TEACHERS' TECHNOLOGICAL, PEDAGOGICAL AND CONTENT KNOWLEDGE

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The development of pedagogical content knowledge

Teaching, like other fields of human endeavour, draws on knowledge systems. In the case of teaching, these knowledge systems relate to content knowledge and, additionally, knowledge of students' thinking and learning (Mishra & Koehler, 2006). There has been a shift in focus from content knowledge as the main reference towards knowledge of students' thinking and learning. This shift can be traced back to the 1980s when the mutual exclusion of pedagogical knowledge from content knowledge began to be seen as undesirable. Shulman was an advocate of a paradigm shift which would allow a blending of pedagogical knowledge and content knowledge into *pedagogical content knowledge*. He regarded pedagogical content knowledge as a particular form of knowledge that can enhance the teacher's ability to teach the subject. Shulman viewed pedagogical content knowledge as the means through which a subject can best be made understood to learners. As he explains,

> *Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one's subject area, the most useful forms of representations of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations – in a word, the ways of representing and formulating the subject that make it comprehensible to others.* (Shulman, 1986)

Following on from the work of Shulman, further research took place into teachers' knowledge. Notably, explorations into the pedagogical and content knowledge (PCK) and content knowledge (CK) of secondary mathematics teachers were conducted in 2004 in the COACTIV project (Krauss, Baumert, & Blum, 2008). The COACTIV project, more formally known as *Professional Competence of Teachers, Cognitively Activating Instruction, and the Development of Students' Mathematical Literacy*, focused on formulating and assessing desirable qualities of secondary mathematics teachers. In the COACTIV project, PCK was considered to be a composite of the knowledge of how to explain and represent mathematics to students, an understanding of how students think and learn, along with knowledge of different ways to solve mathematical problems. CK was considered to be an in depth knowledge of high school mathematics.

The conceptualisations of PCK and CK which were constructed for the COACTIV project were validated through the results of assessment of teachers' knowledge of content and pedagogy. For example, it was found that differences in CK were in line with difference in levels of university training. It was acknowledged that it can be challenging to find assessment items that focus on predominantly on PCK since, not surprisingly, there appeared to be an almost inextricable link between CK and PCK.

The assessment results uncovered, however, the possibilities of two routes to the development of PCK. One pathway was found to be through growth in CK. University students of advanced mathematics, for example, scored well on assessment on CK. These students, despite their lack of training in education, also scored surprisingly well on PCK. This was supportive of the idea that developing more in depth knowledge of a subject leads to a greater ability to teach that subject.

The second pathway to the development of PCK was uncovered from assessment of teachers who had considerable generalised PK but little CK in mathematics. This came to light from the assessment of teachers of Biology and Chemistry who, by the nature of their training, had not been exposed to mathematics in any great depth. Interestingly, these teachers achieved reasonably well on PCK despite their very limited access to CK. It transpired therefore that teachers who had developed pedagogical skills through teaching subjects other than mathematics could blend their existing teaching skills with new knowledge about mathematics. The results suggest, therefore, that development in PCK can be achieved by blending existing CK with new PK or by blending existing PK with new CK (Krauss et al., 2008).

Blending teachers' technological knowledge with their pedagogical and content knowledge

The digital age has brought new possibilities for many aspects of the pedagogical content knowledge that Schulman spoke of in the 1980s. New and powerful representations, illustrations and demonstrations are available to teachers through the use of digital technology. The impact of digital technology in this regard has become so significant that it has justified an augmentation of the 1980s paradigm of pedagogical content knowledge to take into account new forms of technological knowledge relevant to the 21st century.

Researchers in the field of technology use in secondary mathematics perceived a need for new conceptualisations of teachers' knowledge in order to embrace the factor of technology. For example, in their study of teachers in technology-rich environments in different institutional contexts, Goos and Bennison (2007) saw the need for a framework which is sufficiently sophisticated to cope with the complex nature of the teacher's situation (Goos & Bennison, 2007). An important component of such a framework is that it addresses the need for professional development to enable teachers to cope with the subtle connections and tensions between technological, pedagogical and content knowledge.

Mishra and Koehler (2006) have devised a conceptual framework which they refer to as the Technological and Pedagogical Content Knowledge (TPCK) framework. This framework is relevant to various aspects of modern-day mathematics teaching. The TPCK framework helps to identify what teachers need to know about pedagogical and content knowledge in a technology-rich environment and how to gain this knowledge. The TPCK framework can be thought of as a logical development of the concept of pedagogical and content knowledge (PCK) first described in the pre digital technology era of the 1980s (Shulman, 1986). The development of PCK to TPCK may seem like a straight forward progression but it is important to note that digital technology changes more rapidly than other types of technologies that were introduced in previous eras in teaching. The ever changing nature of digital technology increases the level of complexity that teachers need to cope with. Hoyles and Lagrange (2010) recognise the increase in complexity that teachers face when digital technology is introduced into their situation and they explain that,

> *The integration of any new artefact into a teaching situation can be expected to alter the situation's existing equilibrium and requires teachers to undergo a complex process of adaptation. In the case of digital technologies, the modifications required of routine practices are likely to be particularly pronounced.* (Hoyles & Lagrange, 2010)

The TPCK framework brought into focus the intersection of technological, pedagogical and content knowledge that is required for effective technology integration. This intersection was the main feature of the TPCK framework, but discussions arose in relation to other pairings of knowledge within the framework. The combinations of knowledge that the framework supported then expanded to comprise pedagogical and content knowledge (PCK), technological and content knowledge (TCK), technological and pedagogical knowledge

(TPK) as well as technological, pedagogical and content knowledge (TPCK). These combinations of knowledge were referred to as the total package of knowledge (TPACK) that teachers could draw on to bring about technology integration (Niess, 2009). It is helpful that the TPACK framework does not just focus on TPCK but also on the pairings of PCK, TCK and TPK. The value of being able to study these pairings of knowledge is evident, for example, in the descriptions given by Krauss et al. (2008) of the different ways that PCK can be developed.

Browning and Garza-Kling (2010) provide an illustration of the use of the TPACK framework in middle school mathematics. They describe the use of graphics calculators as an exploratory tool which can be used to collect raw data, examine multiple cases, provide immediate feedback and show graphical and numerical displays. To capitalise on these affordances effectively teachers need to draw on technological, pedagogical and content knowledge simultaneously. On a lesson that involves using technology to learn about the meaning of angles, for example, the teacher needs to have technological knowledge about the application and how it displays angles. The teacher also needs to have knowledge of what the students may find difficult to understand and how to devise the lesson to aid the students' understanding. Aside from this, the teacher must also have an understanding of what constitutes the concept of angle, realising, for example, that the measure of an angle is independent of its orientation. Hence, the teacher draws on a combination of technological, pedagogical and content knowledge in order to produce an effective lesson (Browning & Garza-Kling, 2010)

A historical perspective on the development of teachers' knowledge

It is interesting to trace back through the history of the development of teachers' knowledge and perceptions thereof. Shulman (1986) begins this historical journey when he refers to mediaeval times when pedagogical and content knowledge were indistinguishable. As Shulman points out, the very labels of academic distinction of "Master" and "Doctor", which we retain to this day, are etymologically connected with the role of teacher. Travelling onwards in time to 1875, Shulman observes that the tests that prospective teachers took at that time were predominantly related to content. For example, only 5% of the California Teachers Examination of that time was devoted to pedagogy. A little over a century later in the 1980s, Shulman identifies another swing. At this time he observes that teachers' competencies are evaluated in relation to criteria that are more concerned with general teaching procedures, policies and management than they are to do with subject content. And so he begins the movement to re-establish the place of content knowledge in the evaluation of teachers' knowledge. But rather than polarising content and pedagogical knowledge he favours an advantageous blend of these two types of knowledge. Hence pedagogical and content knowledge is spawned (Shulman, 1986).

As the historical journey continues to the beginning of the 20th century the place of digital technology begins to be evaluated. A growing number of voices begin to make this evaluation in real qualitative terms uncoloured by political rhetoric and hype (Watson, 2001). The potential of digital technology to transform the realm of education in parallel with other fields seems unfulfilled. A need to refocus on goals that are pedagogical in nature rather than purely technological emerges. In time, initiatives such as the COACTIV project emerge in which pedagogy and content knowledge and the connections between them are reaffirmed (Krauss et al., 2008). Almost inevitably, technology is drawn into this paradigm with the establishment of a mind-set that promotes a blend of technological, pedagogical and content knowledge. Figure 1 below illustrates the history of these developments.

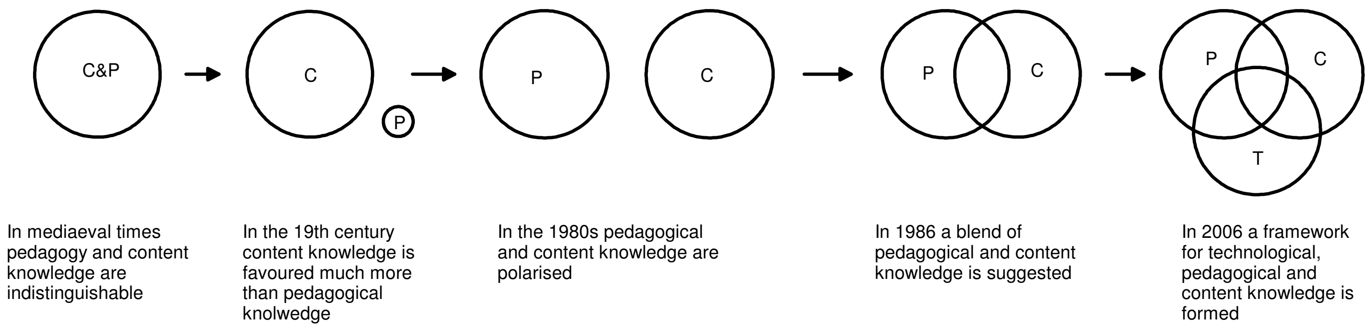

Figure 1: The development of TPCK

Teachers go through stages in acquiring knowledge about technology integration

In 2007, the Association for Mathematics Teachers' Educators (AMTE) Technology committee set about establishing mathematics teacher standards that would outline the knowledge requirements for integrating technology in mathematics. These standards were to be consistent with the rationale of the TPCK model. The standards were constructed in line with four themes associated with teachers' knowledge and beliefs. These themes related to an understanding of 1: the purpose of integrating technology into mathematics, 2: the ways that students think and learn with technology, 3: the way that the curriculum can be integrated with technology and 4: the techniques and representations for teaching and learning mathematics with technology (Niess, 2009).

From these underlying themes the AMTE Technology committee drafted a set of standards for teachers' knowledge in the integration of technology in mathematics. In the process of trialling these standards a developmental model was formed which described the stages that teachers go through in acquiring knowledge about technology integration. The committee described these stages as

> ***Recognising*** *(knowledge), where teachers are able to use the technology and recognise the alignment of the technology with mathematics content yet do not integrate the technology in teaching and learning of mathematics.*
> ***Accepting*** *(persuasion), where teachers form a favourable or unfavourable attitude toward teaching and learning mathematics with an appropriate technology.*
> ***Adapting*** *(decision), where teachers engage in activities that lead to a choice to adopt or reject teaching and learning mathematics with an appropriate technology.*
> ***Exploring*** *(implementation), where teachers actively integrate teaching and learning of mathematics with an appropriate technology.*
> ***Advancing*** *(confirmation), where teachers evaluate the results of the decision to integrate teaching and learning mathematics with an appropriate technology.* (Niess, 2009)

As teachers progress through these stages, their technological knowledge expands and blends in with their pedagogical and content knowledge. Teacher knowledge then emerges in combinations of technological, pedagogical and content knowledge which is referred to as TPACK. The progression through these stages is not linear but rather it is a process that repeats as new technological developments are faced (Niess, 2009).

Teachers' professional development in TPACK

The TPCK framework from its inception included an approach to professional development which was learner centred. This involved a method known as "learning by design" in which teachers engaged in design-based activities such as constructing on-line courses. This approach to teachers' learning mirrored the learning that students would be likely to experience via a student-centred pedagogy in a technology-rich environment (Mishra & Koehler, 2006).

The evolution of the TPCK model into the TPACK model, however, identified new needs for professional development. In particular, methods were sought which would help teachers to work their way through the five stages of knowledge acquisition in technology integration outlined by the AMTE technology committee (Niess, 2009). It emerged that teachers could accelerate their progress through these stages by taking advantage of professional development opportunities in which they can learn from one another. These opportunities may be informal in their local situation or they may take place at a district level. Professional development of this kind is particularly helpful if it is content-specific because this allows teachers to assess whether or not the technology-based activities that are offered can suitably address educational goals (Wachira & Keengwe, 2011). In this way, teachers can progress through the accepting stage by forming favourable attitudes having found appropriate uses for the technology. Akkoc (2011) also sees the benefit of content-specific professional development in helping teachers progress towards higher levels of technological, pedagogical and content knowledge. Working on an assignment involving content-specific coursework proved to be helpful for prospective teachers. An example of this arose when considering how to teach the concept of radian measure. Radian measure is a means of measuring angles by using the ratio of the length of an arc to its radius and is often used as an alternative to degrees. Focusing on this specific part of the course-work helped the prospective teachers to understand the difficulties that students encounter when faced with new concepts and how software can assist the students in overcoming these problems (Akkoc, 2011).

A study of a mathematics teacher's professional development journey in acquiring TPACK (Ozgun-Koca, 2011; Ozgun-Koca, Meagher, & Todd, 2011)was carried out with reference to the five stages of recognising, accepting, adapting, exploring and advancing (Niess, 2009). In the study, a common dilemma of mathematics teachers when faced with integrating technology was the desire on the one hand to ensure that students have a deep understanding of the mathematics involved through by hand methods whilst on the other hand, giving the students the opportunity to take advantage of technological representations of the mathematics. Ozgun-Koca et al. (2011) adjudged that when the teacher sought to ensure that by hand methods of representation preceded technological representations this was an indicator that the teacher’s progress lay somewhere between *recognising* and *accepting*.

Thinking about how to plan lessons to cater for differing abilities of students and/or finding ways to use the technology to achieve cognitive outcomes for students was adjudged to mean that the teacher was somewhere between the *adapting* and *exploring* stages of development. A willingness to construct questions for the students in order to foster an in depth conceptual understanding was taken as a sign that the teacher had moved into the *exploring* stage of development (Ozgun-Koca et al., 2011).

Summary

It was uncovered in the literature that a key factor required to speed up the process of technology integration is the development of teachers’ knowledge. Tracing back to the 1980s, the suggestion was being made at that time that content knowledge of a subject and pedagogical knowledge were not mutually exclusive. A blend of pedagogical and content knowledge which was labelled pedagogical content knowledge (PCK) was deemed to be necessary for effective teaching to take place (Shulman, 1986). The introduction of digital technology into the educational landscape triggered the need for teachers’ knowledge to be expanded still further to incorporate technological knowledge.

A complex blend of knowledge was then identified at the intersection of technological knowledge, pedagogical knowledge and content knowledge. This became known as technological pedagogical and content knowledge (TPCK). A model of TPCK was developed from which suitable professional development for teachers was constructed (Mishra & Koehler, 2006). It became apparent that teachers needed to make connections between types of knowledge in ways other than just the intersection formed at TPCK. Pairings of knowledge were required between technological and content knowledge (TCK), technological and pedagogical knowledge (TPK) as well as the previously established pairing of pedagogical and content knowledge (PCK). This composite of knowledge groupings became known as the total package or TPACK (Niess, 2009).

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