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Examining practicing teachers' perceptions of technological pedagogical content knowledge (TPACK) pathways: a structural equation modeling approach

Joyce Hwee Ling Koh · Ching Sing Chai · Chin-Chung Tsai

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Abstract The seven constructs of the technological pedagogical content knowledge (TPACK) framework has been widely adopted as a theoretical basis for understanding the scope of teachers' information and communication technology (ICT) expertise. Despite this, very little is understood about the inter-relationships between these constructs, especially how these relationships are related to teachers' TPACK. As a result, the theory–practice nexus of this framework remains weak. In this study, a structural equation model based on Mishra and Koehler's TPACK framework was developed to describe the TPACK perceptions of 455 practicing teachers in Singapore. The study shows that teachers, perceived TPACK to be formulated from the direct effects of technological knowledge and pedagogical knowledge. They also perceived these knowledge sources to contribute to the development of technological pedagogical knowledge and technological content knowledge, which also contributed to their TPACK. In these teachers' conceptions of TPACK, however, the effects of content knowledge and pedagogical content knowledge were not evident. The implications of these relationships to the design of teacher professional development in ICT are discussed.

Keywords Technological pedagogical content knowledge · TPACK · Structural equation modeling · TPACK development pathways

Introduction

Technological pedagogical content knowledge (TPACK) (Mishra and Koehler 2006) is a theoretical framework that describes teachers' expertise for information and

J. H. L. Koh (✉) · C. S. Chai
National Institute of Education, Nanyang Technological University, 1 Nanyang Walk, Singapore 637616, Singapore
e-mail: joyce.koh@nie.edu.sg

C.-C. Tsai
Graduate Institute of Digital Learning and Education, National Taiwan University of Science and Technology, #43, Sec. 4, Keelung Rd., Taipei 106, Taiwan

communication technology (ICT) integration. This framework premises technological knowledge, pedagogical knowledge, and content knowledge to be the three sources of teacher knowledge for ICT integration. Four other types of ICT integration knowledge can be derived from their inter-connections. These are: pedagogical content knowledge, technological pedagogical knowledge, technological content knowledge, and TPACK. This conception of teacher ICT knowledge has been received with much enthusiasm by teacher educators because it provides them with a theoretical underpinning for defining teachers' ICT integration competencies (Grandgenett 2008; McCrory 2008). The TPACK framework emphasizes the need to help teachers make connections between technological knowledge, pedagogical knowledge, and content knowledge because these connections define their ICT integration expertise (Mishra and Koehler 2006). A substantial number of TPACK studies of teachers during ICT training have also found support for this proposition (e.g. AACTE 2008; Koehler et al. 2007; Özgün-Koca et al. 2009/2010). Nevertheless, these studies are descriptive and a comprehensive model of the interacting relationships between the seven TPACK constructs has yet to be developed (Chai et al. 2010; Cox and Graham 2009). There has been keen interest among teacher educators to adopt TPACK as a guiding framework for the planning of teacher ICT education (Cox and Graham 2009; Thompson and Mishra 2007). The modeling of such relationships is important because it lends insights to how teachers' ICT instruction could be structured. This can also strengthen the theory–practice nexus of the TPACK framework, which is a gap in extant TPACK research (Cox and Graham 2009).

In this study, a structural equation model based on Mishra and Koehler's (2006) TPACK framework was first developed to describe the TPACK perceptions of 455 practicing teachers in Singapore. The statistically significant pathways leading to teachers' TPACK as revealed by the structural equation model will be then be discussed with respect to their applications to the design of teacher professional development in ICT.

Theoretical framework

The TPACK framework

The notion of teacher expertise as a unique form of knowledge was first suggested by Shulman (1986). Terming this as pedagogical content knowledge, Shulman argued that it is different from teachers' pedagogical knowledge and content knowledge. Mishra and Koehler (2006) drew upon Shulman's work by adding technological knowledge to content knowledge and pedagogical knowledge. They proposed that the term TPACK be similarly used to represent teachers' unique expertise for technology integration. It characterizes how they make "intelligent pedagogical uses of technology" (Koehler et al. 2007, p. 741). TPACK was initially given the acronymn of TPCK which was later changed to TPACK for ease of pronounciation and for a clearer emphasis on the integrated use of technology, pedagogy and content knowledge for effective technology integration (Thompson and Mishra 2007).

Mishra and Koehler (2006) provided a graphical representation of their TPACK framework which attempts to articulate the relationships between technological knowledge, pedagogical knowledge, and content knowledge (See Fig. 1). Technological knowledge, pedagogical knowledge, and content knowledge are being visualized as three main circles whereas their interconnections are represented by the four overlapping areas among these three circles.

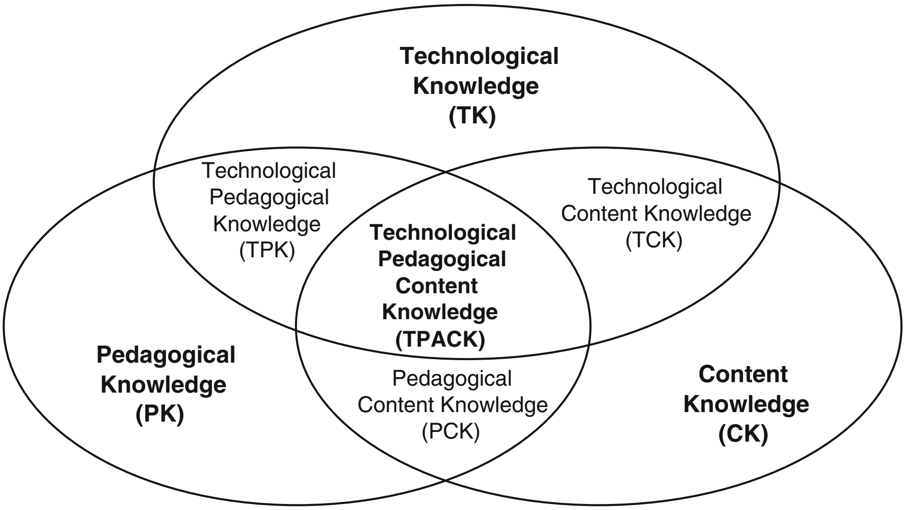

Fig. 1 TPACK framework, as depicted by Mishra and Koehler (2006), pg 1025

Shulman (1986) did not elaborate the extent to which pedagogical knowledge and content knowledge contribute to pedagogical content knowledge but contended these to be distinct. Mishra and Koehler's (2006) depiction of the TPACK framework suggests that pedagogical knowledge and content knowledge are related, with their area of overlap being termed as pedagogical content knowledge. In addition to pedagogical content knowledge, the areas of overlap between technological knowledge, pedaogical content knowledge, and content knowledge can also give rise to the constructs of technological pedagogical knowledge, technological content knowledge, and TPACK. These seven TPACK constructs characterize the body of knowledge teachers need for technology integration which are defined as follows:

1. Technological knowledge (TK)—knowledge of technology tools.
2. Pedagogical knowledge (PK)—knowledge of teaching methods.
3. Content knowledge (CK)—knowledge of subject matter.
4. Technological content knowledge (TCK)—knowledge of subject matter representation with technology.
5. Technological pedagogical knowledge (TPK)—knowledge of using technology to implement different teaching methods.
6. Pedagogical content knowledge (PCK)—knowledge of teaching methods with respect to subject matter content.
7. Technological pedagogical content knowledge (TPACK)—knowledge of using technology to implement teaching methods for different types of subject matter content.

A nation-wide study conducted in the USA found that increased hours of computer skills training did not help teaches better integrate ICT (Moursund and Bielefeldt 1999). This report spurred many schools of education in the USA to explore how the practice of ICT integration could be enhanced within their curriculum through strategies such as faculty modeling, ICT lesson plan design projects, and field-based ICT practice (see Brush et al. 2003; Handler 1993; Strudler and Wetzel 1999). While these strategies were reported to have enhanced teachers' perceived confidence for ICT integration, they did not clearly articulate the types of ICT integration knowledge and competencies that teachers acquired. At this time, the field also lacked comprehensive theoretical models to explain this phenomenon. Mishra and Koehler's (2006) conception of TPACK addressed this theoretical void by defining the different types knowledge teachers need to acquire in terms of ICT integration. Since its conception, the TPACK framework has been widely embraced as a theoretical framework for re-structuring teacher ICT education (e.g. Niess 2007).

Understanding teachers' perceived TPACK pathways through structural equation modeling

Mishra and Koehler's (2006) TPACK framework proposes two pathways to TPACK. The first is through the direct influences of TK, PK, and CK whereas the second is through the effects of the intermediary knowledge forms of TPK, TCK, and PCK. Many qualitative studies have described examples of the seven TPACK constructs for particular subject areas and argued that these different forms of knowledge do exist (e.g. Özgün-Koca et al. 2009/2010). Some found evidence of TPACK emerging as teachers made connections between their TK, PK, and CK (Koehler and Mishra 2005; Koehler et al. 2007) but did not attempt to describe the specific influence of each (Cox and Graham 2009). The two TPACK pathways proposed in the TPACK framework have not been expressly investigated in these qualitative studies. While there is some evidence speaking to the existence of TPACK pathways, it is unclear if the effects of TK, PK, and CK are as strong as the effects from the intermediary knowledge forms of TCK, TPK, and PCK. Furthermore, the theoretical postulations of Mishra and Koehler (2006) do not provide sufficient guidance about these issues which are important for the on-going development of the TPACK framework.

The on-going design and validation of TPACK surveys (see Archambault and Crippen 2009; Graham et al. 2009; Lee and Tsai 2010; Schmidt et al. 2009) have opened up the possibility of explaining these relationships with methods such as inferential statistics and structural equation modeling, a statistical technique whereby models are created to explain multiple dependence relationships postulated by a theoretical framework (Hair et al. 2010). Chai et al. (2010) administered pre and post course TPACK surveys on 889 Singapore pre-service teachers who were attending an introductory ICT module as part of their teacher education program. The direct effects of TK, PK, and CK on TPACK were examined with regression analyses of survey responses which found that among TK, PK, and CK, PK consistently had the largest contribution to TPACK in both surveys. However, the possible moderation effects of TPK, PCK, and TPK have not been considered as only the three main knowledge contributors of TPACK were examined in this study. Chai et al. (2011) examined the effects of TK, PK, CK, and TPK on TPACK through structural equation modeling and found that TK, PK, and CK had smaller positive effects on TPACK than TPK. These studies provide some support for the TPACK framework and suggest that teachers do not perceive the two TPACK pathways as exerting similar influences on their TPACK. However, these studies were conducted with pre-service teachers whereas the perceptions of practicing teachers have yet to be examined.

Methodologically, researchers still face many challenges when attempting to formulate structural equation models for the TPACK framework. Firstly, few published TPACK surveys have been evaluated for their construct validity. This is because several surveys have been administered with small samples sizes of teachers (Graham et al. 2009; Schmidt et al. 2009), some as few as 15 in the case of Graham et al. This has limited the use of exploratory and confirmatory factor analyses for further evaluation of its construct validity. Secondly, factor analyses of large sample TPACK surveys have not been able to establish construct validity for all the seven TPACK constructs postulated by Mishra and Koehler (2006). An exploratory factor analysis of TPACK survey responses from 1,185 Singapore pre-service teachers by Koh et al. (2010) found construct validation for only TK and CK. Items from TPK, TCK, and TPACK were loaded as a factor whereas items from PK and PCK were loaded as another. Similarly, Archambault and Barnett's (2010) factor analysis of survey responses from 500 K-12 teachers in the USA about their TPACK for facilitating e-learning yielded three factors. Like Koh et al., items from TPK, TCK, and TPACK were loaded as a factor. On the other hand, CK loaded with PK and PCK to form another factor. Lee and Tsai (2010) also developed a TPACK survey to assess Taiwanese teachers' web-based TPACK that was based on the constructs of TK, TCK, TPK, and TPACK. Their exploratory factor analysis of survey responses also found the items of TCK and TPK loading as a factor. In addition, Lee and Tsai were able to obtain good fit indexes for their four-factor model through confirmatory factor analysis. These studies show TPACK to be a complex theoretical framework still needing much development and validation, which was also pointed out by Cox and Graham (2009).

The latest work in TPACK survey design showed that surveys targeted at specific pedagogical uses of technology could yield better construct validity. The surveys that were subjected to factor analyses implemented by Koh et al. (2010) and Archambault and Barnett (2010) were adapted from Schmidt et al.'s (2009) generic TPACK survey. This survey was not specifically designed with particular pedagogical approaches in mind. On the other hand, TPACK is a form of knowledge that is highly contextualized to specific lesson topics and pedagogical activities (Cox and Graham 2009). The results of Chai, Koh, Tsai et al. (2011) supported this thesis. These authors designed a survey to assess teachers' TPACK for facilitating technology-based constructivist teaching. They substituted the PK items in Koh et al. (2010) with 13 items that operationalized the five dimensions of meaningful learning with ICT described by Jonassen et al. (2008). The survey was implemented with 834 Singapore primary pre-service teachers where an exploratory factor analysis yielded five factors, that is, TK, CK, PK, TPK, and TPACK. Nevertheless, in this scale, one TCK item loaded with TPACK whereas the other TCK and PCK items were eliminated as they were cross-loaded with other items. To facilitate respondents' ability to differentiate between TCK and PCK items, the stem, "Without using technology…" was added into PCK items. This revised version of the TPACK survey for facilitating meaningful learning with technology was administered on 214 Singapore pre-service teachers. Chai et al. (2011) reported successful extraction of the seven TPACK factors that was validated with adequate model fit through confirmatory factor analysis. The successful construct validation of this TPACK survey has addressed some of the key problems associated with TPACK instrument design. Structural equation modeling can thus be performed with the seven TPACK constructs to derive a more comprehensive model of how teachers perceive the relationships between the different constructs underlying their TPACK. This, in turn, can contribute to teacher educators' and school administrators' planning of teacher ICT development.

Research question

Given the preceding review, the research question addressed by this study is:

What are practicing teachers' perceived pathways to TPACK?

A structural model of the TPACK framework formulated according to the conceptions of Mishra and Koehler (2006) is shown in Fig. 2.

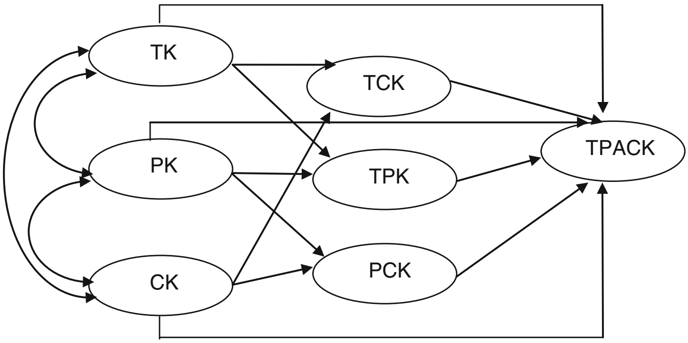

Fig. 2 Structural equation model of the TPACK framework

This structural model hypothesizes two pathways to TPACK:

H1: TK, PK, and CK have direct and positive effects on teachers' TPACK. In Hypothesis 1, TK, PK, and CK are defined as exogenous variables. This hypothesis addresses Mishra and Koehler's (2006) postulation of TK, PK, and CK as the three main sources of TPACK.

H2: TK, PK, and CK have direct and positive effects on teachers' TCK, TPK, and PCK, which in turn have direct and positive effects on teachers' TPACK.

Shulman (1986) described PCK to be distinct from PK and CK. Nevertheless, from Mishra and Koehler's (2006) depiction, it cannot be assumed that the intermediate variables of PCK, TCK, and TPK are unrelated to TK, PK, and CK. Therefore, the intermediate variables of TPK, TCK, and PCK are defined as endogenous variables with direct linkages to TPACK.

Methodology

Study participants

The study participants comprised of 455 practicising teachers in Singapore from 149 primary, secondary, and junior colleges who volunteered to complete the TPACK survey. These participants were solicited from course attendees of an ICT professional development programme organized by a teacher education agency and schools participating in research projects at a teachers' college in Singapore. About 71 % of the study participants were female teachers ($n = 325$) with a mean age of 34.88 years (SD = 6.64), and an average of 8.99 years of teaching experience (SD = 6.49).

This sample is fairly representative of Singapore teachers. In terms of gender profile, 72.9 % ($n = 29{,}875$) of Singapore teachers were females (Ministry of Education 2010). Sixty per-cent of Singapore teachers had less than 10 years of service, 24 % had 10–20 years of service whereas 16 % served more than 20 years. This sample is fairly similar, with 61 % having less than 10 years of service. However, 32 % of the respondents had between 10 and 20 years of service whereas only 7 % had more than 20 years of service. In terms of age, 73 % of respondents were above 30 years of age, which was close to the 70 % reported in Ministry of Education (2010).

Survey instrument

The TPACK survey for Meaningful Learning described in Chai et al. (2011) was used for this study because its construct validity with respect to all the seven TPACK factors has been established previously. It measures teachers' TPACK for facilitating Jonassen et al. (2008) five dimensions of meaningful learning, which are: active learning, cooperative learning, constructive learning, intentional learning, and authentic learning. These dimensions are contextually relevant for practicing teachers in Singapore. The third ICT masterplan unveiled in 2008 supports Singapore students to develop 21st century skills, specifically to harness ICT tools to engage in lifelong self-directed learning and collaborative learning (Teo and Ting 2010). This ICT masterplan also emphasizes teachers' ability to develop students' competencies by integrating ICT-supported pedagogies that engage students in self-directed learning and collaborative learning.

When designing the CK, PCK, TCK, and TPACK items of the TPACK survey for Meaningful Learning, Chai et al. (2011) included questions related to the two curriculum subjects (termed as "Curriculum Subject 1" and "Curriculum Subject 2" in the survey) because all Singaporean pre-service teachers are trained to teach at least two subjects. In this study, the items related to Curriculum Subject 2 were removed because practicing teachers in Singapore typically specialize and take academic leadership in their Curriculum Subject 1 as they gain teaching experience. Their pedagogical experiences tend to be more developed in this subject area and assessing this would was considered to be of greater priority in this study. Therefore, the final survey comprised of 30 items that measured teachers' perceptions with respect to the extent to which they agreed or disagreed with statements related to the seven TPACK constructs. Each statement was rated as a seven-point Likert-type scale where 1—strongly disagree, 2—disagree, 3—slightly disagree, 4—neither agree nor disagree, 5—slightly agree, 6—agree, 7—strongly agree.

Data analysis

Internal reliability of the seven constructs was first established through high Cronbach alphas for all constructs: TK ($\alpha = 0.89$), PK ($\alpha = 0.94$), CK ($\alpha = 0.91$), PCK ($\alpha = 0.94$), TPK ($\alpha = 0.95$), TCK ($\alpha = 0.92$), and TPACK ($\alpha = 0.94$). A measurement model was specified in AMOS 19 with the seven latent constructs (TK, PK, CK, PCK, TCK, TPK, and TPACK) and the 30 survey items as measurement items for their associated construct. Maximum likelihood estimation was used. The standardized regression weights of measurement items and model fit were then assessed to establish construct validity.

Following confirmation of the measurement model, the presence of significant correlations between TPACK constructs were first established with Pearson correlations. The structural model outlined in Fig. 2 was then specified in AMOS 19. After establishing satisfactory model fit, path coefficients were analyzed to test hypotheses 1 and 2.

Results

Measurement model

Table 1 shows the sample size of 455 to be adequate for this seven-construct model as there were no unidentified constructs and all communalities were either above or close to 0.45 as recommended by Hair et al. (2010). All items except one loaded significantly with

Table 1 Descriptive statistics, factor loadings and communality for survey items

Items	Mean	SD	Factor loading	Communality
Content Knowledge (CK: M = 5.83, SD = 0.81)				
CK1—I have sufficient knowledge about my first teaching subject (CS1)	6.03	0.79	0.87	0.76
CK2—I can think about the content of my first teaching subject (CS1) like a subject matter expert	5.62	0.98	0.88	0.78
CK3—I am able to develop deeper understanding about the content of my first teaching subject (CS1)	5.82	0.87	0.89	0.79
Pedagogical Knowledge (PK: M = 5.63, SD = 0.76)				
PK1—I am able to stretch my students' thinking by creating challenging tasks for them	5.67	0.80	0.78	0.61
PK2—I am able to guide my students to adopt appropriate learning strategies	5.67	0.81	0.86	0.75
PK3—I am able to help my students to monitor their own learning	5.55	0.89	0.93	0.86
PK4—I am able to help my students to reflect on their learning strategies	5.47	0.94	0.92	0.85
PK5—I am able to guide my students to discuss effectively during group work	5.63	0.86	0.82	0.68
Pedagogical Content Knowledge (PCK: M = 5.42, SD = 1.03)				
PCK1—Without using technology, I can address the common misconceptions my students have for my first teaching subject (CS1)	5.47	1.09	0.95	0.90
PCK2—Without using technology, I know how to select effective teaching approaches to guide student thinking and learning in my first teaching subject (CS1)	5.38	1.10	0.92	0.84
PCK3—Without using technology, I can help my students to understand the content knowledge of my first teaching subject (CS1) through various ways	5.39	1.08	0.87	0.74
Technological Knowledge (TK: M = 5.21, SD = 1.10)				
TK1—I have the technical skills to use computers effectively	5.63	1.01	0.85	0.73
TK2—I can learn technology easily	5.66	1.06	0.92	0.84
TK3—I know how to solve my own technical problems when using technology	5.01	1.28	0.84	0.70
TK4—I keep up with important new technologies	4.26	1.71	0.64	0.41
TK5—I am able to create web pages	5.29	1.53	0.70	0.49
TK6—I am able to use social media (e.g. Blog, Wiki, Facebook)	5.39	1.46	0.70	0.50
Technological Pedagogical Knowledge (TPK: M = 5.07, SD = 1.10)				
TPK1—I am able to use technology to introduce my students to real world scenarios	5.26	1.18	0.81	0.65
TPK2—I am able to facilitate my students to use technology to find more information on their own	5.36	1.04	0.83	0.69
TPK3—I am able to facilitate my students to use technology to plan and monitor their own learning	4.85	1.26	0.92	0.85
TPK4—I am able to facilitate my students to use technology to construct different forms of knowledge representation	4.92	1.28	0.94	0.87
TPK5—I am able to facilitate my students to collaborate with each other using technology	4.94	1.29	0.90	0.82

Table 1 continued

Items	Mean	SD	Factor loading	Communality
Technological Content Knowledge (TCK: M = 5.05, SD = 1.21)				
TCK1—I can use the software that are created specifically for my first teaching subject (CS1). (e.g. e-dictionary/corpus for language; geometer sketchpad for maths; data loggers for science)	5.06	1.35	0.85	0.72
TCK2—I know about the technologies that I have to use for the research of content of first teaching subject (CS1)	4.97	1.29	0.92	0.84
TCK3—I can use appropriate technologies (e.g. multimedia resources, simulation) to represent the content of my first teaching subject (CS1)	5.11	1.28	0.91	0.83
Technological Pedagogical Content Knowledge (TPACK: M = 5.15, SD = 1.05)				
TPACK1—I can teach lessons that appropriately combine my CS1, technologies and teaching approaches	5.23	1.14	0.89	0.79
TPACK2—I can select technologies to use in my classroom that enhance what I teach, how I teach and what students learn	5.29	1.07	0.94	0.89
TPACK3—I can use strategies that combine content, technologies and teaching approaches that I learned about in my coursework in my classroom	5.19	1.08	0.92	0.85
TPACK4—I can provide leadership in helping others to coordinate the use of content, technologies and teaching approaches at my school and/or district	4.88	1.34	0.77	0.60

standardized regression weights of at least 0.5 (Hair et al.), indicating strong relationship with their associated constructs. The item that did not load significantly was a PK item—"I am able to plan group activities for my students". It may not have loaded well because it described teachers' planning of learning activities whereas the other PK items described learning activities involving teacher-student interaction (See Table 1). This item was removed and satisfactory model fit was obtained (χ^2 = 1,008.34, χ^2/df = 2.88, $p < .0001$, TLI = .94, CFI = .95, RMSEA = 0.06 (LO90 = 0.06, HI90 = 0.07), SRMR = 0.05).

Correlation analysis

Significant positive correlations between the TPACK constructs were established at $p < 0.01$ (See Table 2), indicating that these relationships could be further examined with structural equation modeling. The correlations between TK and TPACK were large as these were above 0.60 (Fraenkel and Wallen 2003) whereas those of PK, and CK were moderate. TCK and TPK had the largest positive correlations with TPACK as these were above 0.70. On the other hand, the correlation between PCK and TPACK was low. These results indicate that the intermediate constructs of TCK and TPK have stronger relationships with TPACK as compared to the main knowledge sources of TK, PK, and CK.

The correlation analysis also suggests the need to reconsider the design of some survey items. TK had moderate positive correlations with PK and CK whereas PK and CK items had strong positive correlation that were greater than 0.60. These findings were similar to those of Archambault and Crippen (2009), Chai et al. (2011), and Sahin (2011). The references to "teaching subject" in the CK items could have resulted in the teachers

Table 2 Inter-correlations between constructs

	TK	PK	PCK	TCK	TPK	TPACK	CK
TK	1						
PK	0.42**	1					
PCK	0.18**	0.40**	1				
TCK	0.63**	0.39**	0.20**	1			
TPK	0.72**	0.49**	0.15**	0.65**	1		
TPACK	0.69**	0.55**	0.23**	0.72**	0.74**	1	
CK	0.35**	0.61**	0.42**	0.47**	0.34**	0.44**	1

$n = 455$, ** $p < 0.01$

establishing correspondence with the instructional pedagogies outlined in the PK items. With respect to the correlations of TK items to PK and CK items, this may indicate a need to consider if non-technological depictions of PK and CK items were sufficiently emphasized in the wording of these items. This is because PCK items with the stem "Without using technology" had low correlations with the items for TK, TPK, TCK, and TPACK.

Structural model

The results of the structural model based on the hypotheses in Fig. 2 are shown in Table 3. The structural model yielded satisfactory model fit ($\chi^2 = 1{,}024.20$, $\chi^2/\mathrm{df} = 2.89, p < .0001$, TLI = .94, CFI = .95, RMSEA = 0.07 (LO90 = 0.06, HI90 = 0.07), SRMR = 0.04). The path coefficients of the structural equation model developed for the TPACK framework are summarized in Table 3.

From Table 3, it can be seen that, by and large, both pathways to TPACK as predicted by H1 and H2 were partially supported. TK and PK were perceived to have direct and positive effects on TPACK. No significant relationships were perceived between CK and TPACK. Therefore, H1 was partially supported. In terms of H2, the proposition that TK, PK, and CK would be perceived to have direct and positive effects on teachers' TCK, TPK,

Table 3 Path coefficients of the TPACK structural equation model

Hypothesis	Path	Path coefficient	Standard error	Critical ratio
1	TK → TPACK	0.16*	0.07	2.64
	PK → TPACK	0.16***	0.07	3.82
	CK → TPACK	N.S.		
2	TK → TCK	0.59***	0.06	12.29
	CK → TCK	0.25***	0.07	5.86
	TK → TPK	0.68***	0.06	14.17
	PK → TPK	0.18***	0.07	4.49
	CK → PCK	0.33***	0.09	5.43
	PK → PCK	0.20**	0.10	3.24
	TCK → TPACK	0.41***	0.04	8.78
	TPK → TPACK	0.30***	0.05	5.83
	PCK → TPACK	N.S.		

*** $p < 0.0001$, ** $p < 0.001$, * $p < 0.01$

and PCK was supported. However, only TCK and TPK were found to be perceived as having direct effects on TPACK. Therefore, H2 was also partially supported.

Direct paths to TPACK

Figure 3 depicts the path coefficients for all paths that have no broken links towards TPACK.

The study results indicated that teachers perceived four direct paths to TPACK from TK, PK, TCK, and TPK. They perceived TK and PK to have some direct effects on their TPACK (See Fig. 3). However, TCK and TPK had larger path coefficients, indicating that these were perceived to have stronger direct effects on TPACK than TK and PK. Among these four direct sources, TCK had the largest path coefficient. Therefore, its effect on TPACK was perceived to be the largest.

Missing paths

The study results indicated that CK and PK were perceived to have direct effects on teachers' PCK. However, no significant path between PCK and TPACK was established, indicating that the teachers did not perceive significant relationships between their PCK and TPACK. The direct effect of CK on TPACK was also not significant. Therefore, the teachers studied did not perceive CK to influence their TPACK.

Discussion

This study used structural equation modeling to analyze the pathways to TPACK perceived by 455 Singapore practicing teachers with respect to the postulations of Mishra and Koehler's (2006) model. This group of teachers perceived that the direct relationships between TK, PK, and TPACK to be weaker than those between TCK, TPK, and TPACK. The teachers did not perceive CK to exert a significant influence on their TPACK. It was perceived to be of impact on only PCK which was not significantly related to TPACK.

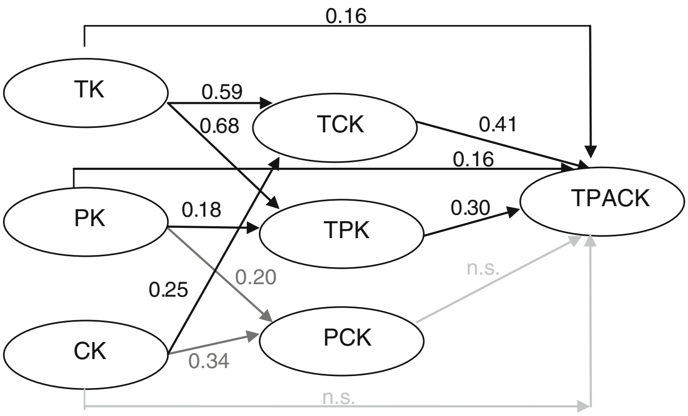

Fig. 3 Unbroken paths to TPACK

Pathway 1—the direct influences of TK, PK, and CK

TK was perceived to have direct positive influence on TPACK. This concurred with Pierson (2001) who found that experienced teachers who were proficient in facilitating student-centered lessons could not translate this type of pedagogical expertise into their ICT lessons when they lacked ICT proficiency. ICT proficiency also fosters teachers' self-efficacy for technology integration (Paraskeva et al. 2008), which is an important indicator of teachers' advancement in TPACK (Niess 2007). The PK items in this study measured teachers' perception of their pedagogical expertise for facilitating meaningful learning. The positive relationship between PK and TPACK indicates that teachers' confidence with such kinds of pedagogical practices had positive influence on their TPACK perceptions which is supported by studies who found that the pedagogical beliefs of teachers had some impact how they use computers in the classroom (Lim and Chai 2008; Wang et al. 2004).

The lack of significant relationship between CK and TPACK could be methodological. References to teachers' first teaching subject (CS1) only appeared in item TPACK1 but not in the other three TPACK items. Cox and Graham (2009) also described TPACK to be subject and topic specific. The descriptions of teaching content in the TPACK items may have been too general. Another reason for these findings could be contextual. While most Singapore classrooms have a computer and a projector, the physical set up is insufficient to encourage pervasive use of computers as cognitive tools for meaningful learning (see Jonassen et al. 2008) which this study measured. Ubiquitous computing such as one-to-one laptop programmes is not yet pervasive in most Singapore schools. For most lessons, teachers' planning and implementation of lessons do not involve student-centred use of computers. Bringing students to the computer laboratory requires special arrangement on the teachers' part. The contextual environment could have led the teachers to naturally consider ICT tools as an element outside rather than within their classroom environment. The dissociation of CK from the technology-related constructs for this study could also be due to this contextual factor. More analysis of the model we obtained with teachers operating in 1:1 computing classrooms could shed more light on this issue.

Pathway 2—The direct influences of TPK, TCK, and PCK

TPACK studies such as Koehler et al. (2007) and Angeli and Valanides (2009) showed that teachers develop new kinds of knowledge when they are able to make connections between TK, PK, and CK. These studies support the transformative view of TPACK which states that the outcome of integrating multiple knowledge sources results in knowledge that is unique and different from a simple addition of its sources (Angeli and Valanides). In this study, it was found that teachers not only perceived TPK and TCK to have positive influences on TPACK, their path coefficients were also larger than the direct influences of TK and PK. These findings support Mishra and Koehler's (2006) contention that teachers' ICT integration expertise was found largely in the areas of overlap among TK, PK, and CK.

Interestingly, for these teachers, TCK was perceived to exert a larger positive influence on their TPACK formation than TPK. These results are different from Koh and Divaharan (2011) who found that Singapore pre-service teachers placed more emphasis on considerations of TPK whereas their consideration of TCK was minimal. This could be because the study participants are experienced practicing teachers with a mean teaching experience of 9 years. Being highly familiar with the school environment and their content area, the fulfilment of curriculum goals is priority for them, as was the case in Lim and Chai (2008).

Therefore, the linkages between content and technology featured more prominently in their consideration of TPACK. In comparison, considerations of TCK may be challenging for Koh and Divaharan's sample of pre-service teachers as they have yet to be thoroughly exposed to the school curriculum. Koh and Divaharan suggested that these teachers may need more exposure to subject-based examples of ICT integration before they can effectively consider TCK.

In this study, it can be seen that the teachers do perceive PK and CK to positively influence their PCK. Their mean PCK score is also fairly high. One reason for the missing link between PCK and TPACK could be methodological. The PCK items are designed with the stem "Without using technology", which may have prompted the teachers to dissociate it from TPACK. Another reason for this missing link could be because these teachers lacked adequate know-how to consider ICT integration in terms of content transformations. According to Angeli and Valanides (2009), such kinds of expertise is known as ICT-TPCK, a form of TPACK that describes teachers' understanding of how ICT can be used to address students' learning difficulties with respect to particular topics. In this conception of TPACK, teachers' understanding of content learning issues (i.e. PCK) determines how teachers choose and integrate ICT to overcome these challenges (i.e. TPACK). Schools and teachers have traditionally treated ICT tools as an external agent that needs to be assimilated or conformed within their classroom system (Papert 1993). Such kinds of environmental contexts tend to foster a techno-centric mindset towards the practice of ICT integration. The teachers may have also perceived their PCK to be adequate for addressing students' learning difficulties. Therefore, they may not have perceived a necessity to consider further content transformations through ICT.

Instructional implications

This study shows that TK was perceived to have positive effects on TPACK, TPK, and TCK. The latter two constructs were also perceived to have positive effects on TPACK. To optimize the influence of these variables on teachers TPACK, teacher ICT development programs should adopt strategies that help teachers to develop knowledge related to both the technology and its pedagogical uses. This is especially important when introducing new ICT tools to teachers. An example could be found in Koh and Divaharan (2011). When teaching pre-service teachers about an ICT tool that was new and unfamiliar to them, TK was first taught through instructor demonstration of the ICT tool, teacher self-paced exploration of the ICT tool, and the sharing of technical features with peers. This provided teachers with the basic knowledge needed to further consider its pedagogical uses through critique of subject-based examples related to integration of the tool, which was aimed at developing their TCK and TPK. Their TPACK was then developed through the design of lesson units that integrated the tool, which was similar to the strategies adopted by Koehler et al. (2007). Koh and Divaharan's instructional process was targeted at the TPACK development of pre-service teachers. When using it with practicing teachers, peer critique and peer observations could be used in addition to the critique of subject-based examples as these kinds of strategies have proven to be effective in teacher professional development (Blase and Blase 1999). The study results show that TPK and TCK had larger effects on teachers' TPACK than TK and PK. Therefore, during teacher development, training of TK should be pitched at a level necessary to facilitate understanding of the ICT tool and its affordances whereas more emphasis should be placed on the strategies that develop teachers' pedagogical reasoning with the tool.

The positive direct linkages perceived between PK and TPACK also points to the need to foster teachers' PK which can in turn contribute to their TPK. This is especially important in this study where PK items were specifically on the pedagogies for facilitating meaningful learning. Chai, Koh, Tsai et al. (2011) described an instructional process which first taught pre-service teachers about PK for meaningful learning. The teachers used this foundation to explore ICT tools and design lessons related to these tools. Pre and post course structural equation models found that this approach not only strengthened teachers' perceptions of the positive impact of PK on TPK, it also strengthened their perceptions of the positive impact of TPK and TPACK. Such kinds of pedagogical instruction are also needed for practicing teachers as studies have found their pedagogical conceptions of ICT lessons to be more strongly shaped by contextual factors such as syllabus requirements and examination results (Lim and Chai 2008). Specific pedagogical training and modeling of the pedagogical uses of ICT tools are even more crucial with new pedagogies that are unfamiliar to their existing teaching practices.

As described earlier, the lack of significant relationship between CK and TPACK, and between PCK and TPACK point needs to be considered with respect to the design of survey items. Going beyond these methodological considerations, an instructional implication would be to examine how a TPACK pathway centered on content transformations can be used to enhance teachers' existing TPACK practices. This pathway can possibly be used when designing teacher development aimed at ICT integration for specific content areas. It has the potential to help teachers to focus ICT integration on challenging subject matter and content transformation. An instructional process that is informed by this pathway can first help teachers to develop good PCK practices with respect to that subject area and then consider how these practices can be enhanced with appropriate ICT tools.

Current research provides some insights about how such an instructional process might occur. Researchers have suggested several strategies for building teachers' PCK. McDiarmid (1990) argued that PCK development involves teachers changing their existing knowledge and attitudes regarding how teaching and learning occur in a subject area. To facilitate such kinds of changes, Kinach (2002) proposed a cognitive strategy whereby Socratic dialogue is used by teacher educators to elicit, challenge, and transform teachers' existing PCK. Besides Socratic dialogue, PCK can also be developed through analysis and peer discussion of teaching cases (Daehler and Shinohara 2001). For practicing teachers, PCK can be developed through active reflection both during teaching (reflection-in-action) and after teaching (reflection-on-action) (Park and Oliver 2008). When articulating the concept of ICT-related PCK, Angeli and Valanides (2005) proposed five steps for transforming PCK with ICT:

1. Identify topics where ICT tools can contribute to students' learning difficulties.
2. Consider how ICT tools can be used to transform content into representations that address students' learning difficulties.
3. Identify teaching strategies that can be more effectively implemented with ICT.
4. Select ICT tools that support the needed content transformations or teaching strategies.
5. Plan how the ICT-enabled lesson activities can be infused into the classroom.

It can be seen that a comprehensive instructional model for facilitating a content-centered pathway of TPACK formation has yet to be developed, which is an area with potential for further research.

Limitations and future research

Several limitations need to be considered when interpreting the results of this study. Firstly, the study results described the TPACK pathways of 455 Singapore teachers who volunteered their participation. While the demographic profile of this convenience sample is close to the profile of Singapore teachers, the study results cannot be deemed to be representative of teachers in general. Secondly, the TPACK pathways were derived from a sample of teachers. It is unclear if these adequately described the TPACK formation pathways of individual teachers. Thirdly, as the purpose of the study was to develop a structural equation model of the TPACK framework, further examination of teachers' TPACK perceptions through in-depth interviews and classroom observations is outside the scope of the study. Only one structural equation model was developed where the intermediary variables of TPK, TCK, and PCK were assumed to be endogenous variables. Therefore, the TPACK pathways described still need to be further validated through both in-depth qualitative studies and an investigation of whether better fit could be derived from alternative modeling of the structural relationships. Finally, the absence of significant pathways between CK, PCK, and TPACK need to be considered with respect to the design of its survey items. Further studies are needed to examine the relationships specified in this pathway.

These limitations provide scope for further study into this area. Firstly, there is a need to make clearer references to the teachers' first teaching subject (CS1) in the TPACK items. The pathways between CK, PCK, and TPACK need to be re-examined with these revised survey items. In addition to TPACK items, there is also a need to consider if adding the stem "Without using technology" into PK and CK items could better dissociate it from TK items. The references to "teaching subjects" in the CK items also need to be reconsidered for clearer interpretation of CK items vis-à-vis PK items. The structural equation modeling needs to be repeated with these survey items to determine the extent to which the design of these survey items could have impacted the study results. Secondly, there is a need to validate the results of this study through a national study. Cluster sampling could be used to ensure adequate representation by either teacher profile or school profile. This can provide validation of the results of this study. In addition, this study can be replicated with pre-service teachers to determine if their perceived TPACK pathways are similar. Another area of future research is to validate the TPACK pathways through qualitative studies of teachers across time through classroom observations, in-depth interviews, and the examination of their ICT lesson designs. Such kinds of in-depth studies also shed light on the presence of TPACK formation pathways that have not been found in this study. Shulman (1986) focused on the description of PCK as being distinct from PK and CK but did not comment on the relationships among these constructs. In this study, relationships between these variables were assumed according to the depiction of Mishra and Koehler (2006). Given the dearth of empirical PCK studies that examine this aspect, an alternative structural equation model with PCK, TCK, and TPK specified as exogenous variables could be examined for comparison of model fit. This would shed light on the epistemological nature of TPACK. A final area of study is to conduct longitudinal studies of teachers from pre-service to in-service. This will provide insights about the development of these pathways across time. It can be used to assess if strategies used in pre-service teacher education courses and teacher professional development programs are effective for facilitating teachers' TPACK development. It can also be used to develop instructional models for facilitating the content-centered pathway of TPACK formation.

Conclusion

This study has articulated some possible TPACK pathways perceived by practicing teachers. These pathways and the possible existence of other pathways are important areas for future research. Such kinds of knowledge can provide sound theoretical foundation for the continuing development of teachers' ICT integration expertise.

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