Computers & Education 78 (2014) 20–29

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

TPACK-in-Action: Unpacking the contextual influences of teachers' construction of technological pedagogical content knowledge (TPACK)

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ARTICLE INFO

Article history:
Received 27 February 2014
Received in revised form
28 April 2014
Accepted 30 April 2014
Available online 10 May 2014

Keywords:
TPACK
ICT
Contextual influences of ICT integration

ABSTRACT

In school-based environments, teachers need to consider contextual factors such as the availability of technology and school policies as they apply TPACK to address instructional problems. However, qualitative TPACK studies tend to exemplify the seven TPACK constructs whereas its contextual influences have not been articulated in detail. This study describes TPACK-in-Action, a framework that can be used to visualize the interplay between TPACK and four contextual factors (Physical/Technological, Cultural/Institutional, Interpersonal, and Intrapersonal) that influence teachers' design of ICT lessons. This was used to analyze the lesson design discussions of 24 school teachers from a Singapore primary school who were teaching the levels of Primary 1, 4, and 5. Content analysis of the transcribed audio-recordings of teachers' discussions and chi-square analysis of coding frequencies found that when the logistics of lesson implementation as per the Cultural/Institutional category dominated group discussions, it curtailed the emergence of TPACK. When Intrapersonal factors such as beliefs of teaching and students were articulated and its pedagogical implications considered, it facilitated TPACK. Furthermore, the team facilitated by an experienced educational technologist also demonstrated higher occurrences of TPACK. These results suggest that for ICT innovation to be effective, the composition of design teams need to be carefully considered. Teachers also need to develop competencies to facilitate and discourse about design such that contextual concerns can be turned into opportunities to support pedagogical improvement.

1. Introduction

Technological pedagogical content knowledge (TPACK) has emerged as a framework to describe teachers' knowledge for the integration of information and communications technology (ICT). It was extended from Shulman's (1986) effort to articulate teachers' unique professional knowledge. Shulman theorized that the interaction of pedagogical knowledge (PK) and content knowledge (CK) gave rise to pedagogical content knowledge (PCK). Given the importance of technology in the 21st century workplace, researchers (e.g. Angeli & Valanides, 2005; Mishra & Koehler, 2006) proposed to include technological knowledge (TK) as part of teachers' knowledge. Just as the interaction of PK and CK gave rise to PCK, Mishra and Koehler (2006) proposed that the inclusion of TK derived other forms of knowledge such as technological content knowledge (TCK), technological pedagogical knowledge (TPK), and technological pedagogical content knowledge (TPACK). Therefore, the three basic forms of teacher knowledge (TK, PK, and CK) as well as the knowledge arising from the interactions among them constituted the seven constructs of the TPACK framework theorized by Mishra and Koehler (2006). This also described teachers' knowledge for designing ICT-integrated lessons. Quantitative studies using structural equation modeling have found that six aspects of the TPACK framework, namely, TK, CK, PK, TCK, PCK, and TPK are significant contributors to teachers' self-reported efficacy for TPACK (Chai, Ng, Li, Hong, & Koh, 2013; Koh, Chai, & Tsai, 2013). Qualitative studies also supported these findings (Angeli & Valanides,

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http://dx.doi.org/10.1016/j.compedu.2014.04.022
0360-1315/

2013; Koehler, Mishra, & Yahya, 2007). Teachers' existing knowledge base therefore acts as the epistemic resources for their construction of TPACK.

Teachers' knowledge is, however, not the only factor influencing their TPACK construction. Teachers' perceptions of their work contexts as well as their personal beliefs are influential factors as well (Chai, Koh, & Tsai, 2013; Mishra & Koehler, 2006; Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013). Earlier literature on ICT integration has identified and discussed these contextual factors and teachers' beliefs as either enablers or barriers for ICT integration. Ertmer (1999) highlighted that the first-order barriers of ICT integration may include access to equipment, time, technical support, as well as ICT training for teachers. When any of these factors are lacking, the facilitating conditions for ICT integration become less desirable, which then results in teachers being less willing to use ICT. Ertmer (1999, 2005) further pointed out second-order barriers, which are teachers' intra-mental variables such as their epistemological or pedagogical beliefs that may amplify or reduce the strength of the first-order barriers. These second-order barriers can constitute a more formidable challenge than first-order barriers.

Contextual factors can influence teachers' ICT practices. In fact, TPACK studies have characterized it as a dynamic form of knowledge that is influenced by teachers' context of practice (Angeli & Valanides, 2009; Porras-Hernández & Salinas-Amescua, 2013). Despite this, the influence of contextual variables on teachers' conceptions of TPACK has not been thoroughly examined; which is a gap observed in TPACK literature (Chai, Koh, et al., 2013; Porras-Hernández & Salinas-Amescua, 2013; Voogt et al., 2013). Case studies of teachers and higher education instructors tend to characterize the seven constructs of TPACK (Anderson, Barham, & Northcote, 2013; Benson & Ward, 2013). How teachers' TPACK conceptions are being influenced by contextual factors such as access to ICT resources and their personal beliefs about ICT integration were briefly alluded to but not analyzed thoroughly in these studies. Understanding this aspect of TPACK is critical for examining how teachers maneuver TPACK in practice. It can also enhance the framework's efficacy for ICT lesson design which has been identified as one of its weakness (Cox & Graham, 2009).

To address this gap, this study first articulates the theoretical justification for a contextualized conception of TPACK which is termed as TPACK-in-Action (Chai, Koh, et al., 2013; Chai, Ng, et al., 2013; Koh, Chai, Tay, & Yuen, 2013). It then applies this framework to analyze how various contextual factors have influenced the pedagogical decisions of three groups of school teachers teaching different levels within an elementary school in Singapore. As part of their routine, teachers teaching a similar level in the school held scheduled meetings for lesson design during each semester. In this study, these meetings were audio-recorded and coded qualitatively with the dimensions of the TPACK-in-Action framework and triangulated with chi-square analysis. Implications for the facilitation of school-based ICT integration lesson design teams are then discussed.

2. Theoretical development

It was proposed that TPACK went beyond a factual understanding of strategies for ICT integration (Bowers & Stephens, 2011) but is contextually situated (Koehler & Mishra, 2008; Koehler et al., 2007). Yet, this aspect has not been fully examined in current TPACK studies (Doering, Veletsianos, Scharber, & Miller, 2009). Teachers' TPACK with respect to different subject areas and pedagogies was measured with survey instruments assessing their perceptions of the seven TPACK constructs (e.g. Archambault & Crippen, 2009; Chai, Koh, & Tsai, 2011; Graham et al., 2009; Lee & Tsai, 2010). These quantitative measures can be used across contexts to measure and compare teachers' perceived TPACK confidence but are not as effective as qualitative studies for capturing teachers' applications of TPACK within their contextual nuances (Koh, Chai, & Tsai, 2010). Some qualitative studies documenting teachers' TPACK development as they learn to use new technological tools have alluded to the influences of factors such as teachers' beliefs and the school environment (e.g. Niess, 2011; Özgün-Koca, Meagher, & Edwards, 2009/2010). These findings correspond with Angeli and Valanides (2009) who viewed TPACK as having a transformative nature where teachers' interpretation of contextual demands can shape how they draw upon and integrate their different knowledge sources. Therefore, the contextual influences of TPACK need to be given deeper consideration.

Porras-Hernández and Salinas-Amescua (2013) proposed that TPACK can be influenced by three contextual levels: macro, mezzo and micro. The macro level corresponded to the sociopolitical and technological environment that teachers were facing. For example, rapid technological advancement could trigger educational policy changes that demand teachers to be integrating ICT. The mezzo level corresponded to the school context where school culture for ICT use could be shaped by factors such as school leadership. The micro level referred to the classroom where factors such as students' profiles could shape how teachers use ICT. The interplay between context and teachers' TPACK could be complex. Zhao, Pugh, Sheldon, and Byers' (2002) study showed the need to pay attention to teachers' beliefs as an intra-mental aspect influencing their innovation of ICT-based teaching. These authors concluded that for a technological innovation to become part of the classroom ecology, that is, for the innovation to be adopted and routinized, it is important to consider the interrelationships between the innovation, the school context, and the innovator. Highly innovative technology had to be implemented by capable innovators with strong beliefs in innovation through ICT to navigate the complex interpersonal and organizational environments that may not support its adoption. A clearer unpacking of the various contextual dimensions, as well as how each could influence teachers' conception of TPACK can help teachers to better manage the complex process of ICT integration. Given the dearth of studies that examined contextual factors with respect to TPACK, both TPACK studies and those describing factors influencing teachers' decisions for ICT integration will be examined in the following sections to draw the possible connections.

2.1. TPACK and dimensions of context

2.1.1. Teachers' beliefs

Teachers' beliefs refer to the views that teachers hold about aspects such as teaching, learning, pedagogy, students, technology, as well as the interaction of these aspects within the myriad of pedagogical situations they experience in classrooms. Beliefs are by nature not rigorously verified but they can function like knowledge. For example, teachers can hold beliefs about students being not ready to perform certain tasks which could stop them from adopting certain strategies. Teachers' beliefs of technology and pedagogy were found to influence their technology adoption (Hew & Brush, 2007; Inan & Lowther, 2010). In quantitative studies, Hermans, Tondeur, van Braak, and Valcke (2008) found that primary school teachers who had stronger beliefs about constructivist, student-centered instruction tend to have higher classroom use of computers whereas Sang, Valcke, van Braak, Tondeur, and Zhu (2011) found that constructivist beliefs positively

contributed to teachers' attitudes and motivation toward ICT use which in turn motivated their classroom use of ICT. Voogt et al. (2013) suggested that both technological and pedagogical beliefs were reflected in the forms of teachers' TPACK. In a qualitative study of teachers learning to use spreadsheets as instructional tools, Niess (2013) found that those who viewed the teaching of mathematics as involving student memorization of rules and processes were less inclined to use the ICT tool whereas those who believed that spreadsheets had affordances for enhancing students' problem-solving and decision-making implemented student-centered activities with spreadsheets. The latter group of teachers was described by Niess as having a higher level of TPACK development. While it appeared that teachers' beliefs drove their ICT integration strategies, Lim and Chai (2008) found that teachers' beliefs were moderated by larger cultural/institutional factors because in their study of teachers in a high stakes exam system, those with constructivist beliefs still used ICT to support information recall activities rather than student-centered ones.

2.1.2. School

Factors such as school culture, school policy and the curriculum were found to have substantial influence on teachers' willingness to integrate technology. Large-scale surveys of teachers found that when school culture was perceived by teachers as being supportive of innovation and change, it was positively related to teachers' adoption of computers to support learning activities rather than to practice IT literacy skills (Tondeur, Valcke, & Van Braak, 2008). Furthermore, school policies stipulating plans and objectives for ICT had significant impact on teachers' use of ICT in classrooms (Tondeur, Van Keer, van Braak, & Valcke, 2008), which encouraged them to experiment and develop knowledge specific to the use of particular ICT tools (Guzey & Roehrig, 2009). Qualitative studies of teachers' ICT integration strategies found that teachers' perception of curriculum influenced their decisions for ICT integration. Eteokleous (2008) found that teachers' perception of a heavy curriculum was a barrier to them integrating ICT into their lessons. Most studies in this area did not specifically examine the impact of school and curriculum factors on TPACK.

2.1.3. Technology

Access to computers and software, the proper functioning of these resources, as well as access to technical support have been recognized as critical factors affecting teachers' willingness to adopt particular ICT tools (Ertmer, 2005; Eteokleous, 2008; Guzey & Roehrig, 2009; Hew & Brush, 2007). When a path model was used to compare different factors affecting technology integration in K–12 classrooms, Inan and Lowther (2010) found that teachers' perceived availability of computer resources was one of the key factors affecting their perceived frequency of technology integration. Typically, barriers to access led teachers to avoid using an ICT tool (Mouza & Karchmer-Klein, 2013; Niess, 2013). Consequently, their TPACK development could be constrained to those tools that they have access to. Yet, other studies suggested that when teachers had strong motivation for using computers, it drove them to overcome access barriers (Drent & Meelissen, 2008; Ward & Parr, 2010). In such cases, teachers produced the appropriate TPACK to circumvent these contextual barriers (Porras-Hernández & Salinas-Amescua, 2013).

2.1.4. Peers

Peer support through the sharing of ideas, peer coaching and collaborative problem solving was found to be essential in teachers' effort to integrate ICT (Galanouli, Murphy, & Gardner, 2004). Time constraint was a factor typically identified by teachers as a barrier to innovative ICT integration (Hew & Brush, 2007). Mutual collaboration with colleagues was cited as a way to mitigate this problem (Guzey & Roehrig, 2009) as collaborative design could potentially enrich teachers' development of TPACK. Levin and Wadmany (2008) termed this as a kind of dialogical learning.

2.2. TPACK-in-Action

From the preceding review, the context surrounding teachers can be interpreted as comprising of four interdependent yet distinguishable dimensions, as suggested by Chai, Koh, et al. (2013). These were intrapersonal, interpersonal, cultural/institutional and physical/technological (see Fig. 1).

To facilitate analysis of school-based factors and technological factors, Ertmer's (1999) description of first-order barriers were refined into two dimensions: Physical/Technological and Cultural/Institutional. The Physical/Technological dimension refers to issues related to the availability and efficacy of resources to support teachers' integration of ICT. These could be resources such as hardware, software, and technology support staff. On the other hand, Cultural/Institutional factors deal with the institutional influences of society and culture, educational policies, school leadership, school policies, and curriculum on teachers' teaching practice. As per Ertmer's (1999) conception of second-order barriers, the Intrapersonal factor in this framework refers to the various forms of beliefs that teachers hold and how these influence their ICT integration. Tsai and Chai (2012) recently proposed that teachers' design thinking could be a third order barrier to their ICT integration and TPACK creation. While Ertmer (1999) viewed the factors underlying the Physical/Technological, Cultural/Institutional and Intrapersonal dimensions from the perspective of barriers to ICT integration, the TPACK-in-Action framework suggests these to be contextual variables teachers need to manage as they enact their TPACK during the design of ICT lessons. Teachers' capacity for design influences how they maneuver their TPACK according to the tensions or opportunities of their context (see Fig. 1). The Interpersonal dimension addresses issues related to problem-solving and innovation through peer collaboration. It is proposed because complex and useful ICT-integrated lessons are usually developed through the collaborative efforts of a team of teachers and sometimes technologists (see Koehler et al., 2007). The interpersonal dimension acknowledges the importance of human relationships within ICT lesson design teams.

2.3. Research question

From the review, it can be seen that many contextual factors have been identified as barriers or enablers to ICT integration but these have not been analyzed in tandem. In this study, we examine teachers' ICT lesson design to understand how the contextual dimensions postulated by Author 1 and Author 2 (2013) influence their TPACK development. The research question studied was:

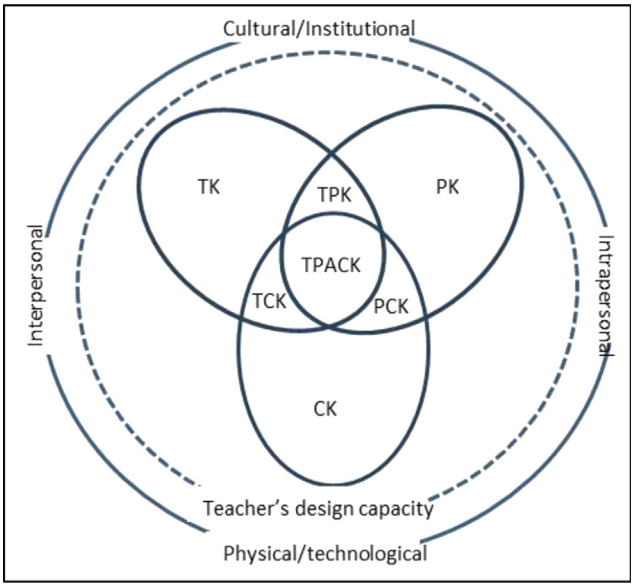

Fig. 1. The TPACK-in-Action framework. Adapted from Chai, Koh, et al. (2013).

What contextual factors influence teachers' co-construction of TPACK when they plan lessons?

3. Methodology

3.1. School context

The data was collected in a Singapore elementary school that is funded by the Ministry of Education under the FutureSchools@Singapore program which supports the implementation of innovative pedagogies through pervasive technology integration within the school curriculum. This school was purposively chosen because it was expected that issues related to ICT integration would be prevalent in teachers' discussion of lesson planning. Within this school, teachers from three levels – Primary 1, 4, and 5 were chosen for this study to cover both upper and lower levels of the six-year elementary school system in Singapore. This also allowed us to understand if grade levels played a part in determining how teachers' interpreted their context. Twenty-four teachers teaching these levels participated in this study. The teachers teaching each level held meetings throughout a semester to discuss lesson ideas, curriculum matters as well as logistical issues related to upcoming lessons. For each group, there was a Lead Teacher who facilitated the team's discussions. The teachers' discussions during these meetings indicated how they applied various aspects of their professional knowledge in relation to the daily contextual challenges they faced. Therefore, these discussions were chosen as the data source.

3.2. Data collection and analysis

Thirteen audio recordings (9 h and 50 min: Primary 1–2 h 58 min; Primary 4–2 h 3 min; Primary 5–4 h 49 min) were made of the meetings conducted by each of the selected grade levels. These recordings were collected from February to April 2012. The teachers were not informed about the purpose of the research and the researchers did not sit-in or facilitate the meetings. This naturalistic approach was adopted to avoid biasing the teachers' discussion, thereby preserving the integrity of data. The audio recordings collected were transcribed and analyzed using content analysis, a method where coding schemes are used to understand textual data (Weber, 1990). After the audio was transcribed into text, the text was broken down into paragraphs. Each paragraph was coded using the a priori categories established in the coding protocol according to the TPACK-in-Action framework (see Table 1). The unit of analysis was by paragraph so that distinctions prior to coding were made syntactically without predisposed meanings (Krippendorff, 2004). To establish inter-rater reliability, two coders coded the transcripts independently and all inconsistencies were negotiated to derive agreement. The coding protocol was also refined and finalized during the process. During coding, it was found that the definition of Cultural/Institutional dimension needs to be expanded to include teachers' discussion of logistical issues related to lesson implementation as this emerged as a critical aspect of teachers' response to the demands of syllabi and policies.

To answer the research question, the relative frequencies of each category were examined to identify the dominant categories emerging from the teachers' discussions of lesson planning. Pearson's chi-square analysis was used to test for significant association between the coded categories by group. We first ascertained that was no violation of Cochran's (1954) guideline that expected values below five should occur in no more than 20% of the cells in the contingency table. To examine the relationship between contextual and TPACK categories within each group, the standardized residuals of each cell was examined. As per Agresti (2007), the range of standardized residuals was set at ± 2. A cell with a residual greater than $+2$ indicated that its observed frequency was above expected whereas a residual smaller than -2 indicated that the observed frequency was below expected. The results obtained from the chi-square analysis were then triangulated against

Table 1
Coding protocol.

Issue	Definition
Contextual factors	
Physical/technological	Comments about the condition of the school's hardware, software, and school physical environment or access to technology by teachers and students.
Cultural/institutional	Comments about nationwide educational initiatives, syllabus, school policies, lesson objectives, and logistical issues related to lesson implementation.
Intrapersonal	Teachers' personal beliefs about teaching, learning, students, or themselves as a teacher.
Interpersonal	Comments about interaction or collaboration with colleagues or stakeholders (e.g. parents)
TPACK factors	
1. Content Knowledge (CK)	Comments about subject matter.
2. Technology knowledge (TK)	Comments about various technologies and their features.
3. Pedagogical knowledge (PK)	Comments about the processes or methods of teaching.
4. Technological content knowledge (TCK)	Comments about subject matter representation with technology.
5. Technological pedagogical knowledge (TPK)	Comments about using technology to implement different teaching methods.
6. Pedagogical content knowledge (PCK)	Comments about teaching methods for different types of subject matter.
7. Technological pedagogical content knowledge (TPACK)	Comments about using technology to implement teaching methods for different types of subject matter.

the emerging themes observed from coding as well as through interviews conducted with three teachers at the end of the semester. These teachers participated in the discussions of the various grade levels examined.

4. Results

Table 2 compares the relative influence of TPACK and contextual factors for the three groups of teachers studied. In the rows describing the Total frequencies obtained, it appeared that Cultural/Institutional factors were dominant in the teachers' discussions as it comprised about 55% of the total units coded. These discussions largely revolved around logistical issues such as the scheduling and organizing of class tests and field trips. In the same rows, discussions related to the seven TPACK factors constituted about 37% of the total units coded. These were discussions about strategies for both non-ICT as well as ICT-integrated lessons.

These results show that in a school context, the need to handle the breadth as well as the urgency of institutional demands was a key contextual factor that teachers had to contend with as they designed lessons. In comparison, the other contextual factors, that is, Intrapersonal, Interpersonal, and Physical/Technological were not as influential as these comprised only about 8% of the total units coded. Chi-square analysis found significant differences among the three groups with respect to the distribution of TPACK and contextual factors ($\chi^2(10, N = 3592) = 1155.15$, $p < 0.01$, Cramer's $V = 0.41$).

4.1. Primary 1 – logistics focused

The Primary 1 team comprised of six teachers and the group had an average teaching experience of about 8 years. Their teaching experience ranged from one to 25 years. From the results obtained for the Primary 1 group in Table 2, it can be seen that the Cultural/Institutional category had the only positive standardized residual that was above +2 as indicated by Agresti (2007). This suggested that the frequencies observed for this category was above expected. Qualitative examination of units coded under this category showed these to be

Table 2
Comparison of contextual and TPACK factors by group.

Group		Contextual				TPACK							Total
		Intrapersonal	Interpersonal	Cultural/ institutional	Physical/ technological	TK	PK	CK	TPK	TCK	PCK	TPACK	
Primary 1	Observed	0.00	4.00	773.00	19.00	26.00	14.00	0.00	0.00	0.00	25.00	3.00	864.00
	Expected	13.00	22.40	475.80	30.30	76.70	24.10	42.60	15.20	1.00	91.90	71.20	864.00
	% of Total	0.0%	0.50%	89.50%	2.20%	3.00%	1.60%	0.00%	0.00%	0.00%	2.90%	0.30%	100.00%
	Standardized residual	−3.60	−3.90	13.60	−2.10	−5.80	−2.00	−6.50	−3.90	−1.00	−7.00	−8.10	
Primary 4	Observed	38.00	78.00	770.00	51.00	53.00	24.00	9.00	40.00	4.00	111.00	93.00	1271.00
	Expected	19.10	32.90	699.90	44.60	112.90	35.40	62.60	22.30	1.40	135.20	104.70	1271.00
	% of Total	3.00%	6.10%	60.60%	4.00%	4.20%	1.90%	0.70%	3.10%	0.30%	8.70%	7.30%	100.00%
	Standardized residual	4.30	7.90	2.60	1.00	−5.60	−1.90	−6.80	3.80	2.20	−2.10	−1.10	
Primary 5	Observed	16.00	11.00	435.00	56.00	240.00	62.00	168.00	23.00	0.00	246.00	200.00	1457.00
	Expected	21.90	37.70	802.30	51.10	129.40	40.60	71.80	25.60	1.60	154.90	120.10	1457.00
	% of Total	1.10%	0.80%	29.90%	3.80%	16.50%	4.30%	11.50%	1.60%	0.00%	16.90%	13.70%	100.00%
	Standardized residual	−1.30	−4.40	−13.00	0.70	9.70	3.40	11.40	−0.50	−1.30	7.30	7.30	
Total	Observed	54.00	93.00	1978.00	126.00	319.00	100.00	177.00	63.00	4.00	382.00	296.00	3592.00
	% of Total	1.50	2.60	55.10	3.50	8.90	2.80	4.90	1.80	0.10	10.60	8.20	100.00

related to the logistics of implementing lesson activities. In this example, teachers discussed the logistics for organizing a learning journey to a fish farm:

Teacher 1: Next week is our learning journey. Please give the [consent] letter by tomorrow … they don't need to bring very much … just bring their water bottles because they are going to be walking around the farm. Cap? Yes cap … *(Cultural/Institutional)*

Teacher 2: My class is the first group. Do they report at the hall or the canteen at 8 a.m.? *(Cultural/Institutional)*

Even though logistical concerns dominated teaches' discussions, this does not mean that the teachers did not discuss pedagogical issues as there were coded units related to the categories of TK, PK, PCK and TPACK. For example, in the category of PCK, teachers discussed the possible implementation problems of a math assessment where the students were required to cut up tangrams on five sheets of paper and re-arrange each tangram into an acceptable shape.

Lead teacher: Teach your children to cut out one set of tangram or they [will] have too many of pieces to handle. All the pieces should be connected but not overlapping. Ok? This is how you will score. Each tangram figure that they create will be awarded one mark … they have to label it … if they are making this really odd-looking thing and they call it monster … give the full 1 mark … Next, if the shapes overlap, we will deduct half a mark overall. That means that if they make five figures, they should get five marks. They forget to name it, they get four and a half [marks]. They overlap the shapes, they get four [marks]. That's how you count. *(PCK)*

Teacher 2: Regardless of how many overlaps? *(PCK)*

Lead teacher: Regardless of how many overlaps … Your job is tell them that for tangrams, there is no overlapping [allowed]. *(PCK)*

Teacher 3: What [if] they lose one shape and they draw? *(PCK)*

Lead teacher: They [can] draw and put it back. That's fine … But you need to tell them. *(PCK)*

However, the standardized residual for the category of PCK was below −2, indicating that its observed frequency was below expected. The category of TPACK had the largest negative standardized residual, indicating that the observed frequency of discussion units that were related to ICT pedagogies was below expected. In teachers' discourse, some concerns related to students' ICT literacies were highlighted as possible reasons for these results. For example, a teacher shared why they switched from a computer-based to a hardcopy mode for the tangram activity:

Lead teacher: We found that to manipulate [the] digital form [of the tangram] on PowerPoint was quite crazy for the children because PowerPoint not only rotates, it also resizes. *(TCK)* In the first year, we wanted them to [have] as much exposure to PowerPoint as possible and handling shapes is one of them. *(TK)* But we didn't realize that their psychomotor skills were not strong enough … [If we] accidently pull it the wrong way … we know how to undo. *(TK)* They don't know … we decided that the paper version still is better … *(PCK)* At our level there is a lot of ground work … I just taught them how to create [a] folder … how to put work in the folder, organize [the] folder. *(TK)*

4.2. Primary 4 – context/pedagogical focused

The Primary 4 team comprised of seven teachers and the group had an average teaching experience of about seven years. The teachers had between five to 15 years of teaching experience. From the results obtained for the Primary 4 group in Table 2, the standardized residual of the Cultural/Institutional category was slightly above the expected standardized residual of +2. However, the standardized residual for the Intrapersonal and Interpersonal factors were higher, indicating that the occurrence of these categories in teachers' discussion was above expected. Qualitative analysis of the coded units for the Intrapersonal category showed teachers sharing their beliefs about various aspects of teaching. For example, when debating if teachers should be asked to participate in remedial classes for weaker students, a teacher shared her belief:

Teacher 1: I always put my students' interest first. Anything can wait except my students. If my students need help, I will be there for them. As simple as that. *(Intrapersonal)*

The standardized residuals for TCK and TPK were above the expected value of +2 and qualitative analysis found that these categories tend to emerge as teachers described how they translated their beliefs into practice. In this example, a teacher explained how the data logger could be integrated into a science lesson. The data logger is an example of TCK since it is a tool used by scientists to collect scientific data. Intrapersonal factors came into play as the teacher expressed her belief that the technological problems of introducing data loggers can be overcome once students are familiar with it. She then went on to elaborate how it was being used with her students:

Teacher 1: There are a few issues with the data loggers just starting off but I think the first few tries are always there *(Intrapersonal)*. As I said, we start off [with] the students. *(PCK)* For my class, they are very familiar with data logger. *(TK)* Because I use that very often for my data sensor beat out of the computer. *(TCK)* That helps a lot. *(TCK)* So when they use it with the computer, they only need to grapple with the computer usage. *(TPACK)* No need [to] grapple with how to use the data … that kind of thing. *(TPACK)* Get them to [be] familiar with using the equipment first. *(TPK)*

In this example, the teacher discussed her beliefs that using both the software and hardware of a computerized data logger system may be problematic with young children. To overcome these difficulties, she proposed a strategy of using just the hardware, which is an example of TPK:

Teacher 1: I have tried to install Eco-lab 4 for my class and it was not easy … the computer does not detect the data logger. *(TK)* So I foresee it is going to be a technically challenging if the whole lot of us [are using] the software. *(TPK)* But if we just use the data logger alone, [and] students just take down the data, it will be ok … *(TPK)* We're using it like a temperature sensor … *(TPK)* My other concern is that if we do the experiment … we have the water, everything … We are to bring this laptop up and kids being kids … water can spill over … a lot things may happen. *(Intrapersonal)*

The group's standardized residual for the Interpersonal dimension was above +2 because teachers discussed ways to collaborate with each other for lesson preparation, for example,

Teacher 4: So [for] that one I will work with you. Ok, I will see how I can come in and support. *(Interpersonal)*

Unlike the examples cited for Intrapersonal factors, talk involving Interpersonal factors rarely developed into further discussions of pedagogical issues. Nevertheless, this indicated the collegiality within this group as it comprised of fairly experienced teachers who worked together since the school started six years ago. A teacher commented that they had a close and collaborative working relationship:

Teacher 1: Teacher 2 comes from assessment point of view … I'm not very good with rubrics … Teacher 3 and I, because we're more close to one another, so if there's anything [wrong] she would have told me already …. It's more of that type of thing we have. That's all. Personal relationship. *(Interpersonal)*

As compared to the Primary 1 teachers, these Primary 4 teachers had fewer concerns about students' ICT competencies:

Teacher 3: Let the students figure out [how to use the software] on their own. Because let's put it this way … next time when they use new technology, they need to transfer their learning. *(Intrapersonal)*

4.3. Primary 5 – TPACK focused

This team comprised of 11 teachers and the team's average teaching experience was ten years. Their range of teaching experience was between one to 20 years. It was led by a teacher who is an experienced educational technologist with 20 years of teaching experience. From Table 2, the standardized residual for the Primary 5 group's Cultural/Institutional category was very much below the expected value of −2 but those for TK, PK, CK, PCK, and TPACK were higher than the expected value of +2. When teachers discussed issues related to TK, they focused on how ICT tools could potentially be exploited to support teaching. In this example, the teachers were exploring options for capturing videos of themselves solving math questions that could be posted online for review by students:

Lead teacher: This free version only allows 15 minutes of continuous videoing so I have to keep my lessons very short … I will break if it is a difficult question … I will break into 2 parts. *(TK)*

Teacher 2: This platform called XXX gives you 500mb per week. But when I upload a 5 minute video, it already takes up 300 something [mb] so I created multiple accounts … used up all [my] email [accounts]. *(TK)*

The discussion of TK-related issues was interspersed within deeper pedagogical discussions of ICT strategies. These teachers rationalized ICT strategies deeply, which were their expressions of TPACK. Below is an example of the teachers' rationalization for creating teaching videos of math problems:

Lead teacher: I thought of creating videos for them to [learn] … own time, own target, own place *(TPK)* … because in class they are sometimes not ready … physically they are not ready … [the weather is] hot and they don't want to listen *(PCK)*. Screen-o-matic is [an] online program and it's free and it basically just captures whatever is on your screen within a frame *(TK)* … I thought I [would] just target the questions that they [students] always have difficulty with. *(TPACK)*

Such kinds of rationalization triggered teachers to discuss issues related to the technology *(TK)* as well as their suggestions for refining their design ideas which in turn generated TPACK. For example, the teachers discussed various options for minimizing the file size of their video recordings:

Teacher 2: I just get a simple Powerpoint, and as I talk I just scroll. *(TK)*

Teacher 3: Teacher 2 was sharing that he actually taped his voice as he was teaching … I think that's the best because weaker students should have an extra round of hearing … So the ideal is as I teach, I tape it and immediately upload it, and immediately get them to view it. *(TPACK)*

These teachers also had more extensive discussion about the content (CK) they were teaching. This was because teachers were concerned about getting the important academic content across to their students who were preparing for their examinations. For example,

Lead teacher: When we use the article 'a' and 'an', we only use it when the 'U' is pronounced as 'U' right? A university … a unicorn. *(CK)*

Another example was in science when the teachers had a sharing from content experts to enhance their content knowledge as the upper primary levels were heavy with content.

Content expert: The modified petal … when there is a wind or breeze … it can move out like that … to attract the pollinators to come. *(CK)*

Non-ICT strategies were also discussed, for example:

Teacher 1: We can see the area of this big rectangle is actually made up of small rectangles. *(CK)* Although, it's not by scale … the area of the big rectangle is actually 7 … 1 times 7 plus 2 times 7. *(CK)* Hence, distributive law tells us that you will take 7 multiplied by 1, 7 multiplied by 2 will give you this and this. *(CK)* So in brief, this is one concrete example about how you can build the explanation when teaching distributive law. *(PCK)*

When interviewed, the lead teacher shared that ICT lent itself better in some subject areas.

Lead teacher: For languages, you can see concrete relations [with ICT] … writing simple sentences, posting journals … I think they will still learn. But for mathematics, it's a little tough … I tried to engage a group of weaker students with mathematics [games] … They can play … add or whatever, but when you ask them to do [the] paper-based [test], they can't do [it].

As for the team dynamics, the lead teacher commented on the importance of the group composition:

Lead teacher: I think we need at least one or two in a group who are very adventurous about technology integration … and always constantly pushing … strong in technology and strong in personality … always asking for time to share the different things that they did … what we need is just the sharing … if you care enough to share, people will take it up, they will try. And when they try, if it's good, it will continue.

5. Discussion and implications

This study examined teachers' talk during group-based lesson design sessions and found that some contextual factors could shape teachers' TPACK construction. The first contextual factor that influenced teachers' co-construction of TPACK was Cultural/Institutional in nature. Across the three groups, it was observed that the higher the proportion of talk that was focused on Cultural/Institutional factors, the lower the proportion of TPACK. These results showed that to improve TPACK co-construction, teachers need to consciously use the time for deeper pedagogical discussions. Yet, factors such as grade level and students' ICT competencies need to be further examined. Even though the lack of time is a common barrier cited by teachers for ICT integration (Hew & Brush, 2007; Lim & Khine, 2006; Tondeur, Van Keer, et al., 2008), the study results showed that despite dedicated time for lesson planning, the Primary 1 teachers still approached pedagogical innovation through an administrative lens. One reason for the findings could be that the Primary 1 teachers had to pre-empt potential problems when working with younger children. This may have led them to focus more on logistical issues than the Primary 4 and Primary 5 teachers. Another explanation of the findings could be that the level of students had some implications on their ICT competencies which in turn influenced the use of ICT by teachers (Vanderlinde, Van Braak, & Tondeur, 2010).

The study results of the Primary 4 group showed that when Intrapersonal factors such as teachers' beliefs were articulated and used to support pedagogical action, they played a part in triggering discussions related to TPACK. This concurred with research findings that teachers' beliefs influenced their practice of ICT integration (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Hermans et al., 2008; Sang et al., 2011). However, the occurrence of Intrapersonal factors were below expected in both the Primary 1 and Primary 5 groups as these teachers seldom discussed their pedagogical beliefs. It could be that such kinds of talk do not naturally occur in teachers' design discussions and need to be expressly elicited. It could also be that Intrapersonal factors need to be considered in tandem with Interpersonal factors as the frequencies of both categories were above expectation for the Primary 4 group. Teachers may need to have close working relationships before they were comfortable to share how their personal beliefs have shaped their practice. These results indicate that the interplay of TPACK, Intrapersonal, and Interpersonal factors needs to be further examined.

The Physical/Technological factor did not appear to influence teachers' TPACK co-construction as its frequency of occurrence was within expectation for all groups. This could be because the study was situated in a school context where creating innovative ICT-based pedagogy is part of the school's mission. The ecology of this system (Zhao et al., 2002) is technology-enriched with supportive administration and work structure.

Besides contextual factors, the study results also suggest that teachers' TPACK enactment in a school-based context can perhaps be facilitated through the careful engineering of the composition of design teams. The three groups were largely equitable in terms of teaching experience. However, results from the Primary 5 group suggested that the presence of an experienced facilitator ensured that TPACK was addressed during discussions. This is supported by Penuel, Roschelle, and Shechtman (2007). We envisage that such kinds of facilitators can encourage teachers to make connections between their knowledge of students' learning and ICT pedagogies, which will in turn enhance the depth of teachers' TPACK co-construction. In addition, the experience of the Primary 5 Lead Teacher showed that having team members who were both savvy and passionate about ICT integration, what Drent and Meelissen (2008) described as having personal entrepreneurship for ICT integration, also enhanced the team's design capacities. The need to consider the facilitation and composition of ICT design teams, as well as its effects on TPACK emerged in this study and can be further examined.

6. Limitations and future directions

The study examined a theoretical lens for analyzing ICT integration in school contexts. The results are limited to a primary school with a mandate for ICT integration. The applicability of the framework and the relationships observed between TPACK and contextual factors need to be validated in other primary schools, secondary schools as well as tertiary levels. These studies can be used to further examine the findings of whether the level of students had any influence on the extent to which teachers considered ICT integration. The replication of the

study in schools with varying degrees of ICT integration is another way of understanding how school contexts may influence teachers' co-construction of TPACK.

This study adopted a naturalistic stance where teachers' co-design work was not supported by external experts such as teacher educators, researchers or curriculum developers. The findings of this study suggest that the presence of strong facilitators could influence the extent of teachers' TPACK construction. Therefore, a future area of research would be to examine if the inclusion of external parties could help to perturb the teachers' design in a positive way, especially if this could lead teachers to espouse the beliefs underlying their pedagogical decisions. These kinds of studies could be used to derive guidelines to better facilitate teachers' design talk during ICT lesson planning. Finally, the applicability of the framework for school leaders and teachers to make more effective plans for ICT integration can be further examined. In this study, perceptions of teachers' TPACK were understood through teachers' discussion and interviews but the actual implementation in class were not studied. In future research, the actual implementation of lessons designed can be used to further understand teachers' design capacities for ICT integration with respect to the educational outcomes produced.

7. Conclusion

A theoretical lens for understanding the contextual influences of teachers' TPACK construction has been examined in this study. By using this framework, teachers can deepen their awareness about the contextual influences and how to turn these into opportunities as they enact TPACK. A major implication of this study is the need for teachers to distinguish between discourse centered upon Cultural/Institutional concerns such as logistics and those focused on pedagogy. This can help teachers to avoid the situation where their design efforts are being bounded by immediate logistical concerns. These findings also point out that teachers need specific competencies to facilitate and discourse about their design in ways that support pedagogical improvement. These appear to be important aspects of teachers' design capacities that require deeper examination in future studies.

Acknowledgements

This paper refers to data from the research project "Understanding And Profiling Teachers' Technological Pedagogical Content Knowledge (TPACK) Development Patterns" (OER12/10/KHL), funded by the Education Research Funding Programme, National Institute of Education (NIE), Nanyang Technological University, Singapore. The views expressed in this paper are the authors' and do not necessarily represent the views of NIE.

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