AOSIS

Mathematics teachers' levels of technological pedagogical content knowledge and information and communication technology integration barriers

CrossMark
click for updates

Authors:
Gabrielle de Freitas[1] 🄳
Erica D. Spangenberg[1] 🄳

Affiliations:
[1]Department of Science and Technology Education, Faculty of Education, University of Johannesburg, Johannesburg, South Africa

Corresponding author:
Erica Spangenberg,
ericas@uj.ac.za

Many mathematics teachers struggle to effectively integrate information and communication technology (ICT) in their teaching and need continuous professional development programmes to improve their technological pedagogical content knowledge (TPACK). This article aims to identify mathematics teachers' levels of TPACK and barriers to integrating ICT as a means to inform their continuous professional development needs. The TPACK framework of Mishra and Koehler was used as a lens for this the study. Both quantitative and qualitative research methods were utilised. Ninety-three mathematics teachers, who completed a quantitative questionnaire, reported higher levels of content, pedagogical, and pedagogical content knowledge, with comparatively lower levels of technology, technological pedagogical, and technological content knowledge. Ten of these participants also participated in semi-structured interviews and revealed six primary barriers to integrating ICT in the classroom, namely curriculum-related time constraints, technological infrastructure, impact of ICT use on the learning process, ineffective professional development, teachers' pedagogical beliefs and poor leadership. Continuous professional development programmes addressing specific ICT-integration barriers can effect significant changes in teachers' TPACK, which may promote better teaching and learning of mathematics.

Keywords: Mathematics; technological pedagogical content knowledge; teachers; information and communication technology; continuous professional development.

Introduction

Technological advances in South Africa over the past two decades have led to information and communication technology (ICT) becoming a significant role player in the educational landscape (Guerrero, 2010). ICTs are more readily available and form part of the general resources in many mathematics classrooms. The effective use of ICTs for teaching and learning adds value to the mathematics curriculum and is associated with improved learner understanding (Nkula & Krauss, 2014). The incorporation of ICTs in the mathematics classroom may also have important implications for mathematics performance in South Africa, which is viewed as under-performing and below international standards (McCarthy & Oliphant, 2013).

Despite the benefits of ICTs for mathematics teaching, Niess et al. (2009) argue that strategies for the effective integration of ICTs in the teaching of mathematics are lacking. Bester and Lautenbach (2014, p. 2175) refer to the 'fumbling use of technology by practicing teachers who did not grow up with technology'. Thus, increased access to and reliance on technology has precipitated an international call for continuous professional development (CPD) to support mathematics teachers' effective use of ICTs in the classroom (Lundall & Howell, 2000; Stoilescu, 2011). In particular, sub-Saharan African governments underscore the value of professional development for teachers focusing on the use of ICT to improve teaching and learning (Hennessy, Harrison & Wamakote, 2010). Given the extent of the master's thesis on which this article draws (De Freitas, 2018), we only report on mathematics teachers' technological pedagogical content knowledge (TPACK) and barriers to integrating ICT.

Mathematics teachers should prepare their learners to become members of a global, technological society by fostering 21st century learning goals in their classrooms (McCarthy & Oliphant, 2013; Spaull & Kotze, 2015). However, many South African teachers' lack of mathematics TPACK could entrench poor achievement in mathematics. In South Africa, learners are often exposed to traditional delivery of content by teachers and are denied teaching strategies that promote collaboration, communication and the sharing of ideas through ICTs due to insufficient and

inappropriate professional development opportunities for teachers to enhance their TPACK.

Nevertheless, much international research focuses on the development of in-service teachers' TPACK (Doering, Veletsianos, Scharber, & Miller, 2009; Stoilescu, 2011). In the United States, Doering et al. (2009) explored how in-service social studies teachers' metacognitive awareness of their TPACK changed through participation in a professional development programme using online learning environments in the classroom. They found that when teachers are encouraged to think explicitly about TPACK and develop metacognitive awareness of their professional knowledge, this leads to positive changes in their teaching practice. However, the study did not focus on the advancement of in-service mathematics teachers' TPACK.

Stoilescu (2011) explored flexible ways of using the TPACK framework for in-service secondary mathematics teachers in Toronto, Canada. In the study, ICT approaches were used to assess learners' work and to provide them with feedback. The findings show that teachers have difficulty persuading learners to use ICTs meaningfully in the mathematics class. They recommend that in-service teachers should receive opportunities to further their TPACK knowledge and skills. Evidence from these studies on TPACK highlights the need for professional development and illustrates the pivotal role it plays in bringing about change in teaching and learning.

Locally, Cassim (2010) conducted a secondary analysis of the data from SITES 2006, with an emphasis on exploring the pedagogical use of ICTs for teaching and learning among Grade 8 mathematics teachers. The results showed that although South African teachers indicated they were enthusiastic to learn new ways to make teaching and learning interesting, they encountered four barriers that hindered their pedagogical use of ICTs, namely confidence, time, access to resources, and professional development. In addition, Leendertz, Blignaut, Nieuwoudt, Els, and Ellis (2013) found that mastery of TPACK by mathematics teachers contributed to more effective mathematics teaching in South African schools. However, these studies did not relate mathematics teachers' current levels of TPACK and their barriers to integrating ICT to CPD programmes.

Therefore, this article aims to identify mathematics teachers' levels of TPACK and barriers to integrating ICT in order to inform the design of CPD programmes. The authors argue that mathematics teaching in South Africa could improve by providing well-designed CPD programmes that address mathematics teachers' current levels of TPACK and specific ICT-integration barriers. Thus, the research questions are:

- How do the mathematics teachers' knowledge domains of the TPACK framework correlate with each other?
- What barriers do mathematics teachers' face when integrating ICT in their teaching?

This article adds to current research studies on ICT integration in the mathematics classroom. The suggested implications for the design of CPD programmes to meet in-service mathematics teachers' levels of TPACK and to overcome the ICT-integration barriers they face may improve mathematics teaching. Improved teaching may translate to enhanced mathematics competence in learners. Learners leaving school with good mathematical knowledge and skills may add to a better-skilled workforce, which could eventually contribute to the South African knowledge-based economy. Mathematical problem solving, critical thinking and innovation are crucial skills for economic growth and development, as well as for South Africa's global competitiveness.

Subsequently, an outline of the TPACK framework is provided, followed by a discussion on barriers affecting CPD of mathematics teachers. Thereafter, the research design, and methodology are delineated and an interpretation of the findings is provided.

Conceptual framework and literature overview
The TPACK framework

Considering international interest in how to teach effectively, Mishra and Koehler (2006) extended the work of Shulman (1986) and developed the TPACK framework, which underpins this article. The TPACK framework describes how teachers can strategically integrate ICTs in their teaching to create meaningful learning experiences (Landry, 2010). TPACK supports teachers in the design and integration of context-specific ICT-based teaching strategies. A teacher who demonstrates the ability to negotiate the dynamic interaction of mathematics content, pedagogy and technology possesses a unique form of expertise, namely TPACK. A teacher with TPACK expertise is superior to a mathematician (content specialist), an experienced teacher (pedagogical expert) or a computer scientist (authority on technology) (Guerrero, 2010), in the sense that they can integrate all three knowledge domains and employ them in their teaching of mathematics.

The TPACK framework consists of three primary knowledge domains (Koehler, Mishra, Kereluik, Shin, & Graham, 2014). The first domain, technology knowledge (TK), associates teaching and learning with the incorporation of knowledge of traditional analogue and digital technologies. Thus, a teacher with TK understands (1) how ICT integration can improve teaching methods and enhance learners' content knowledge, (2) how ICT tools fit into teaching and learning, but also in learners' daily life, and (3) how to use current ICTs. Secondly, the pedagogical knowledge (PK) domain relates to knowledge of teaching strategies to support learner understanding. Lastly, the content knowledge (CK) domain describes the disciplinary knowledge a teacher conveys to learners.

The TPACK framework has four additional domains describing the dynamic interaction between the three primary

knowledge domains. The first is pedagogical content knowledge (PCK). Shulman (1986) describes PCK as knowledge of teaching strategies, learners' prior knowledge, interests and abilities and aspects of teaching specific content. Secondly, technological pedagogical knowledge (TPK) describes the reciprocal relationship between technology and teaching practices and outlines how technology promotes or constrains specific pedagogical processes. Thirdly, technological content knowledge (TCK) considers representational and functional capacities of ICTs to promote or constrain mathematics content. The last and most comprehensive intersecting domain, TPACK, refers to the relationship between technology, pedagogy and content. TPACK enables teachers to design and integrate relevant, context-specific mathematics activities for learners (Koehler et al., 2013). For example, by using dynamic software programmes, such as Geometer's Sketchpad, teachers allow learners to explore and visualise interactive mathematics graph functions and to make informal conjectures about the characteristics of functions, which promotes inquiry-based learning.

Barriers affecting the continuous professional development of mathematics teachers

Structured CPD to support mathematics teachers' TPACK has been linked with the successful integration of ICTs in schools (Lundall & Howell, 2000) and has a significant impact on learner achievement (Anthony & Walshaw, 2009). The effective use of ICTs in the mathematics classroom enhances learner productivity by saving time on calculations, reinforcing the relationship between curriculum and reality, scaffolding learners' exploration and experimentation, and providing immediate feedback (Leendertz et al., 2013). Leendertz et al. (2013) found that if mathematics teachers master TPACK, their teaching of the subject is more effective. Mathematics teachers thus have a responsibility to engage in ongoing CPD in how to use ICTs to offer learners opportunities to succeed in mathematics (Beswick, 2007). In-service teachers who did not grow up with technology often feel threatened when they lack opportunities to develop professionally in the use of ICTs (Hennessy et al., 2010). Therefore, effective CPD for in-service teachers may contribute towards ameliorating teachers' negative attitudes towards the use of ICTs in teaching mathematics (Crompton, 2011).

Numerous barriers exist that impact on the quality and success of CPD programmes. These barriers need to be considered in conjunction with teachers' levels of TPACK to ensure that what teachers learn during CPD interventions translates to their practice. Firstly, teachers engaging in CPD possess different ICT skills, goals, attitudes about their abilities and notions of themselves as ICT integrators (Morsink et al., 2011). As such, CPD cannot assume a one-size-fits-all approach (Guerrero, 2010).

Secondly, Morsink et al. (2011) cite inconsistent models of CPD as a barrier towards teacher development and training in terms of effective ICT integration. This may be exacerbated by the fact that teachers often claim lack of time and access to ICTs as barriers to their participation in both formal and informal CPD (Bennison & Goos, 2010) and is evident in teachers' failure to develop their identities as fluent users of ICTs, even after engagement in CPD. Often CPD efforts are disconnected from classroom practice and the role of reflection is disregarded. Polly and Hannafin (2011) advocate that reflection plays an important role in CPD, which should create opportunities for teachers to examine their own teaching praxis and should be integral to classroom activity and situated in teachers' work. Thus, sharing of ideas, peer coaching and collaborative problem solving are requisite to teachers' efforts to integrate ICTs into teaching (Galanouli, Murphy, & Gardner, 2004).

Furthermore, developing expertise in ICT integration is a time-consuming, long-term process that requires commitment and ongoing effort from teachers (Morsink et al., 2011). CPD programmes should focus on the appropriate use of ICTs by allowing time for teachers to review, evaluate and explore the affordances of different technologies and mathematical software. Teachers need to develop an understanding of when to use ICT as a part of instruction (Crompton, 2011). Polly and Hannafin (2011) advocate that teachers should select the content and activities they want to focus on during CPD. When teachers perceive ownership, they are more likely to adopt and integrate the CPD pedagogies in their own teaching. Cassim (2010) suggests that teachers should design ICT-based lessons in collaboration with their colleagues by forming a community of practice. Knowledgeable teachers should also host informal ICT-mediated workshops to support less knowledgeable teachers.

Mathematics teachers also experience internal barriers to their development of TPACK. Ling Koh, Chai and Tay (2014) argue that teachers' prevailing knowledge bases serve as epistemic resources for their development of TPACK, meaning mathematics teachers' beliefs about how to teach mathematics align with how they were taught mathematics at school. Many mathematics teachers who did not grow up with technology limit their knowledge of teaching strategies and interpretation of transferring mathematics content using ICT to merely demonstrations, verification, memorisation and practice. However, the incorporation of ICTs as a learning tool benefits active engagement of learners in a conducive atmosphere by creating opportunities for authentic, cooperative and inquiry-based learning (Martin & Herrera, 2007). Teachers could implement their TPACK in their teaching by using ICTs around four areas as proposed by Niess et al. (2009): (1) designing of authentic learning environments and experiences that incorporate appropriate ICTs to augment learning and innovation in mathematics, (2) planning of lessons that include applications of suitable ICTs to enhance learning in mathematics, (3) expanding assessment methods and techniques by means of ICTs and (4) developing professionally by utilising ICTs. Therefore, the authors advocate CPD programmes aimed at improving teachers' TPACK, which are grounded in the context in which ICT integration is applied (Ford & Botha, 2010) by taking cognisance of existing barriers

to ICT integration, rather than isolated, once-off isolated professional development programmes.

Research methodology

Research design

Both quantitative and qualitative research methods were employed (Feilzer, 2009) in this study. The use of quantitative methods enabled the researcher to measure and assess the level of TPACK of senior phase mathematics teachers, while the qualitative methods allowed the researcher to explore teachers' views about ICT-integration barriers affecting their teaching.

This study was contextualised in Gauteng, the economic hub of South Africa. Although it is the smallest province, Gauteng receives yearly the second largest budget after KwaZulu-Natal for education (UNICEF South Africa, 2017). Due to this large financial investment, it was expected that Gauteng should include many schools that have access to resources which include ICT infrastructure. Teachers in Gauteng schools might also receive more training opportunities in the use of ICT than teachers in other provinces. Purposive sampling was used to identify 93 senior phase mathematics teachers from 41 schools to participate in the quantitative survey. They were selected according to the following criteria: firstly, all teachers had to teach mathematics at senior phase level (Grade 7, 8 or 9); secondly, mathematics teachers were from public and private schools; thirdly, schools were located in Gauteng; lastly, participation was voluntarily.

For the sample of 93 participants, 73 (78.4%) participants were female. Three ethnic groups were included, namely 10 black African teachers (10.8%), 81 white teachers (87.1%) and 2 Asian teachers (2.1%). The mean age of the sample was 40.5 years (standard deviation, SD = 12.1) with a range between 23 and 71 years. Participants' years of experience using ICTs to teach mathematics are presented in Table 1.

TABLE 1: Frequencies for number of years using information and communication technologies to teach mathematics.

Number of years	n	%
0 years	4	4.5
1–5 years	49	55.1
6–10 years	28	31.5
11–15 years	5	5.6
16–20 years	3	3.4

Source: De Freitas, G. (2018). *Design principles for a professional development programme to advance senior phase mathematics teachers' technological pedagogical content knowledge.* Unpublished master's thesis, University of Johannesburg, Johannesburg, South Africa (p. 106). Retrieved from http://hdl.handle.net/10210/286139

n, number of teachers who fell into the category reported.

Thereafter, a sub-sample of 10 participants from the original sample was again purposively selected to engage in one-on-one semi-structured interviews. The researcher wanted to compare teachers who were frequent users of ICT in their teaching practice with those who reported having no or limited ICT integration in their teaching practices. Therefore, participants were selected who had presented different points in their responses on the TPACK questionnaire. The researcher was also interested in selecting teacher participants who taught at different types of schools (for example, private versus public, primary versus high, and English versus Afrikaans medium schools). By examining the differing opinions, experiences and skills levels of participants, the researcher sought insight into the varying levels of teachers' TPACK.

Quantitative data collection: Questionnaire

A TPACK questionnaire was used to collect quantitative data, which consisted of two sections. The first section, including 12 questions, surveyed participants' biographical information. The second section included 26 Likert-type scale items with a four-point scale (1 = *strongly disagree*, 2 = *disagree*, 3 = *agree*, 4 = *strongly agree*) to assess participants' levels of TPACK according to the seven primary knowledge domains, namely TK (items 1–6), CK (items 7–8), PK (items 9–14), PCK (items 15–16), TPK items 17–19), TCK (items 19–21) and TPACK (items 22–26) (De Freitas, 2018, pp. 238–239). A fifth response option, namely *I cannot respond*, was not weighted and excluded from the data analysis. Although the original surveys offer a mid-point response, *neither agree nor disagree*, it was substituted with the response, *I cannot respond*. The omission of the middle response forced participants with relatively weak opinions to a specific direction. According to Sturgis, Roberts, and Smith (2014), providing a mid-point response may favour (1) participants who are indecisive, (2) those who have an opinion but try to avoid thinking constructively about a directive response, or (3) those who wish to camouflage their ignorance. They also noted that four-point scales compared to five-point scales yield similar reliability, and substituting a neutral response with the *I cannot respond* response meets the key objective of any survey, namely valid inference. Figure 1 illustrates an example of a test item in the questionnaire.

The questionnaire was adapted for in-service mathematics teachers within a South African context from two standardised TPACK instruments, namely the *Survey of Preservice Teachers' Knowledge of Teaching and Technology* (Schmidt et al., 2009) and a TPACK survey developed by Chai, Koh and Tsai (2011).

Item	Strongly disagree	Disagree	Agree	Strongly agree	I cannot respond
I require my learners to use information and communication technology to construct different representations of mathematical content					

Source: De Freitas, G. (2018). *Design principles for a professional development programme to advance senior phase mathematics teachers' technological pedagogical content knowledge.* Unpublished master's thesis, University of Johannesburg, Johannesburg, South Africa (p. 238). Retrieved from http://hdl.handle.net/10210/286139

FIGURE 1: Example of test item 15.

Schmidt et al. (2009) created a self-report survey instrument for measuring preservice teachers' TPACK across four subjects (mathematics, social studies, science and literacy). The survey included 47 TPACK items based on a five-point Likert-type scale and was designed for repeated use by preservice teachers as they progress through their teacher education programmes.

Chai et al. (2011) further developed Schmidt et al.'s (2009) survey instrument for use with Singaporean preservice teachers, who were trained to teach at least two subjects. The CK items in the questionnaire focused on teachers 'first teaching subject' and 'second teaching subject'. Information about the specific teaching subjects of each teacher was collected in the demographic data. The survey specifically contextualised TPACK items according to a constructivist-orientated use of ICT for self-directed and collaborative learning. The newly developed survey consisted of 34 items.

The quantitative data were collected over a period of six months, from June to November. Participants had an option to complete either an online version of the questionnaire, using Google Forms, or a hardcopy version in their own time. While 342 schools were invited to participate, only 41 schools agreed. The researchers sent emails to the senior phase mathematics teachers at these schools. The researchers personally collected 46 completed hardcopy questionnaires from participants, while 47 online versions were automatically sent to the researchers via Google Forms.

Qualitative data collection: Semi-structured interviews

Semi-structured interviews were conducted during March and April the following year aiming to corroborate the quantitative findings pertaining to participants' levels of TPACK and to determine participants' views on barriers regarding the integration of ICTs in their teaching practice. Reflecting on the literature review, initial interview questions were developed. After the analysis of the quantitative data, the interview questions were refined and were as follows:

- How would you describe your level of expertise as a mathematics teacher in terms of your content knowledge?
- What teaching strategies do you use in your mathematics lessons? How do you apply them?
- How do you use ICT in your mathematics classroom?
- What do you perceive as barriers for integrating ICTs into the mathematics classroom? What strategies can you use to overcome these barriers?

All interviews took place at locations convenient to the participants, during school holidays, or after school hours. Interviews were approximately 45 minutes long and were audio-recorded with the consent of the participants and later transcribed.

Data analyses procedures

The raw quantitative data collected from the questionnaire were captured on a Microsoft Excel spreadsheet. Thereafter,

data were cleaned by omitting incomplete, incorrect or inaccurate data from the data set. The quantitative data were analysed using the software package Statistical Package for the Social Sciences (SPSS, version 23). Descriptive statistics were employed for the scale variables for the seven TPACK domains. The researchers also conducted correlational analyses, namely Pearson correlation coefficient (r), to determine the relationship between the seven TPACK domains.

The qualitative data were analysed by first transcribing the audio-recordings of the interviews and conducting pre-coding. The researchers read through the transcripts and underlined significant text to gain an overall impression of the text data. Thereafter, relevant responses were separated from irrelevant responses. Saldaña's (2013) method of inductive coding was applied. Codes sharing the same characteristics were grouped together under the same categories and classified according to the theme. The findings from the qualitative analysis were re-examined in relation to the literature review.

Quality measures

Validity
An overview of literature focusing on the TPACK framework and CPD of mathematics teachers contributed to the theoretical validity of the study. The questionnaire was based on two standardised TPACK surveys, which had been previously validated by the developers. However, due to changes in the number of items used and the wording of some items, an exploratory factor analysis (EFA) was conducted to assess the internal structure of the questionnaire, thus validating the extent to which the test items sufficiently match and exemplify the construct (Watson, 2017). The Kaiser-Guttman rule was used to identify a number of factors (Schmidt et al., 2009). To address face validity, the supervisors of this study reviewed the questionnaire to ensure that the constructs were clearly conceptualised. The questionnaire was amended with regard to language and wording of items to make it more suitable for a South African context. Thereafter, the questionnaire was piloted with four mathematics teachers with regard to clarity, readability and terminology before being administered to the participants in the sample. The piloting process contributed to the coherence and consistency of the questions.

Reliability
The internal consistency of the TPACK domains was determined with the Cronbach's alpha (a) coefficient. The questionnaire used in this study was adapted from the questionnaires developed by Schmidt et al. (2009) and Chai et al. (2011), which both demonstrated acceptable reliability measures. The Cronbach's a coefficient for each domain in the present study was calculated as indicated in Table 2. The total Cronbach's a coefficient for the instrument was 0.93, thus above 0.7, and considered as reliable (Gliem & Gliem, 2003).

Trustworthiness

The rigour and trustworthiness of qualitative research are evaluated through the lenses of credibility, dependability, transferability and confirmability (Baumgartner, 2016). Two data sources, namely questionnaires and interviews, were used to confirm the emerging findings. These findings were compared with trends identified in the literature review. Furthermore, to improve the credibility related to the interviews, the researchers read the transcriptions several times before coding the material. This allowed the researchers to understand and gain insight from the qualitative data to confirm that their interpretations were correct, and that they accounted for the context and spirit of meaning the participants had intended.

The researchers documented the procedures and steps during the study so that others could replicate the processes and confirm the findings, thus contributing to the transferability of the study (Creswell, 2014). Furthermore, by comparing the findings of the interviews against the quantitative results from the questionnaire, the researchers could confirm that trends in the findings had been accurately identified. Lastly, by comprehensively narrating qualitative findings from the interviews, and by using thick descriptions, the researchers further enhanced the trustworthiness of their findings.

Ethical consideration

The ethical committee of the Faculty of Education of the university granted ethical clearance for this study, as well as the Gauteng Department of Education. The reference number for ethical clearance is 2015-080. The researchers complied with all prescribed ethical measures. Data confidentiality by using anonymous reporting in this study also contributed to the trustworthiness of the findings.

Analysis of results

Quantitative data analysis

Exploratory factor analysis is suitable for analysing the underlying concepts of a theoretical construct (Landry, 2010) and was employed to examine the interrelationships (Pallant, 2011) between the seven TPACK knowledge domains. EFA was specifically used to determine whether participant responses revealed each of the seven knowledge domains of the TPACK framework to contain a single factor. Establishing the knowledge domains of the TPACK that teachers foregrounded in their responses to the questionnaire assisted in achieving the objective of the study, namely to identify their levels of TPACK.

Following the process described by Schmidt et al. (2009), the Kaiser-Guttman rule was used to identify a number of factors and their composition. The Kaiser-Guttman rule posits that factors with eigenvalues greater than 1 should be accepted. Because of high loadings among clustered items, and using the Kaiser-Guttman rule, a five-factor solution was produced during the factor analysis. Table 3 shows a summary of the EFA results.

This five-factor solution differs from the two questionnaires on which the current TPACK survey was based. In the original TPACK survey by Schmidt et al. (2009), 10 factors were identified. In the survey developed by Chai et al. (2011), eight factors were identified. Chai et al. (2011) comment that although the TPACK construct is conceptualised as having seven constructs, many researchers have successfully validated only the constructs of TK and CK and find it difficult to differentiate PCK, TPK, TCK, and TPACK through factor analysis. Similarly, Voogt, Fisser, Pareja Roblin, Tondeur, and Van Braak (2012) report that it is difficult to reproduce the seven knowledge domains of the TPACK framework using EFA.

The number of items per knowledge domain in the TPACK questionnaire for this study were unequal. Furthermore, the low participant-to-item ratio may have influenced the inconsistencies in the factor analysis.

Furthermore, the mean and standard deviation pertaining to each of the seven knowledge domains were calculated and are presented in Table 4.

TABLE 2: Cronbach's alpha coefficients for the seven knowledge domains of the TPACK questionnaire.

Subscale	Number of items	Current study α
Technology knowledge (TK)	6	0.87
Content knowledge (CK)	2	0.62
Pedagogical knowledge (PK)	6	0.83
Pedagogical content knowledge (PCK)	2	0.73
Technological pedagogical knowledge (TPK)	3	0.98
Technological content knowledge (TCK)	2	0.87
Technological pedagogical content knowledge (TPACK)	5	0.90
Overall Cronbach's alpha	26	0.93

Source: De Freitas, G. (2018). *Design principles for a professional development programme to advance senior phase mathematics teachers' technological pedagogical content knowledge.* Unpublished master's thesis, University of Johannesburg, Johannesburg, South Africa (p. 111). Retrieved from http://hdl.handle.net/10210/286139

TABLE 3: Exploratory factor analysis results.

Factor	Initial eigenvalues			Extraction sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
Technological based pedagogical content knowledge (TPK and TCK)	9.4	36.2	36.7	5.7	22.1	22.1
Mathematics technological based pedagogical content knowledge (TPACK)	4.3	16.7	52.9	3.6	13.7	35.8
Mathematics pedagogical content knowledge (PCK and CK)	1.7	6.5	59.3	3.7	14.4	50.3
Pedagogical knowledge for teaching mathematics (PK)	1.4	5.4	64.8	1.6	6.3	56.6
General ICT knowledge (TK)	1.7	4.5	69.2	0.9	3.3	59.9

Source: De Freitas, G. (2018). *Design principles for a professional development programme to advance senior phase mathematics teachers' technological pedagogical content knowledge.* Unpublished master's thesis, University of Johannesburg, Johannesburg, South Africa (p. 109). Retrieved from http://hdl.handle.net/10210/286139

TK, technology knowledge; CK, content knowledge; PK, pedagogical knowledge; PCK, pedagogical content knowledge; TPK, technological pedagogical knowledge; TCK, technological content knowledge; TPACK, technological pedagogical content knowledge.

Statistical analyses were undertaken to measure mathematics teachers' levels of TPACK according to the seven knowledge domains included in the TPACK framework. Specifically, correlational analyses utilising Pearson correlation coefficient (r) were employed to investigate the strength and direction of the relationships between the TPACK domains as indicated in Table 5. A significance level of 0.05 was assumed throughout.

Qualitative data analysis

Structural coding, which categorises content-based or conceptual phrases to segments of data (Saldaña, 2013), was employed during the first-cycle coding process to provide an overview of the data and the broad topic *Barriers to integrating ICT* was identified. Coded segments were then summarised together for further analysis. In the second cycle, pattern coding was used to organise coded data identified during first-cycle coding by developing a category label that attributed meaning to the organisation of the codes (Saldaña, 2013). In-depth analysis of the barriers to integrating ICTs led to categories related to curriculum-related factors, technological infrastructure, impact on learning process, professional development, teachers' pedagogical beliefs, and leadership. The themes, categories and codes that transpired from the transcripts of the one-on-one interviews are presented in Table 6.

Discussion of findings

The three primary knowledge domains: Technology, content, pedagogy

Technology knowledge (TK)

Participants' TK is positively correlated with their TPK ($r(93) = 0.53$, $p < 0.01$). This relationship is reflected in the findings of Schmidt et al. (2009), who reported a positive correlation ($r(124) = 0.46$, $p < 0.01$) between American preservice teachers' TK and TPK. Sahin, Celik, Akturk and Aydin (2013) also found a positive correlation between the TK and TPK knowledge domains for preservice teachers in Turkey ($r(163) = 0.40$, $p < 0.01$). These results suggest that advancing teachers' knowledge of various ICTs and improving teachers' technical proficiency in using ICTs (TK) may simultaneously lead to better understanding of how ICTs can be used to change the way teaching and learning occurs (TPK). These knowledge structures might therefore not be independent from one another but could be addressed in an integrated manner.

Participants' TK also correlated positively with their TCK ($r(93) = 0.74$, $p < 0.01$). This finding corroborates the findings of Schmidt et al. (2009) and Sahin et al. (2013), who revealed a positive correlation between preservice teachers' TK and TCK. The strength of the relationship was weaker in those two studies than in the present one ($r(124) = 0.54$, $p < 0.01$ and $r(163) = 0.53$, $p < 0.01$). Participants' TK also correlates positively with their TPACK ($r(93) = 0.71$, $p < 0.01$). This finding is similar to that of Schmidt et al. (2009) and Sahin et al. (2013), who also reported positive correlations between TK and TPACK

TABLE 4: Mean and standard deviation for each of the seven knowledge domains included in the TPACK framework.

Knowledge domain	Items	Mean	Standard deviation
Technology knowledge (TK)	1–6	3.04	0.84
Content knowledge (CK)	7–8	3.63	0.48
Pedagogical knowledge (PK)	9–14	3.25	0.61
Pedagogical content knowledge (PCK)	15–16	3.38	0.55
Technological pedagogical knowledge (TPK)	17–19	2.28	0.87
Technological content knowledge (TCK)	19–21	2.92	0.83
Technological pedagogical content knowledge (TPACK)	22–26	2.76	0.90

Source: De Freitas, G. (2018). *Design principles for a professional development programme to advance senior phase mathematics teachers' technological pedagogical content knowledge*. Unpublished master's thesis, University of Johannesburg, Johannesburg, South Africa (p. 108). Retrieved from http://hdl.handle.net/10210/286139

TABLE 6: Themes, categories and codes for qualitative data analysis. Theme: Barriers to integrating ICT.

Category (Curriculum-related factors)	Codes (Time constraints)
Technological infrastructure	Incompatible devices
	Slow technology
	ICT availability
	Unstable internet connection
	Technological devices have limited battery life
	Software glitches
Impact on learning process	Assessment process does not align with teaching process
	Need for teachers to micromanage learners when using technology
	Technology is a distraction to learners
Professional development	Insufficient or inadequate staff training
	Lack of TK
Teachers' pedagogical beliefs	Fixed mindset
	Understanding of learners' learning styles
Leadership	Insufficient buy-in from all parties

Source: De Freitas, G. (2018). *Design principles for a professional development programme to advance senior phase mathematics teachers' technological pedagogical content knowledge*. Unpublished master's thesis, University of Johannesburg, Johannesburg, South Africa (p. 122). Retrieved from http://hdl.handle.net/10210/286139
TK, technology knowledge; ICT, information and communication technology.

TABLE 5: Correlations table of the seven technological pedagogical content knowledge domains.

Technological pedagogical content knowledge domains	TK	CK	PK	PCK	TPK	TCK	TPACK
Technology knowledge (TK)	1	-	-	-	-	-	-
Content knowledge (CK)	0.02	1	-	-	-	-	-
Pedagogical knowledge (PK)	0.20	0.41**	1	-	-	-	-
Pedagogical content knowledge (PCK)	0.10	0.22*	0.64**	1	-	-	-
Technological pedagogical knowledge (TPK)	0.53**	0.01	0.37**	0.30**	1	-	-
Technological content knowledge (TCK)	0.74**	- 0.05	0.11	0.11	0.64**	1	-
Technological pedagogical content knowledge (TPACK)	0.71**	0.04	0.23*	0.28*	0.70**	0.81**	1

Source: De Freitas, G. (2018). *Design principles for a professional development programme to advance senior phase mathematics teachers' technological pedagogical content knowledge*. Unpublished master's thesis, University of Johannesburg, Johannesburg, South Africa (p. 114). Retrieved from http://hdl.handle.net/10210/286139
Note: *, $p < 0.05$; **, $p < 0.01$.

for preservice teachers in America ($r(124) = 0.42$, $p < 0.01$) and Turkey ($r(163) = 0.41$, $p < 0.01$).

The correlations between the domains indicate that teachers' TK is associated with their TCK and TPACK, and to a lesser extent with their TPK. These results confirm the findings of Finger, Jamieson-Proctor and Albion (2010), who reported that poor TK is linked with limited TPK, TCK and TPACK. Improved TK enables teachers to understand ICT, apply it effectively, identify relevant ICTs for teaching, and adapt to changes and advances in ICT. The statistical correlations between TK and TPK, TCK and TPACK may indicate that a possible avenue to improve teachers' TPACK is to focus first on advancing their TK.

Content knowledge (CK)

Participants' CK correlates moderately and positively with participants' PK ($r(93) = 0.41$, $p < 0.01$). This finding is consistent with those of Sahin et al. (2013), who reported a positive correlation between Turkish preservice teachers' CK and PK ($r(163) = 0.61$, $p < 0.01$). The strength of the relationship in this study is weaker than the correlation reported by Sahin et al. (2013). This result suggests that teachers' improved understanding of mathematics content (CK) is associated with improved understanding of how learners construct mathematical knowledge and develop mathematical skills (PK).

Pedagogical knowledge (PK)

A strong positive correlation is noted between participants' PK and PCK ($r(93) = 0.64$, $p < 0.01$). This result corroborates with previous research findings indicating a positive correlation between preservice teachers' PK and PCK. Sahin et al. (2013) report a strong correlation of $r(163) = 0.8$ ($p < 0.01$) and Schmidt et al. (2009) report a moderate correlation of $r(124) = 0.56$ ($p < 0.01$).

A moderate positive correlation is found between participants' PK and TPK ($r(93) = 0.37$, $p < 0.01$). This finding aligns with that of Schmidt et al. (2009), who reported a positive correlation between preservice teachers' PK and TPK ($r(124) = 0.56$, $p < 0.01$). Improved knowledge about educational goals, learner management, planning and implementing teaching strategies and assessing of learners' understanding (PK) by teachers may equip them to understand how ICTs can be used to achieve PK goals.

The four additional domains: PCK, TPK, TCK and TPACK

The TPACK framework

Based on the results for the CK, PK and PCK domains, participants' responses illustrated in Table 4 indicate that the participants possess adequate knowledge in each of these domains. There is a strong positive correlation between teachers' TPK and TPACK ($r(93) = 0.70$, $p < 0.01$). This relationship corroborates the findings of Schmidt et al. (2009), who reported a similar correlation coefficient between

preservice teachers' TPACK and TPK ($r(124) = 0.71$, $p < 0.01$). Sahin et al. (2013) also reported a strong positive correlation between these domains for Turkish preservice teachers ($r(163) = 0.72$, $p < 0.01$). These findings suggest that CPD to foster teachers' understanding of the relationship between technology and instructional practices, and of how technology promotes or constrains specific pedagogical processes (TPK), may improve the overall TPACK of teachers.

There is also a strong positive correlation between participants' TCK and TPACK ($r(93) = 0.81$, $p < 0.01$). This result is in line with findings by Sahin et al. (2013), who reported a strong positive correlation between preservice teachers' TCK and TPACK ($r(163) = 0.79$, $p < 0.01$). Therefore, to advance teachers' TPACK, CPD activities may need to focus on improving teachers' understanding of representational and functional capacities of ICTs to better explain mathematics content (TCK).

The analysis reveals that participants reported higher levels of CK, PK and PCK, with comparatively lower levels of TK, TPK, TCK and TPACK. Therefore, teachers' CPD needs may relate to an increased focus on knowledge and skills related to how to use ICT effectively in the teaching of mathematics, by developing their knowledge in TPK, TCK and TPACK.

The correlational analyses as discussed above reveal statistically significant, positive relationships between most of the knowledge domains, with only one negative relationship between CK and TCK. These results suggest that TPACK should thus be viewed from an integrative perspective (Doering et al., 2009) as each of the knowledge domains influences the others. An integrative view proposes that TPACK is not a distinct form of knowledge, but is rather integrated in other forms of knowledge during teaching. According to the integrative view, gains in the primary knowledge domains (technology, pedagogy or content) or the intersecting domains translate to a shift in TPACK. Thus, if a teacher lacks TK, then it is impossible for the teacher to approach teaching through a TPACK framework. To advance mathematics teachers' TPACK, intervention strategies should focus on improving each of the underlying knowledge domains.

Discussion of findings of the qualitative data

Qualitative findings from one-on-one interviews with mathematics teachers reveal six primary barriers to integrate ICT effectively in the mathematics classroom. These barriers include curriculum-related time constraints, technological infrastructure, impact on the learning process, professional development, teachers' pedagogical beliefs and leadership. These barriers are significant as they inform mathematics teachers' CPD needs.

Firstly, curriculum-related time constraints serve as a persistent barrier to teachers' effective use of ICTs in the classroom. Participant D (female, 11 April) describes that time is her 'enemy' and prevents her from researching, learning

about and experimenting with new ICTs, while Participant A (female, 30 March) reports 'I have known that there's better ways or easier ways to do things but it's time … you're on the treadmill and you're just repeating things and you haven't had time'. Participant E (female, 12 April) laments that 'there is a huge pressure to get through the syllabus', which prevents her from experimenting with new, creative learning resources, including ICTs. Literature confirms that teachers' lack of time to learn about and experiment with new technologies contributes to them feeling under-prepared to integrate ICTs (Cassim, 2010; Tondeur et al., 2012). Thus, mathematics teachers require CPD that is sensitive to the time demands of their busy schedules and which allows for learning that is sustainable within the context of their teaching.

Secondly, lack of access to reliable, stable technological infrastructure also impacts on mathematics teachers' use of ICTs. This is succinctly summarised by Participant F, who suggests that:

> 'My barrier to technology is that it's unreliable. Like you can prep[are] a lesson and then you haven't charged your iPad and then it's gone or your projector isn't connecting. … There's all those other aspects, especially in our country, that's also going to be a massive barrier.' (Participant F, female, 23 April)

Insufficient access to technology contributes to teachers feeling ill-prepared to incorporate ICTs in their teaching (Tondeur et al., 2012). Borko, Whitcomb and Liston (2009) argue that the affordances and constraints of ICTs in education are inherent in the technologies themselves. Therefore, although teachers may have access to technology, they cannot utilise it effectively in their teaching due to inadequate or unreliable technology, which is not adopted uniformly in the school setting. Literature indicates that teachers' interpretation of contextual demands and opportunities impact on how they draw upon and integrate their existing knowledge sources (Ling Koh et al., 2014). Therefore, if teachers perceive contextual factors to be a hindrance to their effective use of ICTs, this may further entrench their reluctance to adapt their pedagogical approaches to be more inclusive of ICTs.

Thirdly, mathematics teachers may be reluctant to use ICTs in the classroom due to the perceived negative impact of technology on the learning process. Participant E (female, 12 April) expresses frustration that the incorporation of tablets in the mathematics classroom requires additional discipline and micromanaging on the part of the teacher to ensure that the technology is being used in the correct way and for the correct purposes, arguing 'I'm forever checking what they're [*learners are*] doing'. Participant G (male, 23 April) corroborates that the inclusion of ICTs in the classroom requires the teacher to constantly be 'supervising' learners. Furthermore, Participant C (female, 05 April) reports that in some cases, ICTs act as a hindrance to learners' mathematical understanding. She goes on to say: 'I think it's [*ICT is*] also a huge distraction to the learners who are going to be distracted anyway'. Similarly, literature reveals that the incorporation of ICT devices in the classroom can interfere with learners' abilities to pay attention and to understand content (Goundar, 2014). Therefore, CPD should equip teachers with knowledge and skills to harness the potential of ICTs for enhancing learner understanding while limiting the potential distractions that ICTs may introduce in the classroom.

Fourthly, Participant B (female, 03 April) cites 'lack of professional development' as a significant barrier to her use of ICTs. Ford and Botha (2010) argue that insufficient training and lack of effective CPD opportunities for teachers have contributed to the failure of e-education projects in South Africa, and the fact that ICTs are yet to transform teaching and learning in schools (Polly & Hannafin, 2011). Hennessy et al. (2010) report that teachers feel threatened when they lack opportunities to develop professionally in the use of modern ICTs. Furthermore, while some participants cite lack of CPD as a barrier, others describe CPD that is techno-centric in nature and that does not meet their needs. Participant B states that although she has received training in ICTs, the training is ineffective as it focuses solely on how to operate technology, rather than to equip her to integrate and use ICTs for the purposes of teaching. She states that 'there's no input as to how am I going to use this in my class, how do I integrate this in my class' (female, 03 April). Therefore, CPD for mathematics teachers should be frequent and occur on a continuous basis. Furthermore, teachers require exposure to CPD activities that integrate their knowledge of content, pedagogy and technology, rather than training them in the use of technology in isolation from their daily practice. CPD that relates to mathematics teachers' daily practice may be more effective in the long term.

In addition, mathematics teachers' pedagogical beliefs and attitudes towards ICTs may create a persistent internal barrier, which could impact on their effective use of ICTs. Participant D (female, 11 April) concedes that her pedagogical choices are largely influenced and shaped by the teaching strategies she was exposed to during her own schooling. She states, 'I'm still doing the maths lessons like it was 30 years ago. … I used much of my knowledge of how it was explained to me'. Furthermore, Participant A (female, 30 March) adds 'I do know that there's a big part of all of us that is subconsciously teaching the way we were taught'. Holmes (2009) also argues that teachers are unwilling to engage with ICTs, which require them to change their pedagogical practices. Ling Koh et al. (2014) suggest that teachers' prevailing knowledge bases serve as epistemic resources for their development of TPACK. Participant A (female, 30 March) explains that she has a 'natural aversion' and 'resistance' to ICT and that technology does not 'even interest me'. She readily admits that teaching with ICTs feels 'laborious' and goes on to say that 'it shows my own lack of interest in that [*ICT-based*] kind of learning'. Hennessy et al. (2010) refer to technophobia in teachers as a prominent factor that hinders teachers' readiness and confidence to use ICTs in their teaching. Moreover, Naidoo and Govender (2014, p. 2) state that 'the use of technology-based tools

depends on the teacher's attitude towards these tools'. Effective CPD for in-service mathematics teachers should therefore aim to ameliorate teachers' negative attitudes towards the use of ICTs in teaching mathematics (Crompton, 2011). Mathematics teachers require CPD that not only equips them with knowledge and skills of how to use ICTs, but also transforms their beliefs about the value of ICT and role of ICT in teaching. If teachers possess positive attitudes towards ICTs, the long-term efficacy of CPD may be improved as teachers may be more willing to experiment with and integrate ICTs in their teaching.

Lastly, poor school leadership may negatively influence mathematics teachers' effective use of ICTs. In the absence of an effective leader, teachers need to become their own driving force. Participant C (female, 05 April) comments that at her school, there is ineffective or insufficient driving force from heads of department and the school principal regarding ICT integration in the classroom. She suggests 'you've got to have a visionary leader. You've got to have somebody who says change is necessary and who makes it happen and who sustains that change'. Those in leadership positions at schools play a role in policy decisions regarding ICT use, and may be responsible for fundraising and acquiring the ICT infrastructure and resources available to teachers in schools. Leaders in schools also have a responsibility to support and encourage teachers in their ICT use and ensure that policy requirements are implemented. Modisaotsile (2012) argues that those in positions of leadership at schools have a responsibility to ensure that decision-making processes, policy determination, problem-solving processes and general governance of schools are participatory in nature. Encouraging the involvement of different stakeholders, including teachers, parents and learners, may contribute to more effective policies and implementation thereof.

Implications for CPD programmes for mathematics teachers

The quantitative and the qualitative data analyses distill six implications for CPD programmes for mathematics teachers. Firstly, CPD programmes need to be teacher-owned rather than expert-driven. Thus, teachers should have input into what they want to learn about. For example, during one-on-one interviews, Participant E (female, 12 April) describes that she is a trained accounting teacher, who was asked by the principal at her school to teach Grade 8 mathematics. She states 'maths teachers come up with tricks to help them [learners] remember, ways to explain it. I don't have any of that background'. CPD programmes to advance teachers' TPACK should focus specifically on improving their understanding of how to explain particular mathematics concepts to learners and should be driven by teachers' unique, individual needs.

Secondly, in order to meet mathematics teachers' unique needs, CPD programmes should relate to teachers' daily practice. Research demonstrates that stand-alone, isolated CPD opportunities are ineffective in bringing about desired changes (O'Sullivan & Deglau, 2006). In contrast, CPD may be more effective when it pays attention to the teaching-learning context and is situated in the spheres of political, social, curricular and school-level systems. Furthermore, to relate to teachers' practice, CPD programmes should adapt to teachers' time constraints and employ short, frequent and continuous episodes throughout the year, rather than isolated, sporadic and longer interventions which may be ineffective.

Thirdly, teachers require CPD programmes that strengthen the professional community of educators. The efficacy of CPD programmes is improved when they are participatory in nature. Each teacher who participates in CPD programmes should be provided with a voice through sharing, discussing, reflecting on, critiquing and debating personal teaching experiences and related challenges and successes. Peer lesson observation is integral to the formation of professional communities. Wahlstrom and Louis (2008) suggest that increased visibility of classroom practice through teacher peer observation translates to improved instruction, enhanced teacher self-efficacy and better teacher attitudes towards CPD. Teachers may be more courageous and willing to try new things when they can share and learn from the experiences of their colleagues. CPD programmes should provide teachers with the opportunity to observe lessons presented by other teachers, including teachers from other subjects. By examining case studies of their own and others' teaching practice, teachers also extend their knowledge and understanding of what 'good practice' looks like, which may facilitate a broader understanding of how mathematics content can be explained, using different pedagogical approaches and ICT resources.

The fourth implication is that CPD should align with 21st century learning goals such as being able to collaborate and communicate with others, think critically and solve problems, use ICTs in innovative ways, take initiative, and bring together various perspectives when learning (Law, Lee, Chan, & Yuen, 2008). CPD programmes should promote learning and skills for teachers that mirror the learning and skills required by their learners. In this sense, teachers should be treated as active, participatory learners who construct their own meaning and understanding (O'Sullivan & Deglau, 2006).

Drawing on the work of the Koehler et al. (2014), the fifth implication is premised on the notion that in order to advance teachers' TPACK, CPD programmes should build on the foundation of in-service teachers' existing PCK knowledge and move towards TPACK. When building on teachers' PCK and moving towards TPACK, technology should be introduced as a means to scaffold and enrich existing teaching and learning strategies and should build on teachers' years of experience in a natural way. CPD programmes should therefore start with the fundamentals of PCK, in line with Shulman's (1986) model. Early stages of CPD, centred around discussion among teachers, should focus on (1) the most

useful forms of knowledge representation to make mathematics content comprehensible to learners, (2) the value of different analogies, illustrations, examples, explanations and demonstrations that are most powerful in producing learner understanding, and (3) what makes specific topics easy or difficult for learners to understand, by exploring learners' thinking and understanding. In addition, initial phases of CPD discussions should explore and examine the concepts and preconceptions that learners of different backgrounds (different schools) and ages bring with them to the classroom. CPD discussions should focus on establishing curriculum requirements. These initial discussions may enable teachers to make sense of and prioritise multiple factors that impact on learners' understanding and subsequently support their choices of different instructional strategies. This type of approach mirrors that of Harris and Hofer (2009), who advocate an activity-types approach to CPD, where ICT selections are only made after the curriculum learning goals are finalised. Building on teachers' PCK, CPD programmes should then focus on improving teachers' TK by improving their ICT literacy in general. Based on the quantitative results, improved TK may lead to enhanced TPK, TCK and also TPACK. Therefore, combining teachers' areas of strength in CK and PK, with an improved understanding of TK may contribute to extending teachers' TPACK.

Lastly, qualitative findings show that CPD programmes should prepare and support teachers to serve in leadership roles if they are motivated to do so (O'Sullivan & Deglau, 2006). Lack of visible, effective leadership at schools may contribute to teachers' negative attitudes towards ICTs. To overcome this threat, teachers should be empowered to serve as leaders themselves. Therefore, by creating teacher-owned, contextually based professional communities, mathematics teachers will be better equipped to advance their own TPACK and lead others towards developing their TPACK. CPD should not only contribute to the development of teachers' skills but also empower teachers to lead their colleagues to integrate ICTs effectively. Teachers should therefore play a central role in designing and implementing initiatives for their own learning and should be encouraged to view their own classrooms as sites of inquiry.

Conclusion

Despite international trends towards effective use of ICTs in education, South African mathematics teachers often struggle to employ ICTs as a transformative learning tool to support learners' mathematical understanding. The reason may be that CPD programmes training teachers in the use of ICTs do not adequately meet mathematics teachers' needs in terms of their levels of TPACK and barriers to ICT integration. Therefore, this article aimed to identify mathematics teachers' levels of TPACK and barriers to integrating ICT in order to inform the design of CPD programmes.

The findings revealed that in-service mathematics teachers possess adequate CK, PK and PCK knowledge, while they reported comparatively lower levels of TK knowledge and

related TPK, TCK and TPACK. Furthermore, correlational data indicate that TPACK should be viewed from an integrative perspective. Qualitative data revealed that mathematics teachers face six primary barriers in terms of their effective use of ICTs, including curriculum-related factors, insufficient technological infrastructure, perceived negative impact of ICT on the learning process, lack of or insufficient CPD, incorrect or detrimental teacher pedagogical beliefs and ineffective school leadership.

Six implications for the design of CPD programmes are suggested. In order to meet in-service mathematics teachers' levels of TPACK and to overcome the ICT-integration barriers they face, CPD programmes should be teacher-owned, relate to teachers' daily practice, strengthen the professional community of educators, align with 21st century learning goals, build on teachers' PCK while moving towards advancing their TPACK and, lastly, prepare and support teachers to serve in leadership roles.

This article adds to current research studies on the integration of ICT in mathematics teaching. Suggested implications for the design of CPD programmes for mathematics teachers may translate to improved CPD interventions and teaching practices in mathematics, better alignment with international ICT educational trends and eventually improved learner achievement. Research on CPD programmes for mathematics teachers may also promote more passionate, knowledgeable, professional and skilled mathematics teachers facilitating mathematics in schools.

Unfortunately, considering the localised nature of this study by focusing on a single province in South Africa, with an emphasis on a single demographic group in terms of financial resources, the conclusions are restricted to this sample. Also, as only 41 out of 342 schools agreed to participate in the study, the results cannot be generalised to other contexts. Thus, before generalisations of the results can be achieved, the findings should be confirmed through similar studies in other provinces, with teachers from more rural schools. Such studies could determine whether teachers from rural areas have different levels of TPACK knowledge and face different barriers regarding ICT integration from those in the sample of this study.

Further research could examine changes in teachers' TPACK prior to and after engagement in CPD programmes designed according to the suggested implications in this study. These implications may hold the key to effective CPD, which could promote longitudinal changes in teachers' TPACK and teaching practices.

In order to keep abreast of international changes in the educational use of ICTs for teaching mathematics, there is a dire need to train in-service South African mathematics teachers effectively in how to best use ICTs. CPD programmes should aim to increase the number of teachers with sufficient and well-established mathematical content knowledge. In addition, CPD programmes should develop mathematics

teachers' knowledge of how to convey content to learners in an understandable way (pedagogical knowledge). Furthermore, CPD programmes should advance mathematics teachers' understanding and skills related to how and when to use ICTs to support their instruction, thus technology knowledge. Teacher educators, school leadership and mathematics heads of departments should consider mathematics teachers' unique CPD needs in combination with the knowledge domains included in the TPACK framework to prepare and further train in-service mathematics teachers as part of being lifelong learners. Change in pedagogical choices that reflect the successful use of ICTs is needed. This change should be based on a renewed emphasis on reflecting on best practice while promoting the standard of education in South Africa.

Acknowledgements

References

Anthony, G., & Walshaw, M. (2009). Characteristics of effective teaching of mathematics: A view from the West. *Journal of Mathematics Education*, 2(2), 147–164. Retrieved from http://knowledgeportal.pakteachers.org/sites/knowledgeportal.pakteachers.org/files/resources/Characteristics%20of%20Effective%20Teaching%20of%20Mathematics.pdf.

Baumgartner, W.L. (2016). *The development of a strategy for mathematical literacy learners for selected undergraduate studies*. Unpublished master's thesis, University of Johannesburg, Johannesburg, South Africa. Retrieved from http://hdl.handle.net/10210/214488.

Bennison, A., & Goos, M. (2010). Learning to teach mathematics with technology: A survey of professional development needs, experiences and impacts. *Mathematics Education Research Journal*, 22(1), 31–56. https://doi.org/10.1007/BF03217558

Bester, R., & Lautenbach, G. (2014). The digital melting pot: 20th century learners in the 21th century. In *Proceedings of the World Conference on Educational Media and Technology (EdMedia)* (pp. 2175–2180). Tampere, Finland: Association for the Advancement of Computing in Education (AACE). Retrieved from https://www.learntechlib.org/primary/p/147773/.

Beswick, K. (2007). Teachers' beliefs that matter in secondary mathematics classrooms. *Educational Studies in Mathematics*, 65(1), 95–120. https://doi.org/10.1007/s10649-006-9035-3

Borko, H., Whitcomb, J., & Liston, D. (2009). Wicked problems and other thoughts on issues of technology and teacher learning. *Journal of Teacher Education*, 60(1), 3–7. https://doi.org/10.1177/0022487108328488

Cassim, V. (2010). *The pedagogical use of ICTs for teaching and learning within grade eight mathematics in South African schools*. Unpublished master's thesis, North-West University, Potchefstroom, South Africa. Retrieved from https://repository.nwu.ac.za/bitstream/handle/10394/4487/Cassim_V.pdf?sequence=1.

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), 595–603. Retrieved from http://ir.lib.ntust.edu.tw/handle/987654321/32085?locale=en-US.

Crompton, H. (2011). Mathematics in the age of technology: There is a place for technology in the mathematics classroom. *Journal of the Research Center for Educational Technology*, 7(1), 54–66. Retrieved from http://www.doaj.org/doaj?func=abstract&id=754722&recNo=6&toc=1&uiLanguage=en.

De Freitas, G. (2018). *Design principles for a professional development programme to advance senior phase mathematics teachers' technological pedagogical content knowledge*. Unpublished master's thesis, University of Johannesburg, Johannesburg, South Africa. Retrieved from http://hdl.handle.net/10210/286139.

Doering, A., Veletsianos, G., Scharber, C., & Miller, C. (2009). Using the technological, pedagogical, and content knowledge framework to design online learning environments and professional development. *Journal of Educational Computing Research*, 41(3), 319–346. https://doi.org/10.2190/EC.41.3.d

Feilzer, M. (2009). Doing mixed methods research pragmatically: Implications for the rediscovery of pragmatism as a research paradigm. *Journal of Mixed Methods Research*, 4(1), 6–16. https://doi.org/10.1177/1558689809349691

Ford, M., & Botha, A. (2010). A pragmatic framework for integrating ICT into education in South Africa. In P. Cunningham & M. Cunningham (Eds.), *Proceedings of the IST-Africa 2010 Conference* (pp. 1–10). Durban: International Information Management Corporation. Retrieved from http://www.ist-africa.org/Conference2010/.

Galanouli, D., Murphy, C., & Gardner, J. (2004). Teachers' perceptions of the effectiveness of ICT-competence training. *Computers and Education*, 43(1), 63–79. https://doi.org/10.1016/j.compedu.2003.12.005

Gliem, J.A., & Gliem, R.R. (2003). Calculating, interpreting, and reporting Cronbach's alpha reliability coefficient for Likert-type scales. In *Proceedings of the Midwest Research to Practice Conference in Adult, Continuing, and Community Education* (pp. 82–88). Retrieved from https://scholarworks.iupui.edu/bitstream/handle/1805/344/Gliem+&+Gliem.pdf?sequence=1.

Goundar, S. (2014). The distraction of technology in the classroom. *Journal of Education & Human Development*, 3(1), 211–229. Retrieved from http://jehdnet.com/journals/jehd/Vol_3_No_1_March_2014/14.pdf.

Guerrero, S. (2010). Technological pedagogical content knowledge in the mathematics classroom. *Journal of Digital Learning in Teacher Education*, 26(4), 132–139. Retrieved from https://files.eric.ed.gov/fulltext/EJ893871.pdf.

Harris, J., & Hofer, M. (2009). Instructional planning activity types as vehicles for curriculum-based TPACK development. In C.D. Maddux (Ed.), *Research Highlights in Technology and Teacher Education 2009* (pp. 99–108). Chesapeake, VA: Society for Information Technology in Teacher Education. Retrieved from https://pdfs.semanticscholar.org/1996/2d12355e24f962bf385e12574d3b5fe73aef.pdf.

Hennessy, S., Harrison, D., & Wamakote, L. (2010). Teacher factors influencing classroom use of ICT in sub-Saharan Africa. *Itupale Online Journal of African Studies*, 2(1), 39–54. Retrieved from https://pdfs.semanticscholar.org/56ec/8d2248a546352fed0f520972b57034334a45.pdf.

Holmes, K. (2009). Planning to teach with digital tools: Introducing the interactive whiteboard to pre-service secondary mathematics teachers. *Australasian Journal of Educational Technology*, 25(3), 351–365. Retrieved from http://researchdirect.westernsydney.edu.au/islandora/object/uws%3A34475/datastream/PDF/view.

Koehler, M., Mishra, P., Kereluik, K., Shin, T., & Graham, C. (2014). Handbook of research on educational communications and technology. *Educational Technology & Society*, 13(1), 260–263. https://doi.org/10.1007/978-1-4614-3185-5

Landry, G.A. (2010). *Creating and validating an instrument to measure middle school mathematics teachers' technological pedagogical content knowledge (TPACK)*. Unpublished doctoral dissertatiom, University of Tennessee, Knoxville, TN. Retrieved from http://trace.tennessee.edu/cgi/viewcontent.cgi?article=1727&context=utk_graddiss.

Law, N., Lee, M.W., Chan, A., & Yuen, A.H.K. (2008). Factors influencing the impact of ICT-use on students' learning. In *Proceedings of the Third IEA International Research Conference* (pp. 1–17). Taipei: International Association for the Evaluation of Education Achievement. Retrieved from https://pdfs.semanticscholar.org/0c88/6caa570a36dc2c899b40c8a2c6cd2d12783f.pdf.

Leenndertz, V., Blignaut, A.S., Nieuwoudt, H.D., Els, C.J., & Ellis, S. (2013). Technological pedagogical content knowledge in South African mathematics classrooms: A secondary analysis of SITES 2006 data. *Pythagoras*, 34(2), Art. #232, 9 pages. https://doi.org/10.4102/pythagoras.v34i2.232

Ling Koh, J.H., Chai, C.S., & Tay, L.Y. (2014). TPACK-in-action: Unpacking the contextual influences of teachers' construction of technological pedagogical content knowledge (TPACK). *Computers and Education*, 78, 20–29. https://doi.org/10.1016/j.compedu.2014.04.022

Lundall, P., & Howell, C. (2000). *Computers in schools: A national survey of information communication technology in South African schools*. Cape Town: University of Western Cape, Education Policy Unit. Retrieved from http://hdl.handle.net/10625/30529.

Martin, T.S., & Herrera, T. (2007). *Mathematics teaching today: Improving practice, improving student learning* (2nd ed.). Reston, VA: NCTM.

McCarthy, J., & Oliphant, R. (2013). Mathematics outcomes in South Africa. What are the facts? What should be done? In A. Berstein (Ed.), *CDE Insight* (pp. 1–16). Johannesburg: CDE. Retrieved from http://www.cde.org.za/images/pdf/mathematics outcomes in South African schools.pdf.

Mishra, P., & Koehler, M.J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

Modisaotsile, B.M. (2012). The failing standard of basic education in South Africa. *Africa Insitute of South Africa: Policy Brief*. Pretoria: Africa Institute of South Africa. Retrieved from http://www.ai.org.za/wp-content/uploads/downloads/2012/03/No.-72.The-Failing-Standard-of-Basic-Education-in-South-Africa1.pdf.

Morsink, P.M., Hagerman, M.S., Heintz, A., Boyer, D.M., Harris, R., Kereluik, K., & Siegler, T. (2011). Professional development to support TPACK technology integration: The initial learning trajectories of thirteen fifth- and sixth-grade educators. *Journal of Education*, *191*(2), 3–16. Retrieved from http://www.jstor.org/stable/42744201?seq=1#page_scan_tab_contents.

Naidoo, J., & Govender, R. (2014). Exploring the use of a dynamic online software programme in the teaching and learning of trigonometric graphs. *Pythagoras*, *35*(2), Art. #260, 12 pages. https://doi.org/10.4102/pythagoras.v35i2.260

Niess, M.L., Ronau, R.N., Shafer, K.G., Driskell, S.O., Harper, S.R., Johnston, C., … Kersaint, G. (2009). Mathematics teacher TPACK standards and development model. *Contemporary Issues in Technology and Teacher Education*, *9*(1), 4–24. Retrieved from https://www.semanticscholar.org/paper/Mathematics-teacher-TPACK-standards-and-development-Niess-Ronau/ee8b39158adbb90e32aba30d27abf67d2c11a3c8.

Nkula, K., & Krauss, K.E.M. (2014). The integration of ICTs in marginalized schools in South Africa: Considerations for understanding the perceptions of in-service teachers and the role of training. In J. Steyn & D. Van Greunen (Eds.), *Proceedings of the 8th International Development Informatics Association Conference: ICTs for Inclusive Communities in Developing Societies* (pp. 241–261). Port Elizabeth: International Development Informatics Association. Retrieved from http://www.developmentinformatics.org/conferences/2014/papers/20-Nkula-Kirsten.pdf.

O'Sullivan, M., & Deglau, D. (2006). Chapter 7: Principles of professional development. *Journal of Teaching in Physical Education*, *25*(4), 441–449. Retrieved from http://eprints.teachingandlearning.ie/3289/1/OSullivan%20and%20Deglau%202006_principles.pdf.

Pallant, J. (2011). *SPSS survival manual: A step by step guide to data analysis using SPSS* (4th ed.). London: Allen & Unwin.

Polly, D., & Hannafin, M.J. (2011). Examining how learner-centered professional development influences teachers' espoused and enacted practices. *The Journal of Educational Research*, *104*(2), 120–130. https://doi.org/10.1080/00220671003636737

Sahin, I., Celik, I., Akturk, A. O., & Aydin, M. (2013). Analysis of relationships between technological pedagogical content knowledge and educational internet use. *Journal of Digital Learning in Teacher Education*, *29*(4), 110–117. https//doi.org/10.1080/21532974.2013.10784714

Saldaña, J. (2013). *The coding manual for qualitative researchers* (2nd ed.). Thousand Oaks, CA: Sage.

Schmidt, D.A., Baran, E., Thompson, A.D., Koehler, M.J., Shin, T.S., & Mishra, P. (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. Retrieved from https://files.eric.ed.gov/fulltext/EJ868626.pdf.

Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14. https://doi.org/10.3102/0013189X015002004

Spaull, N., & Kotze, J. (2015). Starting behind and staying behind in South Africa: The case of insurmountable learning deficits in mathematics. *International Journal of Educational Development*, *41*, 13–24. https://doi.org/10.1016/j.ijedudev.2015.01.002

Stoilescu, D. (2011). *Technological pedagogical content knowledge: Secondary school mathematics teachers' use of technology*. Unpublished doctoral dissertation, University of Toronto, Toronto, Canada. Retrieved from https://tspace.library.utoronto.ca/bitstream/1807/29879/7/Stoilescu_Dorian_201106_PhD_thesis.pdf.

Sturgis, P., Roberts, C., & Smith, P. (2014). Middle alternatives revisited how the neither/nor response acts as a way of saying "I don't know"? *Sociological Methods & Research*, *43*(1), 15–38. https://doi.org/10.1177/0049124112452527

Tondeur, J., Van Braak, J., Sang, G., Voogt, J., Fisser, P., & Ottenbreit-Leftwich, A. (2012). Preparing pre-service teachers to integrate technology in education: A synthesis of qualitative evidence. *Computers and Education*, *59*(1), 134–144. https://doi.org/10.1016/j.compedu.2011.10.009

UNICEF South Africa. (2017). *Education budget South Africa 2017/2018*. Pretoria: United Nations Children's Fund. Retrieved from https://www.unicef.org/esaro/UNICEF_South_Africa_--_2017_--_Education_Budget_Brief.pdf.

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & Van Braak, J. (2012). Technological pedagogical content knowledge - A review of the literature. *Journal of Computer Assisted Learning*, *29*(2), 109–121. https://doi.org/10.1111/j.1365-2729.2012.00487.x

Wahlstrom, K.L., & Louis, K.S. (2008). How teachers experience principal leadership: The roles of professional community, trust, efficacy, and shared responsibility. *Educational Administration Quarterly*, *44*(4), 458–495. https://doi.org/10.1177/0013161X08321502

Watson, J.C. (2017). Establishing evidence for internal structure using exploratory factor analysis. *Measurement and Evaluation in Counseling and Development*, *50*(4), 232–238. https://doi.org/10.1080/07481756.2017.1336931