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Technological Pedagogical Content Knowledge of Secondary Mathematics Teachers

Boris Handal
The University of Notre Dame Australia
AUSTRALIA

Chris Campbell
The University of Queensland
AUSTRALIA

Michael Cavanagh and Peter Petocz
Macquarie University
AUSTRALIA

Nick Kelly
The University of Sydney
AUSTRALIA

Abstract

The integration of technology, pedagogy, and content in the teaching of secondary mathematics was explored among 280 secondary mathematics teachers in the State of New South Wales, Australia. The study adopted the technological pedagogical content knowledge (TPCK) model through the administration of a 30-item instrument called TPCK-M. The instrument consisted of three major theoretically based constructs: technological content knowledge (TCK), technological pedagogical knowledge (TPK) and technological pedagogical content knowledge (TPCK). Results indicated that PowerPoint and Excel constitute the two TCK modal technological capabilities while TPK scores revealed teachers' lower capacity to deal with the general information and communications technologies goals across the curriculum, such as creating digital assessment formats. TPCK-M scores seem to suggest a healthy standard in teachers' technological skills across a variety of mathematics education goals. However, the magnitude of such influence in practice needs to be further ascertained, given that the study identified a number of instructional, curricular, and organizational factors seriously inhibiting the integration of technology into teaching and learning. In general, to take advantage of more novel learning technologies, teachers need to be trained in working with online tools (webquests, wikis), mobile learning, and interactive whiteboards and in authoring digital learning resources.

Recent Australian policy and curriculum documents emphasize the important role of digital technologies as tools for improving the quality of learning and teaching in mathematics classrooms. The *Standards for Excellence in Teaching Mathematics in Australian Schools* (Australian Association of Mathematics Teachers, 2006) described excellent mathematics teachers as purposefully and responsively adopting a wide range of strategies and techniques for using information and communication technologies (ICTs) in the classroom.

More recently, the *Shape of the Australian Mathematics Curriculum* document (Commonwealth of Australia, 2009) noted the important role of digital technologies as a tool for learning mathematics. Yet, even though the range and availability of technological tools has increased dramatically, research continues to highlight the crucial role of teachers in ultimately determining the impact of technology in the classroom (Norton, McRobbie, & Cooper, 2000; Thomas & Chinnappan, 2008).

Teachers' perceptions of their technological skills (Forgasz, 2006) and their views concerning the usefulness of ICT for classroom instruction have been shown to be powerful predictors of intended and enacted usage of these tools (Stols & Kriek, 2011; Thomas, 2006). Even though technology has the potential to enhance learning and teaching in mathematics classrooms (Ball & Stacey, 2005; Dawson, Heathcote, & Poole, 2010), ICT tools are often employed for an established form of practice (Hayes, 2007; Ruthven & Hennessy, 2002) or for low-level tasks such as online drill and practice that have no significant bearing on student learning outcomes, since their formats resemble many printed rote learning exercises (Cavanagh & Mitchelmore, 2011; Polly, 2011a,b,c).

Teachers' integration of technological skills into teaching and learning needs to be appraised for two main reasons. Upholding high-quality teaching standards in schools is important, as is ensuring that students are exposed to a curriculum that takes into account instructional affordances brought by novel technologies (Handal, Cavanagh, Wood, & Petocz, 2011). Further, identifying current teachers' ICT learning and teaching skills has strategic value for planning professional development programs at both the school and systemic level (Polly, McGee, & Martin, 2010).

Given the rapid technological advances, this project was seen as critical to assist tertiary teacher educators and policy makers in secondary mathematics education. This paper examines the nature of *technological pedagogical content knowledge* (TPCK) of secondary mathematics teachers through a questionnaire survey study. Questionnaires have been found to be useful instruments for investigating teachers' attitudes and skills with respect to the use of technology for learning and teaching (e.g., Goos & Bennison, 2008).

Theoretical Framework

Koehler and Mishra (2008) proposed the characterization of teachers' ICT skills in teaching and learning across various dimensions. In proposing a theoretical model explaining efficient adoption of educational technology, the authors called for the need to integrate three fundamental types of teachers' knowledge, namely, technological knowledge, content knowledge, and pedagogical knowledge. The overlapping effect among these three elements is said to produce various fields each representing specific skills. Sitting at the center of all these intersections, the concept of TPCK emerges at the highest level of skill deployment (see Figure 1).

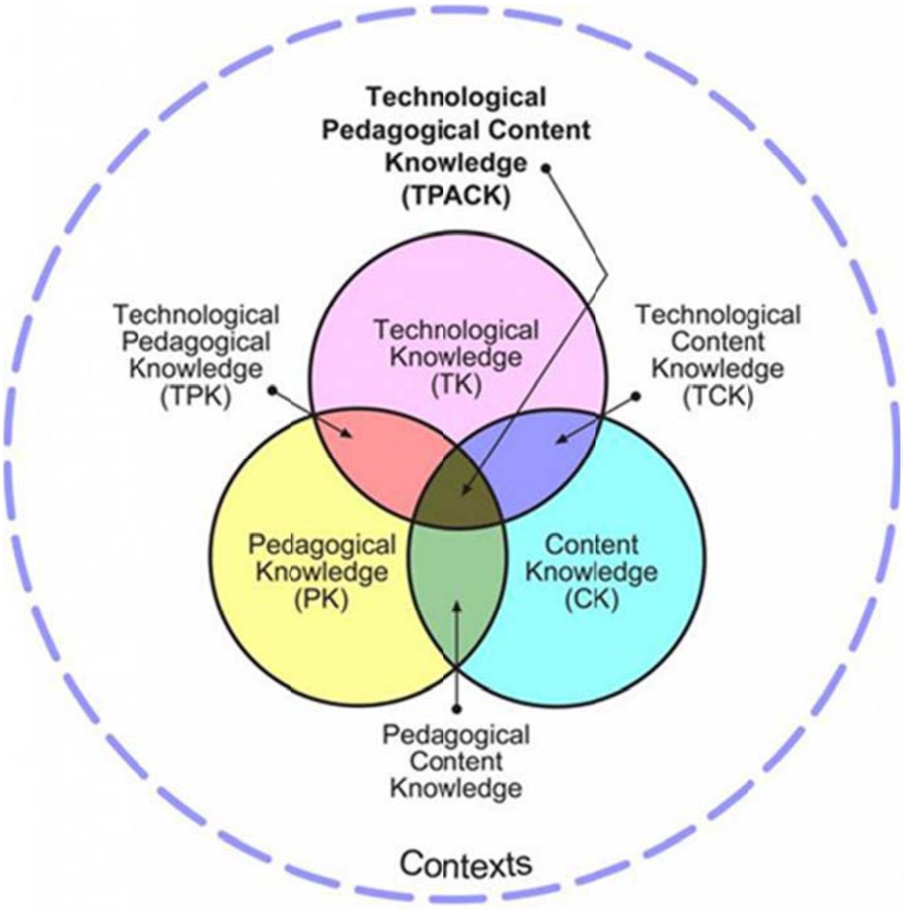

Figure 1. The integration of content, pedagogy, and technology in the TPCK framework (Koehler, 2011; reproduced by permission of the publisher, © 2012 by tpack.org.)

The model portrays the role played by pedagogical knowledge, content knowledge, and their interface, pedagogical content knowledge. Pedagogical knowledge refers to the teachers' *know-how* instructional expertise, including an understanding of teaching-led research literature, along with professional practical experience. Content knowledge is the *know-what* aspect of the subject-matter, more specifically, the body of professional knowledge that skilled practitioners typically must master to qualify in their field. In turn, pedagogical content knowledge is defined as the capability to deliver specific content through appropriate teaching processes leading toward successful student learning (Shulman, 1986).

The model also comprises four technology related fields: technological knowledge (TK), technological content knowledge (TCK), technological pedagogical knowledge (TPK) and TPCK. TK, TPK, and TPCK are strongly interrelated due to their common denominator. While TK refers to a broad range of general technical skills required to operate software and hardware or working with online environments (e.g., downloading a file from the Internet), TCK highlights those technical skills specific to a particular discipline (e.g., using statistics software for mathematicians). In turn, TPK focuses on instructional competencies that allow teachers to enhance learning while incorporating technology in the enactment of the curriculum.

TK and TCK are about deploying general and professional ICT skills, respectively. TPK revolves about various other teaching capabilities needed to work with technology and in specific situations, such as teaching using an interactive whiteboard, educating students on cybersafety issues, or demonstrating classroom management skills at the school computer lab. Finally, TPCK represents the set of competences standing at the highest level of the model, blending seamlessly subject-matter content, pedagogy, and technology and representing efficient teaching and learning through technology (Mishra & Koehler, 2006).

Most of the TPCK discourse on mathematics education has focused on its value in the curriculum, professional development models and methods of measurement (Angeli & Valanides, 2009; Archambault, Wetzel, Foulger, & Williams, 2010; Polly, 2011a,b). A number of TPACK-related scales have been designed to examine teachers' perceptions of integrating technology, content, and pedagogy in areas such as Internet use (Lee & Tsai, 2010), preservice education (Schmidt et al., 2009), online distance education (Archambault & Crippern, 2009), and science education (Graham et al., 2009).

In mathematics education, the TPCK model has been useful for exploring conceptually how teachers articulate content, pedagogy, and technology and for enriching the discourse on using ICTs within the subject area (Grandgenett, 2008; Johnston-Wilder & Pimm, 2004; Niess, 2005; Niess et al., 2009; Polly & Barbour, 2009). As such, this research was the first attempt to conduct an empirical study to apply the TPCK framework in secondary mathematics education through a questionnaire survey study of teachers' self-reported perceptions.

Research Questions

The present study was designed to characterize the TPCK of secondary mathematics teachers. More specifically, the study sought to address the following research questions:

1. What is the nature and magnitude of teachers'
    - TCK?
    - PCK?
    - TPCK?
2. How do school instructional, curricular, and organizational factors affect the integration of content, pedagogy and technology in secondary mathematics education in the context of the TPCK model?

Methodology

The TPCK-M questionnaire was designed to identify teachers' pedagogical content knowledge in secondary mathematics in terms of TCK, TPK and TPCK. These three domains were portrayed in three scales. TK was not included in the questionnaire because of the research emphasis on discipline-related technology (TCK).

Questionnaire Design

The questionnaire deliberately focused on the concept of ability as a measure of a respondent's capacity to carry out a particular task, rather than focusing on the enactment itself. Hence the stems were, "I am able to use technology to ..."(for Scales 1 and 3), and, “I am able to …”(for Scale 2). Such an approach assumed that respondents’ ability might be either potential or effective. Taking the latent approach to ability left open the possibility that the stated capability may have never been enacted for various reasons. The “'I am able to” rather than the “What I do in the classroom” approach had two obvious benefits over simply inventorying skills. First, it enabled the instrument to collect data on both potential or effective ability. We envisioned that professional learning programs and policy-making would benefit more with data relative to skills teachers already had, regardless of their enactment, for whatever reasons.

In particular, the TPCK scale was drawn to represent ideal goals of mathematics education, ones upon which ICT links could be established (Tables 1, 2, and 3 detail A, B, and C scale items, respectively). For example, concepts such as technology ability to “assist students to develop their maths problem solving skills” (C1 questionnaire item in Table 4) deal with providing an environment where computational work can be left to the domain of handheld calculators or dedicated software while the teacher focuses on developing students’ higher order thinking skills.

Deep learning can also be achieved through an ICT's affordance to “represent math problems linking symbolic, numerical, and graphical data” (C2 item), allowing the learner to make richer connections among various concepts and facts. Further, the instructional use of learning objects such as animations, simulations, and online applications helps both teachers and students “demonstrate mathematical models or concepts” (C3) in a more dynamic environment.

The dynamic environment facilitates “identify[ing] trends and patterns to predict possibilities” (C4), because technology can enhance student understanding of chance and data through graphing tools, allowing conjecture and hypothesizing. Further, students can learn to “explore or present mathematical content in a variety of different ways” (C5), because online media amplifies their research capabilities and opens a windows to the world within the classroom or on the field side. In fact, mobile learning, due to its ubiquity, makes learning accessible anywhere, anytime.

For statistical tasks, iPhones and iPads are powerful instructional tools to “collect, analyze and interpret data to make informed judgments” (C6) because of the online access but also due to their multimedia capabilities that allow students to create their own assignments beyond the paper-and-pencil realm. In doing so, learners can “incorporate authentic tasks in the learning of mathematics” (C7) because, as a result of having control on resource design and getting information readily though the Internet, the line between in-school and out-of-school mathematics becomes blurred. Using technology to understand multiple methods of solving a problem, either individually, in groups, or in whole-class discussion, “promotes substantive student communication in a math lesson” (C8).

In general, ICT can effectively realize the pedagogical dream of having the school curriculum more interconnected, that is, by integrating “the study of math with content from other Key Learning Areas” (C9) and by letting students and teachers access a wealth of information, both online and interactive, that goes beyond traditionally dominant printed material in school settings. Audio/video recordings, measuring devices, and other media can “support students’ mathematical investigations with digital tools” (C10), because the students’ role has changed from consumers to producers of knowledge, taking advantage of multimedia capabilities.

Scale Design

The TPCK-M questionnaire was designed to measure teachers' TPCK of secondary mathematics. Questionnaire items are described in Tables 2, 3, and 4. Items were drawn from the current literature and from previous TPCK-related instruments and in some cases modified to reflect the mathematical focus of this study (Archambault & Crippen, 2009; Archambault & Barnett, 2010; Lee & Tsai, 2010; Schmidt et al., 2009).

The questionnaire was focused on secondary mathematics education. Questionnaire items were later trialled with 5 teacher educators and 10 school teachers. During the trials these educators commented on the meaningfulness, appropriateness, and relevance of the items. The questionnaire consisted of two parts. The first section involved three Likert-type scales, namely TCK, TPK, and TPCK, comprising a total of 30 items. The second section involved open-ended responses to capture qualitative information about why teachers might find difficulty enacting their TPCK skills in the classroom.

Sample

Questionnaires were mailed to 123 secondary schools in urban and rural New South Wales (NSW), Australia. Two hundred eighty teachers from 94 secondary schools returned the questionnaires, representing 76% of the total number of schools targeted. The modal characteristics of the sample consisted of a female teacher (57%), holding a bachelor degree plus a diploma in education (42%) followed by bachelor of education holders (38%). Similarly, respondents reported having 3 to 5 years of teaching experience (11%) as the modal frequency, followed by the 30-32 and 18-20 year ranges with 10% and 9% of the participants, respectively. The respondents represent a workforce with the minimum acceptable qualifications in mathematics teaching, although a generational gap is evident. Most schools had access to educational technology such as interactive whiteboards and computers, as well as to ICT professional development, although it varied by school region.

Data Analysis

Scores were used to compare responses to individual questionnaire items. All responses were coded in a 5-point Likert scale arrangement from *strongly agree* to *strongly disagree*. In general, scores less than 3.0 were examined on a continuum ranging through *very low*, *low*, *moderately low* to *slightly below average* (see Table 1), while scores greater than 3.0 represented a continuum ranging from *slightly above average* to *very high*. A score of 3.0 would indicate an orientation that lies midway at a particular ability level.

Results and Discussion

Quantitative Analysis

A significance level of 0.05 was used for all statistical analysis due to the exploratory nature of the study. Two-tailed tests were used on all occasions. Rational equivalence reliability was assessed through Cronbach’s alpha, resulting in reliability coefficients of 0.944, 0.845, 0.867, and 0.924 for the whole instrument and the TCK, TPK, and TPCK scales, respectively. These coefficients suggest fairly high internal consistency reliability. In addition, an exploratory factor analysis is reported elsewhere confirming the structurally soundness of the instrument in terms of validity and reliability (Handal et al., 2012).

Table 1
Questionnaire Score Range

Score Range	Qualitative Descriptor
$1.0 \leq x < 1.5$	Very low
$1.5 \leq x < 2.0$	Low
$2.0 \leq x < 2.5$	Moderately low
$2.5 \leq x < 3.0$	Slightly below average
3.0	Average
$3.0 < x \leq 3.5$	Slightly above average
$3.5 < x \leq 4.0$	Moderately High
$4.0 < x \leq 4.5$	High
$4.5 < x \leq 5.0$	Very high

Descriptive statistics included mean, standard deviation, percentage, and Pearson product moment correlation analysis. Inferential statistics included two-tailed *t*-tests for independent samples and one-way ANOVA.

Technological Content Knowledge

Table 2 shows the mean scores for the TCK items. The relatively high mean scores for items related to Excel spreadsheets (A3, A4), PowerPoint (A1) and Paint/Photoshop (A2) were not unexpected. Excel, PowerPoint, and Paint are all Microsoft tools available in most personal and school personal computers. Mathematics teachers are likely to use spreadsheets for recording student test marks, and PowerPoint is used widely in schools for making presentations in staff meetings and for parents. The other relatively high mean score for locating online applications (A6) probably also reflects the fact that teachers are becoming increasingly knowledgeable in using the Internet as a source of teaching resources. The high mean score and relatively large standard deviation for creating and editing images (A2) may indicate that some teachers use these applications in their personal lives.

The midrange mean score for graphics calculators (A5) and its large standard deviation reflects the limited use of this technology in most NSW schools, though in a small number of (mostly independent) schools graphics calculators were commonly used until quite recently. A decline in the use of graphics calculators seems to have occured in NSW, probably due to the increasing use of free web-based calculators (Handal et al., 2011).

Similar results for dynamic geometry software (A7) are more likely to indicate a gradual growth in the use of this technology, particularly with GeoGebra software. GeoGebra is one of the mathematics software packages available to students and teachers through the Department of Education and Communities laptop program, and it has begun to feature more prominently in mathematics teacher conference presentations (e.g., Mathematical Association of New South Wales) in the last 5 years or so. A shift may be taking place, with a move away from graphics calculators toward dynamic geometry software. Online graphing calculators and GeoGebra are now freely accessible to all as web-based applications, although under a limited version.

Table 2
TCK Scale

I am able to use technology to …	**Mean**	***SD***
A1: Create a PowerPoint presentation	4.36	0.98
A2: Create and edit simple images (e.g. Microsoft Paint or Photoshop)	3.93	1.19
A3: Make calculations on a spreadsheet	4.45	0.75
A4: Create charts/graphs using a spreadsheet	4.35	0.84
A5: Use a graphic calculator	3.66	1.15
A6: Locate and evaluate maths online applications and tools (e.g., learning objects, apps, simulators)	4.04	0.95
A7: Use dynamic geometry software (e.g., GeoGebra, Geometer's Sketchpad, Autograph, Cabri)	3.66	1.12
A8: Use computer algebra software (e.g., Derive, Mathematica)	2.84	1.15
A9: Construct multimedia objects embedding pictures, sound and animations	3.14	1.29
A10: Network with other colleagues and professional associations through online forums, Facebook, etc	3.19	1.35

Computer algebra software such as Derive and Mathematica (A8) yielded low mean scores and large standard deviations, indicating that these resources are not widely used by mathematics teachers. Some teachers seem to use these upper-secondary tools often, while others use them rarely. Similarly, digital-authoring skills seem to be at a developmental level, particularly when it comes to constructing multimedia objects (A9). Using the Internet to network with other colleagues and professional associations (A10) ranked just above the average, representing an incipient understanding of the benefits of being connected to communities of learners at the discipline level through online forums or social media.

Technological Pedagogical Knowledge

The TPK scale items have generally scored lower than the TCK scale items. TPK represent capabilities that teachers enact across the curriculum. The mean scores for the TPK construct (Table 3) were generally lower, and the standard deviations were generally higher than for the TCK construct, indicating a lower and less consistent teacher agreement with these items.

The highest and most consistent response was to the general statement regarding teachers' ability to use technology to support students' research skills (B1) in the form of information literacy skills. Similar results were found for appraising educational websites and software (B10). These results are not surprising given the general nature of these items.

The mid-range response to the interactive whiteboard item (B2) may be an indicator that interactive whiteboards are becoming more readily available in schools, but their uptake is still fairly patchy. Similar results for the item on dealing with cyberbullying (B7) may simply reflect the fact that many mathematics teachers are not called on to respond to incidents of this type.

Table 3
TPK Scale

I am able to ...	**Mean**	***SD***
B1: Use technology to develop students' research skills	3.92	0.81
B2: Teach a concept using an interactive whiteboard	3.62	1.28
B3: Create a webquest to deliver a curriculum unit	2.35	1.13
B4: Use mobile devices (e.g. iPad, smartphone) in teaching	2.63	1.23
B5: Engage students in collaborative learning through wikis	2.44	1.11
B6: Guide students in creating their own multimedia presentations	3.04	1.29
B7: Deal with cyberbullying and cybersafety issues in the school	3.60	1.07
B8: Use technology to provide students with alternative forms of assessment	3.59	1.08
B9: Engage students in critically analysing online texts or images	3.17	1.07
B10: Appraise educational websites and software for usefulness and quality	3.68	1.00

The mean score for the use of technology for alternative assessment tasks (B8) is relatively low but probably reflects the general lack of alternative assessment in secondary mathematics rather than teachers' ICT use. Similarly low responses for online texts and images (B9) and multimedia presentations (B6) probably also indicate that these ICT tools do not have a direct fit with typical pedagogical approaches for secondary mathematics.

The remaining three items relating to mobile devices (B4), wikis (B5), and webquests (B3) have the lowest mean scores for the entire survey, suggesting that teachers are not confident enough to work with those tools.

Technological Pedagogical Content Knowledge

The means and standard deviations for TPCK (Table 4) had the narrowest range of any of the three constructs in the survey, with the mean scores ranging from 3.39 to 4.09 and the standard deviations ranging from 0.84 to 1.14. TPCK was the only scale whose items scored all positively.

The highest mean scores and lowest standard deviations relate to the items for data analysis (C6) and problem solving (C1). These results are not surprising for a secondary mathematics teacher sample. The results were similar for linking symbolic, numerical, and graphical data (C2), mathematical content (C5), substantive student communication (C8) and authentic tasks (C7). These items are all generic, so the midrange responses are not unexpected. Furthermore, these tasks are commonly delivered in class through spreadsheets either for making calculations or creating graphs or charts through typical Microsoft tools like Excel. They are introduced either in the data and chance component of the school curriculum or, in general, to portray modeling situations for problem solving. These mathematical capabilities also scored highly in A3 and A4. Similarly, being knowledgeable in using online maths applications and tools freely available on websites, which also scored highly in A6, might have contributed to that effect.

Table 4
TPCK Scale Item

I am able to use technology to ...	**Mean**	***SD***
C1: Assist students to develop their maths problem-solving skills	4.04	0.84
C2: Represent maths problems linking symbolic, numerical and graphical data	3.98	1.00
C3: Demonstrate mathematical models or concepts through learning objects (e.g., animations, simulations, online applications)	3.73	1.14
C4: Identify trends and patterns to predict possibilities	3.70	1.00
C5: Explore or present mathematical content in a variety of different ways	3.98	0.90
C6: Collect, analyse and interpret data to make informed judgements	4.09	0.84
C7: Incorporate authentic tasks in the learning of mathematics	3.80	0.89
C8: Promote substantive student communication in a maths lesson (e.g., class discussion on multiple methods of solving a problem)	3.89	0.97
C9: Integrate the study of maths with content from other Key Learning Areas (e.g, English, Arts, Science, History)	3.63	1.02
C10: Support students' mathematical investigations with digital tools (e.g., audio/video recording, measuring devices, etc)	3.39	1.10

Lower means and higher standard deviations were found for the remaining TPCK items. These items relate to digital learning objects (C3), identifying trends (C4), integration with other key learning areas (e.g., math, science, English, etc.) (C9), and mathematical investigations (C10). The relatively low mean score for C3 is an indication that digital learning objects are still not being assimilated enough in secondary mathematics except at the personal awareness or familiarity level.

The low means for C9 ("Integrate the study of math with content from other Key Learning Areas"), which scored 3.63, and C10 ("Support students' mathematical investigations with digital tools"), which scored 3.39, are consistent with previous research about the narrow confines and traditional pedagogies typically observed in secondary mathematics lessons (Nesmith, 2008). Item C4 ("Identify trends and patterns to predict possibilities") yielded a moderately high mean, probably reflecting the spreadsheet effect in school statistics topics.

Qualitative Analysis

The questionnaire design intentionally left participants space for identifying possible barriers that hinder the translation of potential ability into enactment. A great deal has been written about factors impeding the implementation of curriculum innovations (Handal et al., 2011). Contemporary approaches to curriculum evaluation tend to focus on appraising teachers' perceptions about a particular aspect of school reforms as means to understand whether those opinions are compatible and, therefore, support change. In the open-ended section of the questionnaire, participants provided a wealth of qualitative information to characterize instructional, curricular, and organizational factors mediating between potential ability and enactment.

Responses were further broken down into smaller subthemes representing single meaningful ideas. A subtheme represented a complete concept expressed by a respondent. Similar subthemes within each theme were collapsed until no more could be made because of saturation. In turn, the emerging themes were grouped, according to their nature, into instructional, curricular, and organizational issues. The comments to follow indicate the complexity in teachers' integrating content, pedagogy, and technology according to the TPCK model when instructional, curricular, and organizational issues situate it within a sociocultural context.

Instructional issues were those identified as associated with teaching and learning issues emerging from integrating content, technology, and pedagogy in the classroom. Curricular issues referred to concerns related to the way ICT was articulated and delivered within the school environment. In turn, organizational issues were those connected with the logistics needed to materialize the integration of ICT into the curriculum.

Instructional Factors

This section discusses various instruction-related issues, which include a student's ability, the balance between pedagogy and technology, and learning to integrate technology, content, and pedagogy while teaching, particularly for specific tasks and activities.

A number of teachers expressed the view that the enactment of ability was dependent on the nature of the student and the subject. They believed that ability enactment depends on a student's capability to perform:

> "What if I can 'engage' some students (say high ability) in a CAS [computer algebra system] lesson, but not others?"
>
> "Incorporation of technology to an extent depends on ability of group and classroom management procedure."
>
> "Often the use of technology is hampered by…students' lack of basic technology"

A sense of purpose while integrating technology, content, and technology also seemed to be a powerful drive to transform ability into practice. Some responses in this regard included the following:

> "I do not use technology for the sake of it, it must enhance the lesson."
>
> "[Technology] is a resource that I use when I believe it best demonstrates/ promotes/ explains a concept."

These responses show teachers' concern for placing pedagogy before technology when designing teaching experiences. Teachers seem to be aware of the need to use technology to support instructional objectives that will eventually advance learning rather than using it as a pastime every once in a while.

The results of this survey suggest that professional development is badly needed. A number of responses indicate a need for more specialized training. The required training seemed to be more relevant to identifying applications for each technology, integrating content and pedagogy. For example, a respondent remarked, “There are so many tools emerging that we could use to assist our students’ learning that I often feel overwhelmed. Which ones can I use? How can I use it to enhance my students learning? How do I use it? Where can I get help?

In particular, training should support the needs of those having graduated a long time ago, which exacerbates professional development needs:

> “I need training in using a lot of technology in math. I went through high school and university without touching a computer.”
>
> “I finished uni[versity] ‘pre-computer’ age and don't seem to have been given the time or training to gain adequate skills in the use of technology.”

Interestingly, to supplement professional competence some teachers resorted to different individual initiatives, such as buying their own ICT equipment to advance their skills: “I am currently trying to upgrade my skills in the area of ICT. I have purchased an iPad last Friday and will engage colleagues as well as the Apple shop to show me how to use it for classroom teaching.”

Others were not embarrassed to make mistakes as they integrated technology, content, and pedagogy (“Everything I do in the classroom I do with technology I have worked through trial and error”) or simply by learning from pupils and adopting a humble posture of learning (“I hope to continue to learn new technologies as they emerge, as well as learning from my students who are always up with the times.”)

More importantly, a number of teachers reached the stage where acquiring ICT skills in teaching had become a developmental and ongoing process:

> “Presently trying to catch up to others by doing courses. It all takes time!”
>
> “I am currently trying to upgrade my skills in the area of ICT…Our school uses Moodle and I would put myself down as an intermediate user, but just past beginner!

Hence, in-school support to integrate technology into teaching and learning is essential, preferably making use of collaborative approaches such as peer mentoring, peer coaching, action research, and professional discussions (Handal, Handal, & Herrington, 2003).

Curricular Factors

Teachers’ ability to interface between new pedagogies associated with ICT tools and the demands from a perceived traditional school culture seemed to dominate the curricular domain along with struggling to cover an overcrowded curriculum and finding meaningful e-learning resources. The integration of technology into the curriculum is vital because it defines the agenda within which instruction is delivered. More importantly, there is a hidden component of the official curriculum when implemented in schools. Often, teachers need to constrain their expectations for innovative teaching to those imposed by conservative local environments.

Responses revealed that teachers struggled in balancing up technology with traditional teaching methods allegedly fostered by a traditionally oriented curriculum:

> Technology is a great supplementary tool, but pen and paper working of problems is still the core focus for the math we teach at our school....Finding it difficult to use ICT effectively in learning math, that is basically rote learning.

Although the quantitative analysis revealed teachers' healthy standards at the level of pedagogical technological beliefs, the qualitative component presented a less glamorous perspective. Teachers' instructional practices are constantly scrutinized by parents and school administrators and must meet their expectations in a way. This aspect is crucial to understanding why so often healthy pedagogical beliefs do not translate into practice. Despite all good intentions embedded in curriculum documents advocating curricular change, school settings still seem to remain conservative in the implementation of new reforms. In particular, a number of school administrators and parents are more prone to support teaching that leads to the acquisition of basic skills, relegating problem solving and new technologies to a second plane (Handal & Herrington, 2003).

An overcrowded curriculum seems to be another reason why abilities are not translated into practice. Ideally, as a teacher commented, “Most successful math lessons/units are those that have a good balance of digital technologies and ‘traditional’ mathematics teaching methods.” However, the lack of time to deliver course content seems to be a factor restraining teachers in using their ICT skills: “In most cases, TIME is a restricting factor and all the concepts need to be taught in a very short time so that students are prepared for the exams. If all concepts aren't taught, parent and student complaints follow.”

Finding high-quality e-learning resources appropriate to a particular learning objective seems to be another curricular inhibiting factor: “Most tools are better as demonstration tools, rather than for the students to use.” In regard to mobile learning devices, a respondent remarked: “Big fan of iPod Touches, iPads but am yet to find software apps that are particularly useful. Some graphics apps are good, but overall not great.”

Organizational Factors

Teachers reported being pressured by various logistics demands such as accessing well-functioning equipment and technical issues managing students’ computers.

Most references to logistic inhibiting factors relate to access to hardware and software in schools.

> “I personally have many skills in the use of technology in the classroom. However, I do not have access to useable technology in the classroom. E.g., Internet connections, data projectors, speakers and SmartBoards.”
>
> “We don’t have any dynamic geometric software to comment on....Very difficult to integrate technology when you don’t have it.”

It is well known that the infrastructure to support online learning technologies, both software and hardware, is onerous to schools budgets, which are constantly under financial pressure.

Teachers' concerns also included unreliable school technology systems: "I feel that one of the factors that retard the positive use of technology in the classroom is the unreliability and un-user friendliness of the networks and unavailability in highly resourced computer labs."

Similarly, teachers found it frustrating to deal with carrying the teaching work while attending to other more technical and logistics issues: "Setting lessons based on laptops usage are [sic] extremely frustrating given the number of students who 1. forget laptops, 2. have it in for repair, 3. don't have it charged, 4. can't access work."

Other organizational factors included the banning of mobile devices, as reported by a teacher: "The blockage of personal devices at school prevents developing students' skills in this area and the ability to utilize this function." Such attitudes indeed reflect the traditional nature of some schools that are resisting change and not allowing the full integration of digital technologies into teaching and learning.

In general, these instructional, curricular, and organizational factors show a variety of issues surrounding the translation of TPCK into teaching and learning. All these factors mount pressure on many teachers who, although willing to integrate technology, feel constrained by the multiple demands as well as by limitations inherent in school settings. As a teacher wrote,

> 2011 is my first year of full-time teaching since 2001. Technology has crept in very heavily during that time and I have been trying to equip myself with the necessary skills to survive in the classroom each day and perform all administrative tasks.

Conclusions and Implications

Archambault and Barnett's (2010) assertion that "TPCK creates additional boundaries…and already ambiguous lines drawn between pedagogy and content knowledge" (p. 1658) was confirmed by the complexity revealed when situating the analysis within a mathematics education framework. In a way, disaggregating TK, TPK, and TPCK into discrete units is difficult, as these three concepts are dynamically intertwined and overlap in some cases. The TPCK analysis became further enriched by considering both quantitative and qualitative data. Such perspective added a sociocultural dimension as the analysis encompassed instructional, curricular, and organizational school contexts.

Quantitative data were useful in diagnosing how 280 secondary mathematics teachers appraised their own TPCK and abilities. The study found that, in general, teachers relied on longstanding Microsoft tools like Excel, PowerPoint, and Paint. As tools derived from business models and adult education, teachers appeared to master them and adapt them to the exigencies of school environments. While this finding may not be surprising due to the extensive accessibility to these tools in schools, offices, and homes, it comes at the expense of more specialized pedagogical activities requiring teachers' engagement in producing their own digital resources. Nevertheless, it is indispensable to acknowledge that learning experiences that appropriately use digital resources are also a function of training and time to generate such specialized tasks and activities, as discussed in the qualitative component of this study.

Teachers' knowledge of more novel learning technologies usually associated with online media is still developing and has low impact. Some tools that have been in the educational arena for a while, such as webquests, graphics calculators, and interactive whiteboards, have not been widely adopted. Further, more recent online resources, including learning objects, social networking, and mobile technology, appear to be way behind their implementation in the mathematics classroom. When it comes to technological pedagogical capabilities operating across the curriculum, teachers' self-reported abilities might fall at the initial stages of adoption, normally characterized by awareness and personal learning (Handal, Chinnappan, & Herrington, 2004).

The Internet keeps making its mark, and teachers appear to discover its benefits more as experimenting in class than as a part of a guided curricular process. More likely, teachers seem to appreciate the potentialities of those tools in teaching and learning but are deterred by instructional, curricular, and organizational factors mediating between readiness and actual skill enactment.

The need for more professional development programs is highly evident, not only for the mastery of the tools themselves but also for their pedagogical application to specific learning objectives. Moreover, teachers need professional development in teaching generic skills across the curriculum associated with the Internet, ranging from providing cyberbullying/cybersafety strategies to deploying digital forms of assessment.

In transferring their TPCK to practice, teachers' responses reveal an intricate decision-making process interwoven with instructional, curricular, and organizational factors. Teachers might refrain from using technology, even when it is mandated or recommended, based on various personal observations, such as a child's cognitive development, the nature of the topic, classroom management issues, or simply the pressure of being forced to deliver a crowded curriculum under schedule. Learning activities associated with technology might be subtly considered within the school system as extra to the curriculum. Keeping the balance between what is considered innovative teaching and traditional curriculum delivery is, therefore, a major dilemma.

Apart from a pressing need for professional learning, teachers' readiness in using technology seems to be hindered by lack of ability and support in locating digital resources and activities that are pedagogically productive. Educational bodies would do well to provide such discipline-specific professional support, along with technical training with a strong emphasis on pedagogy. Furthermore, shortages of appropriate educational software and hardware as well as poor technical maintenance of school networks appeared to be perceived not only as an infrastructure deficit but also as lack of official priority.

Given these reflections, initiatives to enhance mathematics education through technology must be creative and thoughtful. Teachers' responses suggest that change can not be only about delivering professional development or logistic resources. Instructional, curricular, and organizational school factors must be identified at the local level and those issues negotiated with teachers, so that change incorporating TPCK becomes more possible.

Because teachers' TPCK perceptions in this study are self-reported and cannot be immediately verified (Cohen, Manion, & Morrison, 2011), further research through participant observation studies is recommended to ascertain the nature, magnitude, and direction of the interaction among teachers' TPCK elements and the reality of school contexts.

References

Angeli, C., & Valanides, N. (2009). Epistemological and methodological issues for the conceptualization, development, and assessment of ICT-TPCK: Advances in technological pedagogical content knowledge (TPCK). *Computers & Education, 52*(1), 154-168.

Archambault, L. M., & Barnett, J. H. (2010). Revisiting technological pedagogical content knowledge: Exploring the TPCK framework. *Computers & Education, 55*, 1656-1662.

Archambault, L. M., & Crippen, K. (2009). Examining TPCK among K-12 online distance educators in the United States. *Contemporary Issues in Technology and Teacher Education, 9*(1), 71-88. Retrieved from http://www.citejournal.org/vol9/iss1/general/article2.cfm

Archambault, L., Wetzel, K., Foulger, T. S., & Williams, M. K. (2010). Professional development 2.0: Transforming teacher education pedagogy with 21st century tools. *Journal of Digital Learning in Teacher Education, 27*(1), 4-11.

Australian Association of Mathematics Teachers. (2006). *Standards for excellence in teaching mathematics in Australian schools*. Adelaide, Australia: Author.

Ball, L., & Stacey, K. (2005). Teaching strategies for developing judicious technology use. In W. J. Masalski & P. C. Elliot (Eds.), *Technology-supported mathematics learning environments* (67th Yearbook of the National Council for Teachers of Mathematics; pp. 3-16). Reston, VA: National Council for Teachers of Mathematics.

Cavanagh, M., & Mitchelmore, M. (2011). Learning to teach secondary mathematics using an online learning system. *Mathematics Education Research Journal, 23,* 417-435.

Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education*. London, England: Routledge.

Commonwealth of Australia. (2009). *Shape of the Australian curriculum: Mathematics*. Retrieved from http://www.acara.edu.au/verve/_resources/Australian_Curriculum_-_Maths.pdf

Dawson, S., Heathcote, L., & Poole, G. (2010). Harnessing ICT potential: The adoption and analysis of ICT systems for enhancing the student learning experience. *International Journal of Educational Management*, *24*(2), 116-128.

Forgasz, H. (2006). Factors that encourage or inhibit computer use for secondary mathematics teaching. *Journal of Computers in Mathematics and Science Teaching, 25,* 77-93.

Goos, M., & Bennison, A. (2008). Surveying the technology landscape: Teachers' use of technology in secondary mathematics classrooms. *Mathematics Education Research Journal, 20,* 102-130.

Graham, C. R., Burgoyne, N., Cantrell, P., Smith, L., St Clair, L., & Harris, R. (2009). Measuring the TPACK confidence of inservice science teachers. *Tech Trends, 53*(5), 70-79.

Grandgenett, N. F. (2008). Perhaps a matter of imagination: TPCK in mathematics education. In The AACTE Committee on Innovation and Technology (Ed.), *Handbook of technological pedagogical content knowledge (TPCK) for educators* (pp. 145-165). New York, NY: Routledge.

Handal, B., Campbell, C., Cavanagh, M., Petocz, P., & Kelly, N. (2012). Integrating technology, pedagogy and content in mathematics education. *Journal of Computers in Mathematics and Science Teaching, 31*(4), 387-413.

Handal, B., Cavanagh, M., Wood, L., & Petocz, P. (2011). Factors leading to the adoption of a learning technology: The case of graphics calculators. *Australasian Journal of Educational Technology, 61*(2), 70-75.

Handal, B., Chinnappan, M., & Herrington, T. (2004, October). *Adopting graphics calculators in NSW.* Proceedings of the 2nd National Conference on Graphing Calculators (pp. 29-43), University Sains Malaysia. Retrieved from http://math.usm.my/Events/NCGC04Proc/PDF/BorisHandal.pdf

Handal, B., Handal, P., & Herrington, A. (2003). Training teachers in evaluating educational tutorial software. *Electronic Journal for Technology in Education, 2*(1). Retrieved from http://ejite.isu.edu/Volume2No1/handal.htm

Handal, B., & Herrington, T. (2003). Mathematics teachers' beliefs and curriculum reform. *Mathematics Education Research Journal*, *15*(1), 59-69.

Hayes, D. N. A. (2007). ICT and learning: Lessons from Australian classrooms. *Computers & Education, 49,* 385-395.

Johnston-Wilder, S., & Pimm, D. (2004). *Teaching secondary mathematics with ICT. Learning and teaching with ICT.* Berkshire, England: Open University Press.

Koehler, M. J. (2011). TPCK – Technological pedagogical and content knowledge. Retrieved from http://www.tpck.org/

Koehler, M. J., & Mishra, P. (2008). Introducing TPCK. In The AACTE Committee on Innovation and Technology (Eds.), *Handbook of technological pedagogical content knowledge for educators* (pp. 1-29). New York, NY: Routledge.

Lee, M-H., & Tsai, C-C. (2010). Exploring teachers' perceived self efficacy and technological pedagogical content knowledge with respect to educational use of the World Wide Web. *Instructional Science*, *38*, 1-21.

Mishra, P., & Koehler, M.J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, *108*(6), 1017-1054.

Nesmith, S.J. (2008). Mathematics and literature: Educators' perspectives on utilizing a reformative approach to bridge two cultures. *Forum on Public Policy, 2008*(2). Retrieved from http://forumonpublicpolicy.com/summer08papers/archivesummer08/nesmith.pdf

Niess, M. L. (2005). Scaffolding math learning with spreadsheets. Learning connections—Mathematics. *Learning & Leading with Technology, 32*(5), 24-25.

Niess, M. L., Ronau, R. N., Shafer, K. G., Driskell, S. O., Harper S. R., Johnston, C.,... & Kersaint, G. (2009). Mathematics teacher TPACK standards and development model. *Contemporary Issues in Technology and Teacher Education*, *9*(1), 4-24.

Norton, S., McRobbie, C. J., & Cooper, T. J. (2000). Exploring secondary mathematics teachers' reasons for not using computers in their teaching: Five case studies. *Journal of Research on Computing in Education, 33,* 87-109.

Polly, D. (2011a). Developing teachers' technological, pedagogical, and content knowledge (TPACK) through mathematics professional development. *International Journal for Technology in Mathematics Education, 18*(2), 83-95.

Polly, D. (2011b). Examining how the enactment of TPCK varies across grade levels in mathematics. *Journal of Computers in Mathematics and Science Teaching, 30,* 37-59.

Polly, D. (2011c). Examining teachers' enactment of technological pedagogical and content knowledge (TPACK) in their mathematics teaching after technology integration professional development. *Journal of Computers in Mathematics and Science Teaching, 30*(1), 37-59.

Polly, D., & Barbour, M. (2009). *Developing teachers' technological, pedagogical, and content knowledge in mathematics*. Paper presented at the Society for Information Technology & Teacher Education International Conference 2009, Charleston, SC.

Polly, D., McGee, J. R., & Martin, C. S. (2010). Employing technology-rich mathematical tasks in professional development to develop teachers' technological, pedagogical, and content knowledge (TPCK). *Journal of Computers in Mathematics and Science Teaching, 29*, 455-472.

Ruthven, K., & Hennessy, S. (2002). A practitioner model of the use of computer-based tools and resources to support mathematics teaching and learning. *Educational Studies in Mathematics, 49,* 47–88

Schmidt, D. A., Baran, E., Thompson, A. D., Mishra, P., Koehler, M. J., & Shin, T. S. (2009). Technological pedagogical content knowledge (TPCK): The development and validation of an assessment instrument for preservice teachers. *Journal of Research on Technology in Education, 42*(2), 123-149.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4-14.

Stols, G., & Kriek, J. (2011). Why don't all maths teachers use dynamic geometry software in their classrooms? *Australasian Journal of Educational Technology, 27*, 137-151.

Thomas, M. O. J. (2006). Teachers using computers in mathematics: A longitudinal study. In J. Novotná, H. Moraová, M. Krátká & N. Stehlíková (Eds.), *Proceedings of the 30th annual conference of the International Group for the Psychology of Mathematics Education* (Vol. 5, pp. 265-272). Prague, Czech Republic: Program Committee.

Thomas, M. O. J., & Chinnappan, M. (2008). Teaching and learning with technology: Realising the potential. In H. Forgasz, A. Barkatsas, A. Bishop, B. Clarke, S. Keast, W-T.

Seah, ... S. Willis (Eds.), *Research in Mathematics Education in Australasia 2004-2007* (pp. 167-194). Sydney, Australia: Sense Publishers.

Author Notes

Boris Handal
The University of Notre Dame Australia
AUSTRALIA
email: boris.handal@nd.edu.au

Chris Campbell
The University of Queensland
AUSTRALIA
email: chris.campbell@uq.edu.au

Michael Cavanagh
Macquarie University
AUSTRALIA
email: michael.cavanagh@mq.edu.au

Peter Petocz
Macquarie University
AUSTRALIA
email: peter.petocz@mq.edu.au

Nick Kelly
The University of Sydney
AUSTRALIA
email: Nick.kelly.mail@gmail.com