Teachers' knowledge of students' mathematical learning: an examination of commonly held assumptions. *Mathematics knowledge in teaching seminar series: conceptualising and theorizing mathematical knowledge for teaching.* University of Cambridge.
The Norwegian Directorate for Education and Training (2020). *Læreplan i Matematikk 1.–10. Trinn. (MAT01–05)*. https://www.udir.no/lk20/mat01-05?lang=nob
UiS (2021a). *Matematikk 1 emne 2 MGL1111.* University of Stavanger. https://www.uis.no/nb/course/MGL1111_1
UiS (2021b). *Matematikk 1 emne 2 MGL2114.* University of Stavanger. https://www.uis.no/nb/course/MGL2114_1
Valtonen, T., Sointu, E., Kukkonen, J., Kontkanen, S., Lambert, M. C. & Mäkitalo–Siegl, K. (2017). TPACK updated to measure pre–service teachers' twenty–first century skills. *Australasian Journal of Educational Technology*, 33 (3), 15–31. doi: 10.14742/ajet.3518
Verloop, N., Van Driel, J. & Meijer, P. (2001). Teacher knowledge and the knowledge base of teaching. *International Journal of Educational Research*, 35 (5), 441–461.
Voogt, J. & McKenney, S. (2017). TPACK in teacher education: Are we preparing teachers to use technology for early literacy? *Technology, Pedagogy and Education*, 26 (1), 69–83. doi: 10.1080/1475939x.2016.1174730
Wang, W., Schmidt–Crawford, D. & Jin, Y. (2018). Preservice teachers' TPACK development: a review of literature. *Journal of Digital Learning in Teacher Education*, 34 (4), 234–258.
Williams, B., Onsman, A. & Brown, T. (2010). Exploratory factor analysis: a five-step guide for novices. *Australasian Journal of Paramedicine*, 8 (3), 990399.
Yeh, Y. F., Chan, K. K. H. & Hsu, Y. S. (2021). Toward a framework that connects individual TPACK and collective TPACK: a systematic review of TPACK studies investigating teacher collaborative discourse in the learning by design process. *Computers & Education*, 171, 104238. doi: 10.1016/j.compedu.2021.104238

Yurdakul, I. K., Odabasi, H. F., Kilicer, K., Coklar, A. N., Birinci, G. & Kurt, A. A. (2012). The development, validity and reliability of TPACK-deep: a technological pedagogical content knowledge scale. *Computers & Education*, 58 (3), 964–977.
Zelkowski, J., Gleason, J., Cox, D. C. & Bismarck, S. (2013). Developing and validating a reliable TPACK instrument for secondary mathematics preservice teachers. *Journal of Research on Technology in Education*, 46 (2), 173–206. doi: 10.1080/15391523.2013.10782618

Appendix 1

Factor Loadings for EFA employing Principal axis factoring on whole sample with Promax rotation. Factor loadings < 0.40 are removed.

	Factor								
	1	2	3	4	5	6	7	8	9
TK1				.765					
TK2				.713					
TK3				.680					
TK4				.592					
TK5				.735					
TK6				.439					.642
CK1									
CK2									
CK4		.678							
CK5							.718		
CK6		.859							
CK7		.717							
CK8		.742							
CK9		.643							
PK1			.713						
PK2			.868						
PK3			.782						
PK4			.588						
PK5			.488						
PCK1			.490						
PCK2								.473	
PCK3							.702		
PCK4								.679	
PCK6								.534	
TCK1						.624			
TCK2					.639				
TCK3					.467	.451			
TCK4					.893				
TCK5					.640				
TPK1	.437								
TPK2	.467								
TPK3						.466			
TPK5	.671								
TPK7				.600					
TPK8									
TPK9	.466								
TPACK2	.575								
TPACK3	.821								
TPACK4	.732								
TPACK5	.745								
TPACK6	.727								
TPACK7	.782								
TPACK8	.456						.424		
TPACK9	.642								
TPACK10	.537								
TPACK11	.538								

Notes. Extraction Method: Principal axis factoring.
Rotation Method: Promax with Kaiser normalization.
Rotation converged in 9 iterations.

Appendix 2

Expert ratings, communalities and factor loadings for deleted items.

Sl. No	Item	Expert rating	Communality	Factor loading
1	TK6	5.8		Cross-loaded with 4 & 9
2	TK7	7.6	Low	
3	CK1	8.4		Low factor loading
4	CK2	7.6		Low factor loading
5	CK3	9.2	Low	
6	CK5	9.8		Misplacement, factor 7 (non-interpretable)
7	PK6	5.2	Low	
8	PK7	9.6		
9	PK8	9.8	Low	
10	PCK1	9.8		Misplacement with PK factor
11	PCK3	9.6		Misplacement, factor 7 (non-interpretable)
12	PCK5	9.6	Low	
13	TCK1	5.8		Misplacement, factor 6 (non-interpretable)
14	TCK3	7.8		Misplacement, factor 6 (non-interpretable)
15	TCK6	7.0	Low	
16	TPK1	9.0		Misplacement with TPACK factor
17	TPK2	9.6		Misplacement with TPACK factor
18	TPK3	7.2		Cross-loaded with 5 (TPK) & 6
19	TPK4	9.6	Low	
20	TPK5	9.2		Misplacement with TPACK factor
21	TPK6	6.0	Low	
22	TPK7	9.4		Misplacement with TPACK factor
23	TPK8	5.6		Low factor loading
24	TPK9	7.8		Misplacement with TPACK factor
25	TPK10	9.0	Low	
26	TPK11	7.6	Low	
27	TPACK1	8.0	Low	
28	TPACK8	9.2		Cross-loaded with 1 & 7

Appendix 3

Item total statistics and Cronbach's Alpha values

	Scale means if item deleted	Scale variance if item deleted	Corrected item-total correlation	Cronbach's alpha (α)	α if item deleted
	Technological knowledge (TK)			.82	
TK1	14.48	7.73	.57		.79
TK2	14.37	7.33	.68		.76
TK3	14.98	6.74	.67		.76
TK4	14.75	7.03	.56		.79
TK5	14.49	7.53	.56		.79
	Content knowledge (CK)			.85	
CK4	15.55	9.03	.63		.83
CK6	15.70	8.12	.73		.80
CK7	15.80	8.51	.66		.82
CK8	15.97	7.73	.69		.81
CK9	15.83		.60		.84
	Pedagogical knowledge (PK)			.84	
PK1	14.95	6.53	.66		.79
PK2	14.81	6.85	.62		.80
PK3	14.48	7.36	.67		.79
PK4	14.79	6.71	.64		.79
PK5	14.73	6.70	.58		.81
	Pedagogical content knowledge (PCK)			.83	
PCK2	6.98	2.74	.64		.81
PCK4	7.16	2.37	.72		.74
PCK6	7.35	2.15	.72		.74
	Technological content knowledge (TCK)			.79	
TCK2	7.22	3.30	.54		.80
TCK4	6.73	2.84	.69		.63
TCK5	6.66	2.97	.65		.69
	Technological pedagogical content knowledge (TPACK)			.90	
TPACK2	26.91	24.08	.68		.88
TPACK3	26.85	24.07	.69		.88
TPACK4	27.39	23.28	.61		.89
TPACK5	26.99	23.65	.72		.89
TPACK6	27.14	23.27	.62		.89
TPACK7	27.21	23.50	.73		.88
TPACK9	27.22	23.64	.68		.88
TPACK10	26.98	23.86	.60		.89
TPACK11	26.89	23.72	.63		.89

Appendix 4

Administered Survey (in Norwegian)

Spørreundersøkelse om lærerstudenters kunnskap om matematikkundervisning og teknologi

Takk for at du tar deg tid til å svare på denne undersøkelsen. Vær vennlig og svar på hvert spørsmål etter beste evne ved å velge det svaralternativet du mener passer best. Hele undersøkelsen tar ca. 20 minutter. Spørreundersøkelsen er anonym.

Demografisk informasjon

Hvilken aldersgruppe tilhører du?

a. Under 19
b. 19–22
c. 23–26
d. 27–30
e. 30+

Hvor langt i grunnskolelærerutdanningen har du kommet?

1. år
2. år
3. år
4. år
5. år

Hvor mange uker med praksis har du gjennomført i matematikk så langt i lærerutdanningen?

o 1 – 6 uker
o 7 – 13 uker
o 14 – 20 uker
o 20 uker eller mer

Kjønn:

o Mann
o Kvinne
o Jeg ønsker ikke å svare

Har du hatt annen utdanning (eller andre kurs) før du begynte med lærerutdanningen?

o Ja
o Nei

Hvis ja, hva slags utdanning (eller kurs) var det? Presiser.

Hva var omfanget av utdanningen og eller kursene (antall studiepoeng)?

Teknologi er et begrep som kan defineres på mange ulike måter. I denne undersøkelsen brukes begrepet teknologi i betydningen digitale verktøy som representerer produkter eller tjenester som brukes i kommunikasjon, overføring, kringkasting, innhenting, organisering, produksjon, lagring, eller forvaltning og beskyttelse av informasjon og digitalt innhold. Typiske eksempler er PC, nettbrett, operativsystemer, interaktive tavler, læringsplattformer (f.eks. Itslearning og Canvas), programvare for programmering, behandling av tekst og bilder, skytjenester, tjenester for sikker identifisering, tjenester for strømming av videoinnhold eller lyd, osv.

Svar på hvert spørsmål ved å velge ett av de fem alternativene.
Helt uenig = 1 Uenig = 2 Verken enig/uenig = 3 Enig = 4 Helt enig = 5

Teknologisk kunnskap (TK)
I denne spørreundersøkelsen betraktes teknologisk kunnskap med henvisning til en bred definisjon av teknologi – som beskrevet ovenfor.

TK1 Jeg vet hvordan jeg skal løse mine egne teknologiske problemer.
TK2 Det er enkelt for meg å lære meg nye digitale verktøy.
TK3 Jeg holder meg oppdatert på nye digitale verktøy.
TK4 Jeg liker å utforske digitale verktøy.
TK5 Jeg har de tekniske ferdighetene jeg trenger for å bruke digitale verktøy.
TK6 Jeg har hatt tilstrekkelige muligheter til å bruke ulike digitale verktøy.
TK7 Når jeg støter på et problem når jeg bruker digitale verktøy, søker jeg hjelp fra andre.

Fagkunnskap (CK)
Fagkunnskap er kunnskap om det aktuelle faget som du underviser i (matematikk i denne undersøkelsen). Lærere må forstå det faget de underviser i og må ha kunnskap om sentrale fakta, begreper, teorier og metoder i faget.

CK1 Jeg har tilstrekkelig matematisk kunnskap for å undervise matematikk i grunnskolen.
CK2 Jeg har ulike strategier for å utvikle min matematisk forståelse.
CK3 Jeg kjenner til ulike eksempler på hvordan matematikk kan anvendes i dagliglivet.
CK4 Jeg har en god forståelse for tall.
CK5 Jeg har en god forståelse for sannsynlighet og statistikk.
CK6 Jeg har en god forståelse for algebra.
CK7 Jeg har en god forståelse for geometri.
CK8 Jeg har en god forståelse for funksjoner.
CK9 Jeg har en god matematisk forståelse utover grunnskolematematikken.

Pedagogisk kunnskap (PK)
Pedagogisk kunnskap er i denne sammenheng dybdekunnskap om lærings- og undervisningsstrategier. Denne type kunnskap handler om elevenes læring, klasseromsledelse, utvikling og gjennomføring av undervisning og vurderinger av elever.

PK1 Jeg vet hvordan jeg skal vurdere elevenes læring.
PK2 Jeg kan tilpasse undervisningen min ut fra det elevene til enhver tid forstår eller ikke forstår.
PK3 Jeg kan tilpasse undervisningen min i forhold til hvilke elever jeg underviser.
PK4 Jeg kan vurdere elevenes læring på flere måter.
PK5 Jeg kan bruke et bredt spekter av undervisningsmetoder i undervisningen.
PK6 Jeg er kjent med teoretiske perspektiver på elevers forståelse og misoppfatninger.
PK7 Jeg behersker klasseledelse.
PK8 Jeg vet når det er hensiktsmessig å bruke en rekke undervisningsmetoder (f.eks. prosjektarbeid, utforsking og problemløsning, samarbeidslæring og tavleundervisning).

Fagdidaktisk kunnskap (PCK)

Fagdidaktisk kunnskap handler blant annet om å vite hvilke undervisningsmetoder som egner seg til et gitt faglig innhold, og hvordan det faglige innholdet best kan organiseres. Det handler også om å kunne velge representasjoner og begreper, og å ha kunnskap om hva som gjør begreper vanskelige eller enkle å lære og innsikt i elevenes forkunnskaper. Fagdidaktisk kunnskap omfatter også kunnskap om undervisningsmetoder som gir gode konseptuelle fremstillinger for å håndtere elevenes vanskeligheter og misoppfatninger og fremme meningsfull forståelse.

PCK1 Jeg kan velge gode undervisningsmetoder for å støtte elevenes matematiske tenkning og deres læring.
PCK2 Jeg kjenner til ulike tilnærminger til undervisning av tall og tallforståelse.
PCK3 Jeg kjenner til ulike tilnærminger til undervisning av sannsynlighet og statistikk.
PCK4 Jeg kjenner til ulike tilnærminger til undervisning av algebra.
PCK5 Jeg kjenner til ulike tilnærminger til undervisning av geometri.
PCK6 Jeg kjenner til ulike tilnærminger til undervisning av funksjoner

Teknologisk fagkunnskap (TCK)

Teknologisk fagkunnskap er kunnskap om sammenhengen mellom digitale verktøy og faginnholdet. Nyere digitale verktøy muliggjør mer varierte representasjoner i matematikk og gir større fleksibilitet i å navigere på tvers av disse representasjonene. Lærerne må kunne faget de underviser i, men de må også forstå hvordan innholdet kan tilpasses og presenteres (ved) bruk av digitale verktøy.

TCK1 Jeg kjenner til digitale verktøy som jeg kan bruke for å arbeide med og utvikle forståelse for tall.
TCK2 Jeg kjenner til digitale verktøy som jeg kan bruke for å arbeide med og utvikle forståelse for sannsynlighet og statistikk.
TCK3 Jeg kjenner til digitale verktøy som jeg kan bruke for å arbeide med og utvikle forståelse for algebra.
TCK4 Jeg kjenner til digitale verktøy som jeg kan bruke for å arbeide med og utvikle forståelse for geometri.
TCK5 Jeg kjenner til digitale verktøy som jeg kan bruke for å arbeide med og utvikle forståelse for funksjoner.
TCK6 Jeg vet at bruk av digitale verktøy kan forbedre elevenes forståelse av matematiske begreper.

Teknologisk pedagogisk kunnskap (TPK)

Teknologisk pedagogisk kunnskap er kunnskap om ulike digitale verktøy og hvilke muligheter disse har for bruk i undervisning og for elevers læring, samt hvordan undervisning kan endres ved bruk av disse verktøyene.

TPK1 Jeg kan velge digitale verktøy som styrker undervisningen i et tema.
TPK2 Jeg kan velge digitale verktøy som styrker elevenes læring for et tema.
TPK3 Lærerutdanningen min har fått meg til å tenke nøyere over hvordan digitale verktøy kan påvirke metodene jeg bruker i min undervisning.
TPK4 Jeg reflekterer kritisk på hvordan jeg kan bruke digitale verktøy i min undervisning.
TPK5 Jeg kan tilpasse bruken av digitale verktøy jeg lærer om til bruk i ulike undervisningsaktiviteter.
TPK6 Ulike undervisningsmetoder krever ulike digitale verktøy.
TPK7 Jeg har de teknologiske ferdighetene jeg trenger for å bruke digitale verktøy på en god måte i undervisning.

TPK8 Jeg har de ferdighetene i klasseledelse som jeg trenger for å bruke digitale verktøy på en god måte i undervisning.
TPK9 Jeg kjenner til hvordan jeg kan bruke digitale verktøy i ulike undervisningsmetoder.
TPK10 Undervisningsmetodene mine endres når jeg bruker digitale verktøy.
TPK11 Å ha kunnskap om hvordan jeg bruker et bestemt digitalt verktøy betyr at jeg også kan bruke det i undervisning.

Teknologisk pedagogisk fagkunnskap (TPACK)
Teknologisk pedagogisk fagkunnskap er grunnlaget for å kunne gi god undervisning i faget (matematikk) ved bruk av digitale verktøy. Slik kunnskap omfatter god forståelse av digitale verktøy sine styrker og svakheter ved bruk i undervisning og hvilke undervisningsmetoder som egner seg for å bruke verktøyene på en konstruktiv måte. Det omfatter også kunnskap om hva som gjør faglige begreper vanskelige eller enkle å lære, og hvordan digitale verktøy kan bidra til elevers læring. Kunnskap om elevenes forkunnskaper og hvordan digitale verktøy kan brukes til å bygge disse forkunnskapene til både å utvikle ny kunnskap og styrke gammel kunnskap er også inkludert.

TPACK1 Jeg kan anvende strategier som kombinerer matematikk, bruk av digitale verktøy og undervisningsmetoder som jeg lærte om i min lærerutdanning.
TPACK2 Jeg kan velge digitale verktøy som fremhever det matematiske innholdet i en undervisningstime.
TPACK3 Jeg kan velge digitale verktøy til undervisning som styrker det jeg underviser, hvordan jeg underviser, og hva elevene lærer.
TPACK4 Jeg kan bistå andre ved at jeg tar ansvar for å koordinere hvordan digitale verktøy brukes i undervisning i ulike tema på min skole.
TPACK5 Jeg kan undervise temaer som på en god måte kombinerer matematikk, digitale verktøy og undervisningsmetoder.
TPACK6 Det er enkelt og greit for meg å integrere digitale verktøy i min matematikkundervisning.
TPACK7 Jeg kan undervise temaer som på en god måte kombinerer tallforståelse, digitale verktøy og undervisningsmetoder.
TPACK8 Jeg kan undervise temaer som på en god måte kombinerer sannsynlighet og statistikk, digitale verktøy og undervisningsmetoder.
TPACK9 Jeg kan undervise temaer som på en god måte kombinerer algebra, digitale verktøy og undervisningsmetoder.
TPACK10 Jeg kan undervise temaer som på en god måte kombinerer geometri, digitale verktøy og undervisningsmetoder.
TPACK11 Jeg kan undervise temaer som på en god måte kombinerer funksjoner, digitale verktøy og undervisningsmetoder.

Appendix 5

Finalized Survey Items (in Norwegian)

TK1	Jeg vet hvordan jeg skal løse mine egne teknologiske problemer.
TK2	Det er enkelt for meg å lære meg nye digitale verktøy.
TK3	Jeg holder meg oppdatert på nye digitale verktøy.
TK4	Jeg liker å utforske digitale verktøy.
TK5	Jeg har de tekniske ferdighetene jeg trenger for å bruke digitale verktøy.
CK4	Jeg har en god forståelse for tall.
CK6	Jeg har en god forståelse for algebra.
CK7	Jeg har en god forståelse for geometri.
CK8	Jeg har en god forståelse for funksjoner.
CK9	Jeg har en god matematisk forståelse utover grunnskolematematikken.
PK1	Jeg vet hvordan jeg skal vurdere elevenes læring.
PK2	Jeg kan tilpasse undervisningen min ut fra det elevene til enhver tid forstår eller ikke forstår.
PK3	Jeg kan tilpasse undervisningen min i forhold til hvilke elever jeg underviser.
PK4	Jeg kan vurdere elevenes læring på flere måter.
PK5	Jeg kan bruke et bredt spekter av undervisningsmetoder i undervisningen.
PCK2	Jeg kjenner til ulike tilnærminger til undervisning av tall og tallforståelse.
PCK4	Jeg kjenner til ulike tilnærminger til undervisning av algebra.
PCK6	Jeg kjenner til ulike tilnærminger til undervisning av funksjoner
TCK2	Jeg kjenner til digitale verktøy som jeg kan bruke for å arbeide med og utvikle forståelse for sannsynlighet og statistikk.
TCK4	Jeg kjenner til digitale verktøy som jeg kan bruke for å arbeide med og utvikle forståelse for algebra.
TCK5	Jeg kjenner til digitale verktøy som jeg kan bruke for å arbeide med og utvikle forståelse for geometri.
TPACK2	Jeg kan velge digitale verktøy som fremhever det matematiske innholdet i en undervisningstime.
TPACK3	Jeg kan velge digitale verktøy til undervisning som styrker det jeg underviser, hvordan jeg underviser, og hva elevene lærer.
TPACK4	Jeg kan bistå andre ved at jeg tar ansvar for å koordinere hvordan digitale verktøy brukes i undervisning i ulike tema på min skole.
TPACK5	Jeg kan undervise temaer som på en god måte kombinerer matematikk, digitale verktøy og undervisningsmetoder.
TPACK6	Det er enkelt og greit for meg å integrere digitale verktøy i min matematikkundervisning.
TPACK7	Jeg kan undervise temaer som på en god måte kombinerer tallforståelse, digitale verktøy og undervisningsmetoder.
TPACK9	Jeg kan undervise temaer som på en god måte kombinerer algebra, digitale verktøy og undervisningsmetoder.
TPACK10	Jeg kan undervise temaer som på en god måte kombinerer geometri, digitale verktøy og undervisningsmetoder.
TPACK11	Jeg kan undervise temaer som på en god måte kombinerer funksjoner, digitale verktøy og undervisningsmetoder.

Ramesh Gautam

Ramesh Gautam is a PhD research fellow at the University of Stavanger. His research interests are centered around quantitative educational measurements, assessment and comparative studies. Aiming to assess pre-service teachers' technological, pedagogical, and content knowledge (TPACK), he is currently working on the project "TPACK in teacher education: preparing pre-service teachers to use technology in mathematics."

ramesh.gautam@uis.no

Arne Jakobsen

Arne Jakobsen is a professor of mathematics education at the University of Stavanger. He has experience from numerous international collaboration projects in mathematics education, focusing on the use of lesson study in the professional development of teachers and teacher educators. His research interests include mathematics, mathematical knowledge for teaching, lesson study, quantitative studies and international collaboration in mathematics education.

arne.jakobsen@uis.no