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Modeling pre-service teachers' technological pedagogical content knowledge (TPACK) perceptions: The influence of demographic factors and TPACK constructs

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The TPACK framework comprises seven constructs that describe teachers' technology integration expertise. These TPACK constructs address a theoretical void in the area of educational technology and have been widely adopted by colleges of education for the planning of teacher technology integration courses. This study first describes Singapore pre-service teachers' TPACK perceptions with respect to these seven constructs. Using a stepwise regression model, this study then analyzes the relative impact of age, gender, and TPACK constructs on the TPACK perceptions of pre-service teachers. It was found that TPACK constructs had significant impact on pre-service teachers' TPACK perceptions whereas the demographic variables of age and gender were not signficant. Among the TPACK constructs, only technological pedagogical knowledge and technological content knowledge were found to be significant predictors of TPACK. The implications of these findings on the design of pre-service teacher ICT courses are discussed.

Keywords: Technological pedagogical content knowledge, TPACK, teacher ICT education.

Introduction

Technological Pedagogical Content Knowledge (TPACK) is a theoretical construct formulated by Mishra and Koehler (2006) to characterize teachers' expertise with respect to the integration of information and communication tools (ICT) into teaching and learning activities. It is anchored upon the notion that teachers need to combine the three knowledge sources of technological knowledge, pedagogical knowledge and content knowledge when integrating ICT. In doing so, they develop four other kinds of ICT integration knowledge namely technological pedagogical knowledge, technological content knowledge, pedagogical content knowledge, and technological pedagogical content knowledge. The unique contribution of Mishra and Koehler's TPACK framework is the specification of these seven TPACK constructs which addressed the lack of theoretical specification for the teachers' body of ICT integration expertise in the field of educational technology (Koehler & Mishra, 2008).

This framework has since been widely adopted for the planning of teacher ICT education (Cox & Graham, 2009; Thompson & Mishra, 2007) and used as a theoretical underpinning for the development of surveys to measure teachers' TPACK perceptions. This is because TPACK surveys assess the various categories of teacher ICT integration knowledge which has not been addressed in established technology integration surveys as these tend to focus on teacher attitudes towards technology adoption (Christensen & Knezek, 2002). TPACK surveys serve to inform teacher educators about pre-service teachers' information gaps with respect to ICT integration. Quantitative results from TPACK surveys can also be used to establish statistical models that explain the factors affecting pre-service teachers' TPACK. Examples of such factors would be age and gender, which have traditionally influenced teachers' attitudes towards computer use (e.g. Markauskaite, 2006; Teo, 2008). There is also evidence that teachers' overall TPACK perceptions are influenced by TPACK constructs such as pedagogical knowledge and technological pedagogical knowledge (Chai, Koh, & Tsai, 2010; Chai, Koh, Tsai, & Tan, 2011). By understanding the relative influences of these different factors, teacher educators can better support ICT program design and evaluation. However, such kinds of studies have not often been carried out as many TPACK surveys are still in the process of construct validation (see Graham et al., 2009; Schmidt et al., 2009).

This study therefore seeks to first describe the TPACK perceptions of Singapore pre-service teachers through a TPACK for Meaningful Learning survey that was validated in a prior study by Chai, Koh, and Tsai (in-press). It then describes the factors affecting pre-service teachers' TPACK through a regression model that incorporates age, gender, and TPACK constructs as independent variables. Implications for the design of teacher ICT programs are then discussed.

Literature review and research questions

The TPACK framework

Shulman (1986) posited that teachers possess a special form of expertise for teaching that is derived from the combination of both their content knowledge and pedagogical knoweldge. He termed this unique form of teacher know-how as pedagogical content knowledge (PCK), describing it as teachers' expertise for teaching particular subject matter. Mishra and Koehler (2006) extended Shulman's work by adding technological knowledge to content knowledge and pedagogical knowledge, proposing that the term technological pedagogical content knowledge be similarly used to represent teachers' expertise for technology integration, that is, to characterize how they make "intelligent pedagogical uses of technology" (Koehler, Mishra, & Yahya, 2007, p. 741). Technological pedagogical content knowledge was initially given the acronymn of TPCK which was later changed to TPACK to emphasize the integrated use of Technology, Pedagogy And Content Knowledge for effective technology integration (Thompson & Mishra, 2007). The TPACK framework, as depicted by Mishra and Koeher (2006) is shown in Figure 1.

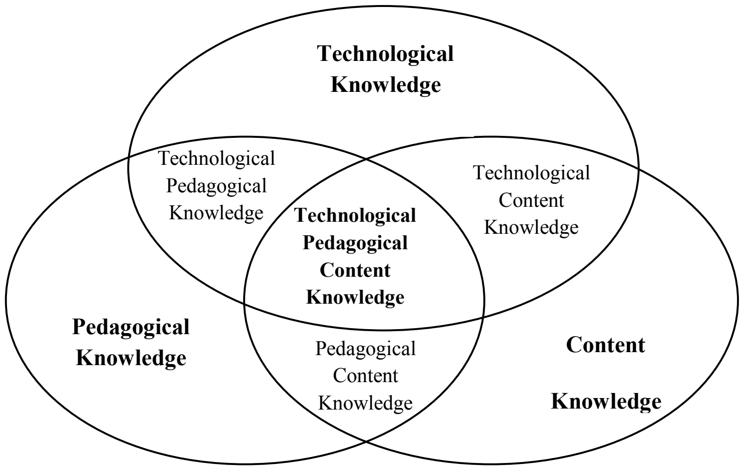

Figure 1: The TPACK Framework, as depicted by Mishra and Koehler (2006), pg 1025

The seven TPACK constructs are defined as follows:

35. Technological Knowledge (TK) – knowledge of technology tools.
36. Pedagogical Knowledge (PK) – knowledge of teaching methods.
37. Content Knowledge (CK) – knowledge of subject matter.
38. Technological Pedagogical Knowledge (TPK) – knowledge of using technology to implement teaching methods.
39. Technological Content Knowledge (TCK) – knowledge of subject matter representation with technology.
40. Pedagogical Content Knowledge (PCK) – knowledge of teaching methods with respect to subject matter content.
41. Technological Pedagogical Content Knowledge (TPACK) - knowledge of using technology to implement constructivist teaching methods for different types of subject matter content.

Factors affecting pre-service teachers' TPACK

Demographic factors

A factor that could influence teachers' TPACK perceptions is gender. Teacher attitude studies found that male teachers tend to be more confident of their ability to use computers than female teachers (Markauskaite, 2006; Tsai, 2008). The results of a large sample TPACK survey that was administered on 1,185 Singapore pre-service teachers by Koh, Chai, and Tsai (2010) were somewhat similar. This study found that male teachers rated themselves more highly on TK and CK. The effects on TPACK could not be assessed in the study because an exploratory factor analysis could not isolate the TPACK survey items as a factor.

Teo (2008) found that Singapore pre-service teachers' attitude for computer use were influenced by their age. This corresponded with studies of in-service teachers that have mostly found older teachers to be less confident with using computers (Yaghi, 2001). Similarly, Lee and Tsai (2010) studied Taiwanese in-service teachers' TPACK perceptions for using web-based technology and found the older teachers to be less confident. However, for pre-service teachers, Koh et al. (2010) found the negative correlation between age and TK to be weak. The authors conjectured that age may be a factor more pertinent for in-service teachers, which needs to be further explored.

The influence of TPACK constructs – TK, PK, CK, TPK, TCK, and PCK

There is some evidence that TPACK constructs could impact teachers' TPACK perceptions. Chai et al. (2010) found strong correlations between TK, PK, CK and TPACK. When examining the structural relations among TPACK constructs, Chai et al. (2011) found that PK and TPK had the strongest effects on pre-service teachers' TPACK. Nevertheless, these studies did not examine the influence of TPACK constructs in tandem with demographic variables. Furthermore, not all the seven TPACK constructs were included in these studies. For example, Chai et al. (2010) did not consider the intermediary constructs of TPK, TCK, and PCK while the TPACK survey used in Chai et al. (2011) could only establish construct validation all the seven TPACK constructs. Therefore, the structural model in the study did not include the construct of TCK.

Finding a suitable TPACK survey for statistical modeling

From the above review, it can be seen that a challenge faced when attempting to model TPACK relationships is the lack of TPACK surveys that have construct validity for the seven TPACK constructs as theorized by Mishra and Koehler (2006). The earliest general TPACK survey was Schmidt et al's (2009) Survey of Preservice Teachers' Knowledge of Teaching and Technology that was administered on 124 pre-service teachers in the USA. A limitation of this study is that construct validation through exploratory or confirmatory factor analysis was not reported. Besides Schmidt et al.'s TPACK survey, Graham et al. (2009) also developed a content-specific survey for TPACK in Science survey that is based on McCory's (2008) eight pedagogical uses of ICT for Science teaching. However, this survey was pilot-tested with 15 teachers in the USA, a sample size that was inadequate for statistical construct validation. On the other hand, several studies reported difficulties with TPACK construct validation. For example, Archambault and Barnett's (2010) exploratory factor analysis of a TPACK survey for online teaching found that the items for CK, PK and PCK loaded as one factor whereas the items for TPK, TCK, and TPCK loaded as another. These findings were similar to Koh et al. (2010). Lee and Tsai (2010) were able to isolate the factors of TK, TPK, TCK and TPACK, but found that the PK and PCK items had loaded as a factor. Some forms of statistical modeling through regression analysis or structural equation modeling have been carried out by Chai et al. (2010, 2011). As described above, the TPACK framework theorized by Mishra and Koehler (2006) could only be modeled partially because of challenges faced with construct validation.

A recent work by the Chai, Koh, and Tsai (in-press) reported that better construct validation for TPACK surveys could be obtained in two ways; firstly, by focusing the PK and TPK items on specific pedagogies and secondly, adding a stem "Without using technology…" into the PCK items to differentiate the applications of content knowledge within and outside a technological context. When these modifications were incorporated into Schmidt et al's (2009) survey, the seven TPACK constructs were successfully extracted through exploratory factor analysis of survey results from 214 Singapore pre-service teachers (Chai et al., in-press). Such kinds of validated TPACK surveys can address the issues associated with the comprehensive modeling of TPACK relationships as described above. These surveys can therefore be used in this study to facilitate the statistical modeling of factors affecting teachers' TPACK.

Research questions

Given the above review, this study seeks to use a validated TPACK survey to facilitate the development of a statistical model that incorporates the seven TPACK constructs theorized by Mishra and Koehler (2006). This statistical model also seeks to incorporate pertinent demographic factors such as age and gender so that a comprehensive model of pre-service teachers' TPACK perceptions could be examined. The following research question will be addressed in this study:

What is the impact of demographic factors (age and gender) and TPACK constructs (TK, PK, CK, TPK, TCK, and PCK) on Singapore pre-service teachers' TPACK perceptions?

Methodology

Study participants

The study participants were 350 pre-service Singapore teachers who were attending a compulsory ICT module during August semester of 2010. These teachers were also in the first semester of their teacher training programme. The TPACK for Meaningful Learning Survey used by Chai et al. (in-press) was administered to these pre-service teachers at the beginning of the semester through a web-based URL that was sent through their course tutors. Participation in the survey was voluntary and was not associated with any course activity or assignments. A total of 214 teachers responded to the survey, constituting a response rate of 61.14%. The survey respondents were largely female teachers (n=149, 69.6%). The mean age of the study participants were 26.61 years (SD=5.00).

TPACK Survey

The TPACK for Meaningful Learning Survey validated in Chai et al. (in press) for pre-service teachers was used in this study. This 30-item survey was adapted from Schmidt et al.'s (2009) survey that was based on the seven TPACK constructs theorized by Mishra and Koehler (2006). Chai et al. (in press) used Jonassen, Howland, Mara, and Crismond's (2008) five dimensions of meaningful learning with ICT as a theoretical basis for designing the PK and TPK items of this survey. These dimensions are based on the use of ICT to support constructivist learning, and purport that meaningful learning occurs through learning activities that support students to learn through authentic problems, intentionality of learning goals, knowledge construction, active learning, and collaborative learning. These dimensions support the notions of student self-directedness and collaborative learning, which are also the focus of Singapore's third IT Masterplan for education (Teo & Ting, 2009), which are relevant for the target group of study. In Singapore, pre-service teachers are trained to teach at least two subjects which are known as "Curriculum Subject 1" and "Curriculum Subject 2". Therefore, minor changes were made to Schmidt et al.'s items for CK, PCK, TCK, and TPACK to incorporate these two subject areas. Each item on the survey was rated on 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, and 7 - Strongly Agree.

Data analysis

The research question was analyzed by first checking for the internal reliability of the survey and its constructs through the computation of the Cronbach alpha. After establishing internal reliability, the construct validity of the survey instrument was examined through exploratory factor analysis. The possible relationships between TPACK constructs and age were then examined through Pearson correlation whereas the possible relationship between gender and TPACK constructs were examined through independent sample t-tests. After establishing the relevance of these variables, stepwise multiple regression analysis was carried out by specifying the TPACK constructs and the pertinent demographic factors as independent variables and TPACK as the dependent variable.

Results

Internal reliability and construct validity of survey

A Cronbach alpha of 0.95 was obtained for the TPACK for Meaningful Learning scale, indicating adequate internal reliability. Exploratory factor analysis yielded eight factors and explained 71.47% of the total variance. The CK items were split between Curriculum Subject 1 and Curriculum Subject 2. These factors were re-named as CK-1 and CK-2 (See Table 1). This is to be expected since these Singapore pre-service teachers were being prepared to teach two curriculum subjects, and may have perceived their CK for these two subjects as being distinct. A similar factor structure was also obtained by Chai et al. (in press) with Singapore pre-service teachers. All the other six TPACK constructs were derived as distinct factors with factor loadings of at least 0.50 (e.g. Fish & Dane, 2000). Two items, TCK2 and TCK4, were cross-loaded with TPACK items and removed from the analysis as per the guidelines of Bentler (1990). Adequate internal reliability was derived on all the eight factors derived from the exploratory factor analysis as their Cronbach alphas were all above 0.80: TK (α=0.87), PK (α=0.93), CK-1 (α=0.84), CK-2 (α=0.86), PCK (α=0.87), TPK (α=0.92), TCK (α=0.91), and TPACK (α=0.94). Therefore, sufficient internal reliability and construct validity for the survey was established. A regression model incorporating all the TPACK constructs postulated by Mishra and Koehler (2006) could therefore be examined with these survey results.

Pre-service teachers' TPACK perceptions

From Table 1, it can be seen that the pre-service teachers rated themselves above five on a seven-point scale for TK, PK, and CK-1, indicating a fairly high level of confidence for these TPACK areas. In terms of CK, they were less confident about their CK-2 (M=4.83) which is to be expected as Curriculum Subject 1 was their main area of concentration for teaching. Notably, their ratings for the intermediate forms of TPACK knowledge, that is, PCK, TCK, and TPK, were all below five. Among these, the pre-service teachers were most confident about TPK (M=4.72) but least confident about TCK (M=4.41). On the other hand, their TPACK perceptions were quite equitable with their perceptions of TPK (M=4.76).

Table 1: Factor loadings from exploratory factor analysis

Items	Factor Loadings
Factor 1 – Technological Knowledge (TK, M=5.10, SD=0.91) TK1 - I have the technical skills to use computers effectively.	.80
TK2 - I can learn technology easily.	.84
TK3 - I know how to solve my own technical problems when using technology.	.73
TK4 - I keep up with important new technologies	.62
TK5 - I am able to create web pages.	.67
TK6 - I am able to use social media (e.g. Blog, Wiki, Facebook).	.64
Factor 2 – Pedagogical Knowledge (PK, M=5.01, SD=0.86) PK1 - I am able to stretch my students' thinking by creating challenging tasks for them.	.65
PK2 - I am able to guide my students to adopt appropriate learning strategies.	.73
PK3 - I am able to help my students to monitor their own learning.	.79
PK4 - I am able to help my students to reflect on their learning strategies.	.82
PK5 - I am able to plan group activities for my students.	.70
PK6 - I am able to guide my students to discuss effectively during group work.	.74
Factor 3 – Content Knowledge-1 (CK-1, M=5.13, SD=1.09) CK-11 - I have sufficient knowledge about my first teaching subject (CS1)	.80
CK-12 - I can think about the content of my first teaching subject (CS1) like a subject matter expert.	.74
CK-13 - I am able to develop deeper understanding about the content of my first teaching subject (CS1).	.54
Factor 4 – Content Knowledge-2 (CK-2, M=4.83, SD=1.06) CK-21 - I have sufficient knowledge about my first teaching subject (CS1)	.79
CK-22 - I can think about the content of my first teaching subject (CS1) like a subject matter expert.	.87
CK-23 - I am able to develop deeper understanding about the content of my first teaching subject (CS1).	.58
Factor 5 – Technological Pedagogical Knowledge (TPK, M=4.72, SD=1.01) TPK1- I am able to use technology to introduce my students to real world scenarios.	.50
TPK2 - I am able to facilitate my students to use technology to find more information on their own.	.62
TPK3 - I am able to facilitate my students to use technology to plan and monitor their own learning.	.60
TPK4 - I am able to facilitate my students to use technology to construct different forms of knowledge representation.	.57
Factor 6 – Technological Content Knowledge (TCK, M=4.41, SD=1.13) TCK1- I know about the technologies that I have to use for the research of content of first teaching subject (CS1).	.68
TCK2- I can use appropriate technologies (e.g. multimedia resources, simulation) to represent the content of my first teaching subject (CS1).	Dropped
TCK3 - I know about the technologies that I have to use for the research of content of my second teaching subject (CS2).	.72
TCK4 - I can use appropriate technologies (e.g. multimedia resources, simulation) to represent the content of my second teaching subject (CS2).	Dropped
Factor 7 – Pedagogical Content Knowledge (PCK, M=4.62, SD=1.18) PCK1 - Without using technology, I know how to select effective teaching approaches to guide student thinking and learning in my first teaching subject (CS1).	.56
PCK2 - Without using technology, I can help my students to understand the content knowledge of my first teaching subject (CS1) through various ways.	.69
PCK3 - Without using technology, I know how to select effective teaching approaches to guide student thinking and learning in my second teaching subject (CS2).	.85
PCK4 - Without using technology, I can help my students to understand the content knowledge of second teaching subject (CS2) through various ways.	.89
Factor 8 – Technological Pedagogical Content Knowledge (TPACK, M=4.76, SD=1.01) TPACK1- I can teach lessons that appropriately combine my CS1, technologies and teaching approaches.	.75
TPACK2 - I can select technologies to use in my classroom that enhance what I teach, how I teach and what students learn.	.77
TPACK3 - I can use strategies that combine content, technologies and teaching approaches that I learned about in my coursework in my classroom.	.82
TPACK4 - I can provide leadership in helping others to coordinate the use of content, technologies and teaching approaches at my school and/or district.	.80
TPACK5 - I can provide leadership in helping others to coordinate the use of content, technologies and teaching approaches at my school and/or district.	.70

Relationships between TPACK perceptions and age

The inter-correlations between age and TPACK constructs were examined to derive a preliminary understanding of their possible relationships before the implementation of regression analysis (see Table 2). Age was found to have significant but small negative correlations with PK, TK, and TPK. CK-1 and CK-2 had positive moderate correlation with each other. CK-1 had positive correlations with PK, TCK, PCK, and TPACK while CK-2 had similar correlations with all these constructs except for PCK. All the TPACK constructs were positively correlated with each other. Only the correlation between TK and PCK was not significant. Strong positive correlations were found between TPK, TCK, and TPACK as these were above the 0.60 recommended by Fraenkel and Wallen (2003). TK also had moderate positive correlations with TPK, TCK, and TPACK that were close to 0.60. The other correlations between TPACK constructs were comparatively weaker. These results suggest the possibility that the relationships between TPACK constructs could have stronger influences on teachers' TPACK perceptions as compared to age during the regression analysis.

Table 2 – Correlations between Age and TPACK constructs

	Age	CK-1	CK-2	PK	TK	TPK	TCK	PCK	TPACK
Age	1	.02	-.07	-.15*	-.18*	-.16*	-.07	-.02	-.09
CK-1		1	.53**	.54**	.18**	.26**	.47**	.39**	.39**
CK-2			1	.41**	.23**	.19**	.39**	.15*	.34**
PK				1	.28**	.57**	.53**	.34**	.55**
TK					1	.53**	.38**	.06	.44**
TPK						1	.53**	.31**	.68**
TCK							1	.29**	.65**
PCK								1	.26**
TPACK									1

* p< 0.05 ** p<0.01

TPACK perceptions by gender

No significant gender differences were found across all the eight TPACK factors derived through exploratory factor analysis. Therefore, the variable of gender was not considered in the subsequent regression analysis.

Regression model

Stepwise regression of the models was statistically significant. Between models 2 and 3, the addition of CK-2 increased the R^2 values marginally from 0.58 to 0.59. Therefore, it can be seen that among the independent variables, pre-service teachers' TPACK perceptions were primarily influenced by TPK and TCK. These two variables explained 58% of the total model variance whereas age and the other independent variables were not significant. Between TPK and TCK, TPK had a stronger influence in pre-service teachers' TPACK perceptions, as indicated by the beta values for Models 2 and 3.

Table 3 – Stepwise regression models

Model	Predictors	B	Std. Error	Beta	Significance	R^2
1	(Constant)	1.54	.24		***	0.45
	TPK	.68	.05	.68	***	
2	(Constant)	.94	.23			0.58
	TPK	.47	.05	.47	***	
	TCK	.36	.05	.40	***	
3	(Constant)	.60	.27		*	0.59
	TPK	.48	.05	.47	***	
	TCK	.32	.05	.36	***	
	CK-2	.10	.05	.11	***	

*p<0.05   *** p<0.0001

Discussion

This study attempted to examine how age, gender, and the TPACK constructs of TK, PK, CK, TPK, TCK, and PCK affected pre-service teachers' perceptions of TPACK through stepwise multiple regression. Gender was dropped from the regression model as a preliminary analysis with independent sample t-tests found no significant differences between male and female teachers with respect to the TPACK constructs. The subsequent regression analysis found TPK and TCK to be predominantly the two significant predictors of TPACK. The following are possible explanations for these results:

Gender differences

In published studies, gender differences between teachers were apparent when comparisons were made of their confidence for using computers (see Markauskaite 2006). In this study, however, there were no significant differences between pre-service teachers' TPACK by gender. A reason for these findings could be that TPACK assesses teachers' perceptions of different ICT integration expertise. Teachers' attitudes with respect to computer use could impact their TPACK perceptions but these are not necessarily similar. Therefore, the gender differences associated with teachers' computer attitudes may not be totally applicable when studying teachers' TPACK perceptions. In a large scale TPACK study of Singapore pre-service teachers, Koh et al. (2010) also found the significant gender differences associated with TPACK constructs to have small effect sizes. North and Noyes (2002) suggested that the prevalence of computers in schools could provide both males and females with equal opportunities for computer use, thereby equalizing their perceived differences with respect to computer use. Therefore, the impact of gender differences on TPACK may become less significant with future cohorts of pre-service teachers.

Age

The results of this study were consistent with Koh et al. (2010) who found the correlations between age and TPACK constructs to be almost negligible. Age also did not emerge as a significant predictor in the regression model. One explanation for these findings could be that TPACK describes teachers' pedagogical expertise with respect to technology integration. The pre-service teachers in this study were all undertaking their first semester of teacher education studies during the semester of data collection. Regardless of their age, these pre-service teachers have yet to attend sufficient methods courses and were also inexperienced in terms of actual teaching practices. In comparison, TPACK studies of in-service teachers found larger negative correlations between teachers' age and TPACK perceptions (e.g. Lee & Tsai, 2010). As compared to pre-service teachers, the teaching experiences of in-service teachers differ according to their school environment. Across time, this could result in them having different ICT integration experiences, which may influence their TPACK perceptions. Therefore, age may not be a factor that significantly impacts pre-service teachers' TPACK perceptions, which is also a conclusion of Koh et al. (2010).

TPACK constructs

The study results show that the TPACK perceptions of pre-service teachers tend to be influenced more strongly by TPACK constructs rather than the demographic variables of age and gender. An earlier study by Chai et al. (2010) found that TK, PK, and CK were all significant predictors of TPACK, with PK being the most influential. In this regression model, when the intermediate constructs of TPK, TCK, and PCK were considered, only TPK and TCK emerged as the significant predictors of pre-service teachers' TPACK. Mishra and Koehler (2006) premised that teachers' ICT integration expertise was to be found in the intermediate constructs of TPK, TCK, PCK, and TPACK. This is because these constructs embody the different connections that teachers can formulate by combining TK, PK, and CK. The results of this study support this postulation as they suggest that the effects of the intermediate constructs to be more important than those of TK, PK, and CK alone.

Mishra and Koehler (2006) postulated that teachers' ICT integration knowledge was embodied in seven constructs. In this study, however, the constructs of TK, PK, CK, and PCK did not have any significant influence on TPACK. One explanation for these findings could be the pre-service teachers' relative inexperience with the school curriculum as they have yet to be fully exposed to the methods courses where the PCK associated with the teaching of their curriculum subjects are being covered. Therefore, they have yet to appreciate this as a body of knowledge to be considered when integrating ICT. On the other hand, emergence of TPK and TCK as significant predictors of TPACK showed the pre-service teachers recognizing the need to consider technology in tandem with pedagogy and content during ICT integration. However, at this point of their teacher training, they may not have the sufficient exposure to teaching practices to make tight connections between the TPACK constructs. This premise can be supported by the findings of Chai et al. (2010) who constructed regression models analyzing how TPACK constructs predicted pre-service teachers' TPACK perceptions before and after they attended an ICT course. The post-course model showed higher R^2 values, indicating that the pre-service teachers were better able to make linkages between the TPACK constructs and TPACK after ICT training. Therefore, the pre-service teachers in this study may need to gain further knowledge through ICT integration and methods courses before they could be able to appreciate the contributions of TK, PK, CK, and PCK.

The study results are somewhat consistent with Chai et al.'s (2011) structural equation analysis which found TPK to have the largest influence on TPACK among TK, PK, and CK. Chai et al. (2011) were not able to incorporate TCK into their structural equation model because of construct validation issues but this study contributes further insights, showing that pre-service teachers did not perceive TCK to be as important as TPK for shaping their TPACK. In a qualitative study of how pre-service teachers approached the learning of new ICT tools, Koh and Divaharan (2011) also found that they focused mostly on issues associated with TPK and were less able to consider content integration. One possible explanation could be that these pre-service teachers were unlike in-service teachers who need to grapple with curriculum requirements and student difficulties with content representations on a daily basis. The importance of content issues may not feature as prominently as the pedagogical uses of ICT at this point of their teacher training.

Implications for pre-service teacher ICT development

The results of this study suggest the following implications for the design of pre-service teacher ICT courses:

- Age and gender differences may not be a priority for pre-service teachers – Pre-service teachers' TPACK perceptions did not differ by gender. Neither did age impact their TPACK perceptions. Therefore, curriculum differentiation specifically for age and gender differences may be more pertinent for in-service rather than pre-service teachers. Nevertheless, the influences of age and gender need to be further monitored to determine their relevance.
- Focus on TPK and TCK – Pre-service teachers largely placed importance on the impact of TPK and TCK on their TPACK. In ICT courses, conscious modeling of the pedagogical uses of technology and content representations with technology should be emphasized to strengthen the contributions of these elements to TPACK.
- Help pre-service teachers foster the "missing" TPACK linkages – According to Mishra and Koehler (2006), the complete body of ICT integration expertise comprises of seven constructs. This study suggests that pre-service teachers have yet to appreciate the impact that TK, PK, CK, and PCK has on TPACK. ICT course need to provide opportunities for the creation of these linkages. An approach to be considered would be Koh and Divaharan's (2011) TPACK-Developing Instructional Model which proposes the integrated use of tutor modeling, vicarious observation, self-paced exploration, critique of ICT integrated lessons, and hands-on ICT integration design experiences to develop these aspects of pre-service teachers' TPACK. An instructional system that supports pre-service teachers to engage in design activities helps them to develop TPACK (Koehler et al., 2007). This is because such a system provides them with opportunities to connect the PK, CK, and PCK learnt in methods courses to their ICT courses.

Future directions

Several areas of future research can be considered to better understand the TPACK perceptions of pre-service teachers. Firstly, this study needs to be replicated with more cohorts of teachers, both within and outside Singapore. The current sample of teachers is not representative of pre-service teachers in general and further validation of the regression model derived in this study is still needed, especially to determine if age and gender effects are pertinent. Secondly, longitudinal studies are needed to track the TPACK development of cohorts of pre-service teachers across time. This is because this study was conducted with pre-service teachers who were doing their first semester of teacher education. The regression model therefore captured the factors affecting the pre-service teachers' TPACK perceptions as they entered teacher education but not in other stages of their teacher education journey. Thirdly, similar studies with in-service teachers are needed. A comparison of the regression models for pre-service and in-service teachers could better highlight the different knowledge gaps and development needs of each group in this study. This aspect was not covered in this study as it focused on pre-service teachers. Finally, statistical techniques such as structural equation modeling can be applied to better understand the role of TPK, TCK, and PCK as moderating variables of TPACK. In this study, the use of multiple linear regression analysis only allowed the researchers to understand the linear relationships between age, the TPACK constructs, and TPACK. Yet, the correlation analysis in Table 2 showed significant correlations among the TPACK constructs which may not have been sufficiently captured in the regression model of this study. Structural equation modeling allows the simultaneous analysis of moderating and intervening variables (Hair, Black, Babin, Anderson, & Tatham, 2010) which may better capture the dynamics of these relationships. This may also enhance the R^2 of the current regression model through a more sophisticated mapping of TPACK framework relationships.

Conclusion

This study attempted to develop a comprehensive regression model of pre-service teachers' TPACK perceptions that examines the impact of demographic variables and the TPACK constructs. Such kinds of modeling provide teacher educators with insights about the relative impacts of factors affecting teachers' perceptions of ICT integration expertise. More comprehensive statistical models of teachers' TPACK perceptions need to be developed to better understand the complex phenomenon of teacher ICT integration knowledge development. This is an important area warranting further consideration in future research.

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