Characterizing TPACK Transformations in the Design of School-Based Pedagogical Change

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Abstract: The technological pedagogical content knowledge (TPACK) framework has been accepted as a powerful framework to examine ICT integration in the classroom. However, nearly a decade of TPACK research has not documented clearly how teachers synthesize the different aspects of their existing technological, pedagogical and content knowledge into a new form of knowledge to support ICT-integrated lessons. This study unpacks how teachers and researchers who are collectively engaged in lesson design sessions by putting their existing knowledge together through talk and jointly designing new TPACK to support pedagogical change in a school-based context. The study found that to do so, TPACK transformations need to occur in the areas of pedagogy, content, and technology through iterative problem-solving. The study indicates that such kinds of design efforts are potentially very important to develop deep pedagogical understanding among teachers.

Keywords: Technological pedagogical content knowledge, design thinking, teacher professional development

1. Introduction

Information and communications technology (ICT) has been envisioned as the catalyst of pedagogical change in schools. However, empirical studies of teachers' computer use in classrooms show that ICT is predominantly being used to support information transmission (Gao, Choy, Wong, & Wu, 2009; Lim & Chai, 2008; Ward & Parr, 2010). Obviously, teachers have yet to change their pedagogical practices towards the constructivist and student-centered uses of ICT that are often associated with pedagogical change. One reason could be that teachers are drawing upon their knowledge of existing instructional repertoires whereas pedagogical change requires them to design new pedagogical practices (Hammerness et al., 2005). Teachers therefore need to develop new forms of technological pedagogical content knowledge (TPACK), or knowledge for ICT integration (Mishra & Koehler, 2006) to support these changes.

It is premised that TPACK is transformative in nature (Angeli & Valanides, 2009) and studies have found that it emerges as teachers engage in lesson design activities (Koehler, Mishra, & Yahya, 2007). During lesson design, teachers draw upon their technological knowledge, pedagogical knowledge, and content knowledge to create concrete lesson ideas that are expressions of their TPACK (Cox & Graham, 2009). Teachers' lack of design expertise has been identified as a critical barrier against their successful integration of ICT (Tsai & Chai, 2012). However, we suggest that teachers' design expertise is encapsulated in their ability to use and transform their existing TPACK as epistemic resources during lesson design. Ideas for ICT innovations can only emerge successfully when teachers are able to successfully maneuver these TPACK transformations. At present moment, there are ICT lesson design models (eg. ASSURE, Heinich, Molenda, Russell, & Smaldino, 1999) that depict the ICT lesson design processes. However, how teachers form and develop TPACK throughout lesson design is still not well understood (Cox & Graham, 2009). Though it is acknowledged that TPACK is formed through collaborative design, recent reviews did not surface any studies that unpack how the transformation of TPACK emerges through design talk (see Chai, Koh & Tsai, 2013).

This study therefore aims to characterize the kinds of TPACK transformations that take place during teachers' attempt to design new pedagogies for their existing lessons. Using content analysis, we studied a team of teachers in a Singapore primary school who were revamping their math curriculum with inquiry-based learning. Audio recordings were made of their regular design discussions across six months and content analysis using Mishra and Koehler's (2006) TPACK framework was used to characterize how teachers transformed their TPACK as they made critical design decisions. Implications for the development of teachers' design capacities are discussed.

2. Literature Review

2.1 The TPACK Framework

The TPACK framework was proposed by Mishra and Koehler (2006) as an extension to Shulman's (1986) proposition that teachers possess a unique form of know-how termed as pedagogical content knowledge. Shulman emphasized that pedagogical content knowledge went beyond teachers' pedagogical knowledge and content knowledge. It encapsulates how teachers draw upon their knowledge of classrooms, students, and curriculum to formulate instructional activities for specific groups of students. To consider teachers' knowledge of ICT integration, Mishra and Koehler proposed that seven forms of teacher knowledge can be derived from the interconnections among technological knowledge, pedagogical knowledge, and content knowledge. These are:

1. Content Knowledge (CK) – knowledge of subject matter.
2. Technology knowledge (TK) – knowledge of various ICT tools.
3. Pedagogical knowledge – knowledge of the processes or methods of teaching.
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 for different types of subject matter.
7. TPACK – knowledge of using technology to implement teaching methods for different types of subject matter.

TPACK describes ICT pedagogies employed for specific lesson topics whereas TCK and TPK describe the general technologies that can be used to support different content or pedagogical areas respectively (Cox & Graham, 2009).

2.2 TPACK Transformations Through Design

Niess' (2013) study of in-service teachers' TPACK across three years suggest that they needed to first recognize an ICT tool's relevance before they were able to make the pedagogical changes to adapt, explore, and advance these tools within their school curriculums. Teachers' conception of lesson strategies, and therefore their TPACK enactment, are also influenced by school policies, day-to-day logistical concerns as well as the kinds of ICT resources available in their schools (Koh, Chai, & Tay, 2014; Porras-Hernández & Salinas-Amescua, 2013). Such kinds of decision-making may not be adequately captured in existing ICT lesson design models. An example is ASSURE which characterizes design as having defined stages including learner analysis, statement of standards and objectives, selection of pedagogies and media, implementation, evaluation and revision (Heinich, et al., 1999). This model may not depict the reality of teachers' lesson design practices as recent studies found these processes to be iterative and emergent rather than procedural (Laurillard, 2012; Summerville & Reid-Griffin, 2008). In fact, the latter descriptions of teachers' ICT lesson design practices are closer to the processes used by designers in fields such as product design and architecture. It was found that these designers engaged in iterative rounds of "reflection-in-action" where they would tinker with ideas in order to better understand their design problems (Cross, 2001; Schön, 1983). To these designers, design is essentially a process whereby their knowledge about design problems are continually being created, refined and therefore transformed through the exploration of ideas (Lawson, 1997).

For teachers, there is evidence that they create TPACK as they design ICT lessons with respect to particular instructional problems. Analysis of graduate students and pre-service teachers' reflections of their engagement in lesson design projects assigned during teacher education courses found that their consideration of single knowledge sources such as TK and PK were more predominant at the early stages of lesson design whereas their considerations of integrated knowledge sources such as TPK and TPACK were more predominant at the later stages of lesson design (Koehler, et al., 2007; Koh & Divaharan, 2011, 2013). The presence of the integrated sources of TPACK in teachers' reflections is a particularly important finding because this indicates teachers' ability to connect their different knowledge bases in order to create particular pedagogical uses of ICT. Mishra and Koehler (2006) remarked that these integrated sources of TPACK depict teachers' ICT integration capacities. While the studies of graduate students and pre-service teachers cited earlier do provide some insight about teachers' TPACK development, there is little detail about the design processes that enable teachers to develop the integrated forms of TPACK. Furthermore, these studies are based on design projects carried out in teacher education courses and may not be reflective of how lesson design occurs in school-based contexts. It is important to understand how teachers develop TPACK to support pedagogical change but there is a dearth of studies in this area at present moment. Correspondingly, the applicability of the TPACK framework for guiding teachers' lesson design has often been questioned (Cox & Graham, 2009).

2.3 Research Question

Considering the gaps in extant TPACK research, the following will be the research question of this study:

What kinds of TPACK transformations are needed to support a pedagogical change?

3. Methodology

3.1 Study Context

The study was carried out with a team of six teachers from a Singapore primary school. As a participant of the FutureSchools@Singapore programme, the school has a mandate to develop ICT-enabled pedgogical innovations. The team comprised of the Head of Department (HOD) of Mathematics and five other teachers who had between 5-10 years of teaching experience. Researchers from a teacher education institution and a math specialist supported the teachers in this change and participated in these discussions. In a prior analysis of their students' performance in the different math exam questions, the team felt that their students' communication of mathematical reasoning could be strengthened. As this is an important component in national examinations that students take at primary 6, the teachers wanted to help students build this important skill from primary 3. From their experiences in teaching Science, the teachers felt that an inquiry-based approach could be used because it engages students to explore and explain phenomenon. The teachers therefore chose to adapt the 5E inquiry-based approach used in their Science lessons for this purpose. In this approach, learning occurred through five phases of inquiry - Engagement, Exploration, Explanation, Elaboration and Evaluation (Bybee et al., 2006). This approach was finally integrated into the topics of number patterns, fractions, money and area and perimeter, which were topics that students had more difficulty with.

3.2 The Pedagogical Change

Prior to the integration of the 5E approach, teacher-centered pedagogies were largely used to deliver the various math topics. The design of the inquiry-based lessons was progressively developed and refined as the teachers implemented the lessons for each of the various topics throughout the school year. Generally, the 5E approach was implemented by first Engaging students with a video-based scenario of a real-world problem associated with the math concept they were going to learn. For example, to bring out the issues related to units of measurement in the topic of area and perimeter, teachers showed a scenario of two students who derived different answers for the area of the same table when it was measured using different square units. Using this as a stimulus, students constructed what they know and questions about what they wanted to know about the topic of area (i.e. the K and W portions) of their K-W-L chart. From their responses to the W portion of the K-W-L chart, students voted for four questions that they wanted to Explore and teachers then planned lesson activities to facilitate that. After exploring the concepts, teachers planned further real-world scenarios for students to Elaborate their understanding of the concept. Students then completed the L (what they learned) portion of their K-W-L chart as an Evaluation of their learning and this was consolidated into an individual concept map for the topic. Teachers' instruction of mathematical concepts as well as the worksheets and exercises typically used in these topics were integrated where appropriate.

The students were each equipped with a mobile phone that had apps enabling them to take photos, make sketches, draw concept maps as well as do postings on the school's learning management system. These features of the phone were used to support students in the activities for Explore and Elaborate as they used multi-modal formats to express their understandings of mathematical concepts. Besides the phone, teachers also used the discussion forum on the school's learning management system to share and consolidate students' work. The teachers chose a mid-ability class comprising of 43 students to pilot-test these approaches. It was envisioned that these lessons will be implemented throughout the primary 3 classes during the following school year.

3.3 Data Collection and Analysis

Data was collected during the design meetings that teachers held from July to November 2013 where they discussed lesson ideas, drafted lesson plans and resources as well as reviewed video recordings of implemented lessons to make improvement. A total of ten audio recordings were made of these meetings that lasted between 1.5 to two hours each. The recordings were transcribed into text and further broken down by sentence as the unit of analysis. To answer the research question, content analysis (Weber, 1990) was used to code each sentence according to the seven TPACK constructs. During data coding, it was found that a second layer of codes explicating how the team shared, clarified, and justified ideas was needed explicate the stage-by-stage TPACK transformations. Smith (1994) described these as group-mediated cognition to create and extend knowledge. To ascertain the reliability of coding and credibility of data analysis, a second rater reviewed the initial coding and discrepancies were negotiated till there was full agreement.

4. Findings

4.1 Pedagogical-related Transformations

To support the pedagogical change, teachers had to first transform their knowledge of pedagogical approaches for teaching math (PCK) and their pedagogical knowledge (PK). In the initial stages of the project, teachers were confronted with the need to create their own understandings of the 5E inquiry stages as the framework's application in science may not be directly transferable to math. For example, in this discussion, teachers and a researcher discussed how to differentiate the "Explain" and "Elaborate" stages of the 5E inquiry process as they reviewed the design of a lesson activity (See Table 1).

<u>Table 1 – Pedagogical-related Transformations</u>

Transcript	TPACK Transformations
1. Researcher	
a. In these two activities where the students need to make explanations, where does Explain stop and where does Elaborate start?	PK (Clarify)
b. What is your definition?	PK (Clarify)
2. HOD – hmm…what is the difference?	PK (Clarify)
3. Researcher	
a. Does Elaborate mean that the student can explain the basic principles with more examples?	PK (Clarify)
b. I don't see the difference between the two activities.	PK (Identify Gap)
c. You may want to review if you need both the stages or redefine them.	PK (Propose New idea)

Transcript	TPACK Transformations
4. Math specialist – In science, Elaborate means that you explain the standard situation and be able to apply and extend it into different scenarios.	PK (State existing practice)
5. HOD a. For math it is a bit difficult. b. I would think [in fractions for example], Explain means that they can explain that fractions are made up of equal parts and be able to make comparisons. c. Elaborate means that if they go to the ordering of fractions, they can explain how they make the comparisons.	 PCK (Identify Gap) PCK (Propose New idea) PCK (Propose New idea)
6. Teacher A a. I am thinking… can Explain mean that the students are able explain their thoughts and answers. b. Elaborate means to be able to draw conclusions from what has been discussed or to apply in a certain context.	 PK (Propose New idea) PK (Propose New idea)
7. HOD – Which means they can use their explanations to extend to another situation.	PK (Refine new idea)

The above process of TPACK transformation began with the researcher seeking to clarify the team's PK that is expressed in their design of the lesson activities (line 1a), which leads to a deeper question of possible gaps in their PK with respect to how they are envisioning the 5E stages (lines 1b, 2, 3a and 3b). The pedagogical-related transformations started in line 3c where the researcher suggested a new way of approaching this problem, which is an example of new PK. The team's existing PK of how the Elaborate stage of 5E is being used in Science is reviewed in line 4 following which the HOD recognized a gap in their existing PCK (line 5a) and started to propose new kinds of lesson activities, which are examples of new PCK (lines 5b and 5c). Teacher A generalizes the HOD's example as their team's pedagogical definition, which is an example of new PK (lines 6a and 6b). The HOD further refines the PK expressed by Teacher A (line 7). Through this discussion, the team transformed their understanding of both PK and PCK to support the pedagogical aspects of their change.

4.2 Content-related Transformations

As teachers sought to deepen the students' mathematical reasoning, they were confronted with the problem of how to better distinguish between different levels of mathematical reasoning. Teachers found that they needed to develop new Content Knowledge (CK) about mathematics. For example, for questions in fractions such as the one illustrated in Figure 1, teachers debated about the kinds of mathematical expressions that could be accepted as evidences of students' mathematical reasoning.

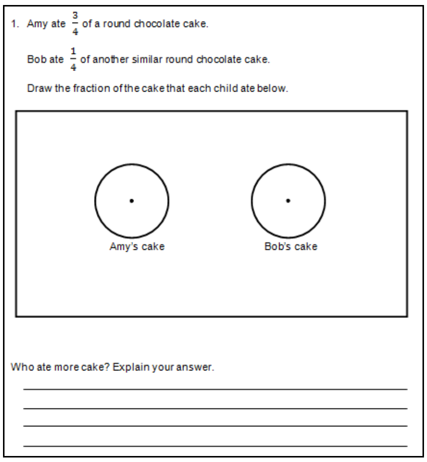

Figure 1. Sample math question on fractions.

Table 2 shows a segment of this discussion.

Table 2 – Content-related Transformations

Transcript	TPACK Transformations
1. Teacher A a. What does a correct approach mean? b. Draw and label the parts correctly? c. Eventually, are we talking about how detailed the drawing is? d. The different levels [of reasoning] have to be obvious because [the student] can draw, draw and label, or draw and label and explain	 CK (Clarify) CK (Clarify) CK (Clarify) CK (New idea)
2. HOD a. Then the first level is to draw. b. Usually they (students) will shade. c. That is level 1.	 CK (Refine new idea) PCK (Support new idea) CK (Refine new idea)
3. Teacher A – Level 2 – draw and label all the parts.	CK (Refine new idea)
4. HOD a. This is what we want to see. b. During their Primary 2 Summative Assessment II, a lot of them didn't label.	 CK (Support new idea) PCK (Support new idea)
5. Teacher C – Level 2 will then be to draw and shade and label all the parts	CK (Refine new idea)
6. HOD – The shading is not the problem – need to label.	PCK (Support new idea)
7. Teacher A – If they explain [the wrong answer correctly] ... no marks for reasoning because it is wrong.	CK (Refine new idea)
8. HOD – [What] if explanation is clear?	CK (Clarify new idea)
9. Teacher D - Zero marks – [the] concept is wrong.	CK (Refine new idea)

Content-related transformation began with Teacher A seeking to clarify the team's understanding of what it means to say that students have taken the correct approach to explicate their mathematical reasoning (lines 1a to 1c). She shares the conception of approaching the different kinds of expressions made by the student as levels (line 1d). This idea of "levels" is taken up and refined by the HOD who identifies the first level as drawing (lines 2a and 2c). She justifies her suggestion by using her knowledge of how students typically answered such kinds of math questions, which is her PCK (line 2b). The teachers and the HOD continue refining the idea by describing what they envision the different levels to be (lines 3c to 6). Along the way, the HOD supports the idea development by drawing upon her PCK of students' test performance to emphasize how it can help teachers to better target students' areas of weaknesses (lines 4b and 6). Lines 7 to 9 show the teachers refining their CK to include situations where students provide clear reasoning but had the wrong mathematical conception (lines 7 and 9).

4.3 Technological-related Transformations

In terms of technological-related transformations, Table 3 shows that it involves teachers clarifying their pedagogical conceptions of ICT use. This discussion occurred after teachers reviewed the implementation of a 5E lesson they designed to have students explore how the concept of equal parts in fractions were used in the design of national flags.

Table 3 – Technological-related Transformations

Transcript	TPACK Transformations
1. HOD a. Did we consolidate and collate their responses? b. In our initial conception, we said that they could key their responses into the portal so that they can revisit their own or their friends' answers.	 TPK (Clarify) TPACK (Clarify)

Transcript	TPACK Transformations
c. Since they have so many responses, why don't they key it in somewhere? d. They can use their phone or the laptop.	TPACK (Propose New idea) TK (Propose New idea)
2. Teacher A - There were two questions on the LMS forum for them to write their points about the flags.	TPACK (Clarify)
3. HOD a. How about archiving their own responses? b. How about a GoogleDoc for each group? c. It will be good to record their own learning, consolidate and share with their friends.	 TPACK (Clarify) TPACK (Refine new idea) TPACK (Support new idea)
4. Teacher B – The problem with the phone is that students cannot access shared postings … even using GoogleDoc on the phone is quite hard	TK (Identify Gap)
5. HOD a. For certain assignments, the students can use the phone but when they consolidate their learning they can use the laptop or desktop so that it is easy for them to read. b. The forum cannot really help them to consolidate their learning. c. It just collates the postings and comments. d. They won't have an overall picture of their learning. e. When they do their concept map later, it is not easy for them to revisit [what they have learnt about the topic]	 TPACK (Refine new idea) TPK (Identify Gap) TK (Identify Gap) TPK (Identify Gap) TPACK (Gap)
6. Teacher C – Is there anything that you can use to see the students' responses immediately [in class]?	TK (Identify Gap)
7. Teacher A – The Socrative app, but it does not allow posting of pictures and you can't archive the responses.	TK (Identify Gap)
8. HOD a. But that is only during the instance of posting but what I meant is that the students can [keep a] record their own learning. b. We highlighted the limitation of the phone but we can also explore beyond it.	 TPACK (Refine new idea) TK (Refine new idea)
9. Researcher a. How about online stickies? b. Teachers just need to set it up and the students can access with the URL as long as teachers don't delete the canvas.	 TK (Refine new idea) TK (Justify new idea)

The HOD conceptualized ICT being used to compile the students' responses to build knowledge as a community (lines 1a and 1b). These are aspects of TPK and TPACK that did not emerge in their implementation of lesson activities. She suggests new lesson ideas which are TPACK (line 1c) and proposed some tools that can be used (TK, line 1d). This idea was not picked up immediately as Teacher A clarified that they have collected the students' ideas through forum postings (line 2). The HOD reiterates that the pedagogical idea (TPACK) is to use ICT for archival of personal learning and extension of learning by accessing the ideas of their learning community (lines 3a and line 3c). Teacher B raises another issue of the limitation of the current technology for supporting this new pedagogical aim (TK, line 4). The HOD refines her conception of TPACK by asking the team to consider how different technologies can support different kinds of math activities (line 5a). She makes general comments on the weaknesses of the forum as a personal space for archival and consolidation which is an example of the team articulating TK and TPK (lines 5b-5d). She then applies this knowledge to highlight the gap when applying it to a specific lesson activity of concept mapping (TPACK, line 5e). Teachers pick up the idea of using alternative technologies and explore their TK to determine if there are any technologies that can help the teacher compile students' responses in class (lines 6 and 7). The HOD refines her conception of ICT use (TPACK) by reminding teachers that the pedagogical aim is also for students to archive their own learning (line 8a) and reiterates that they need not limit their TK to their current ICT tools (line 8b). The researcher suggests new TK in terms of a possible ICT tool and explains its pedagogical affordances (lines 9a and 9b).

5. Discussion

The results of this study show that in school-based context, the design of pedagogical change occurs through a process whereby different forms of TPACK are being shared, clarified and extended. This is because such kinds of change tend to be what Rittel and Weber (1973) describe as wicked problems where the desired outcomes as well as the means of achieving these outcomes are not clear at the outset of the project and emerges through design. Current TPACK studies (e.g. Koehler, et al., 2007; Koh & Divaharan, 2011, 2013) describe the kinds of TPACK that teachers create at the beginning and end of ICT courses. This study extends the knowledge of TPACK creation by exemplifying how lesson ideas are progressively being created and refined. It also shows that TPACK transformations in the area of pedagogy, content, and technology are needed to support the design of pedagogical change. Even as teachers seek to make transformations in the technological aspect, it requires concurrent clarification of the pedagogical aims of the change before the role of ICT can be clearly ascertained. Correspondingly, pedagogical change can also redefine how teachers approach their current pedagogies as well as their content knowledge. They key features of TPACK transformations needed for pedagogical change are:

5.1 Problems and gaps as catalysts

From Tables 1 to 3, it can be seen that opportunities for TPACK transformation begin when the gaps of current practices are raised for clarification. These kinds of interactions set the directions for the team to approach their design of the problem solution. In design literature, designers' conception of design problems are termed as design frames and reflection-in-action occurs as designers create and re-create frames as they evolve their problem solution (Cross, 2004; Schön, 1983). The study findings show that when the team is able to accept new frames and design ideas suggested within the team, it opens up opportunities for pedagogical change to emerge.

5.2 Iterative refinement

The findings of this study show that the ideas for pedagogical change are being refined progressively and iteratively. While the process of instructional design has been described as a systematic process with defined steps (e.g. Heinich, et al., 1999), the study findings support Laurillard (2012) and Summerville and Reid-Griffin's (2008) findings that it is emergent and iterative. The findings also show that lesson design ideas become progressively clearer as its associated problems and gaps are being discussed and clarified. Therefore, the ability of team members to "spar" effectively with each other as well as the willingness to provide time for the emergence of ideas are also important elements that facilitate TPACK transformations during pedagogical change.

5.3 Building on teachers' routine expertise

It can be seen that teachers' PCK played an important role in moving the design process forward in technological, pedagogical, and content transformations. Teachers' existing knowledge of students and classrooms are being used as epistemic resources to evaluate the possible success or failure of their design ideas. These findings show that for design to be effective, teachers' routine expertise needs to be tapped. Yet, a challenge of design is how teachers can be facilitated to make epistemic leaps beyond their routine expertise (Marra, 2005).

6. Limitations and Future Research

This study is limited to a primary school and a team of six teachers who were working on a math project. As the team was working on the project centered upon the adaption of a pedagogical approach, this might have influenced the findings. Therefore, the findings still need to be verified in different kinds of pedagogical change projects as well as with teachers designing for different subject areas, as well as in secondary and higher levels.

In this study, we examined the teachers' design talk. The talk could be further verified with teachers through interviews to improve the credibility of the study. In this study, researchers and a math specialist were also involved. This could have influenced the direction of the design decisions. In future studies, an area of study would be to examine the differences in pedagogical transformations with and without the inclusion of external parties could be compared. In addition, the relationships between design talk and effectiveness of implementation could be further correlated and examined in future studies. These kinds of studies could be used to derive guidelines on how design talk for pedagogical change could be better facilitated in school-based design teams to derive the educational outcomes they desire.

7. Conclusion

Windschitl (2002) observed that when teachers are not able to achieve deep pedagogical understanding, the kinds of pedagogical change that emerge from their design are typically characterized by surface level changes. A better understanding of teachers' design talk as well as how TPACK transformations can be better facilitated in team-based settings is one way of addressing this issue. These areas are worthy of more extensive study in future studies.

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