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Frameworks for analysing the expertise that underpins successful integration of digital technologies into everyday teaching practice

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Introduction

Although the uptake of digital technologies in mathematics teaching continues to be inhibited by factors such as poor resourcing of schools, limited recognition in curricula, and lack of acceptance in examinations, such barriers are slowly diminishing. This brings to the fore what is perhaps the most crucial influence on the successful integration of digital technologies into everyday teaching practice: relevant expertise on the part of the teacher. This paper will examine three contemporary frameworks for analysing such expertise, and explore commonalities, complementarities and contrasts between them: the Technological, Pedagogical and Content Knowledge (TPACK) framework (Koehler & Mishra, 2009); the Instrumental Orchestration framework (Trouche, 2005); and the Structuring Features of Classroom Practice framework (Ruthven, 2009). To concretise the discussion, the use of digital technologies for algebraic graphing, a now well established form of technology use in secondary school mathematics, will serve as an exemplary reference situation. Each of the frameworks will be illustrated through its application in a study of teacher expertise relating to this topic.

The Technological, Pedagogical and Content Knowledge (TPACK) framework

Core ideas

The first of these frameworks, originally Technological Pedagogical Content Knowledge [TPCK] (Mishra & Koehler, 2006), now Technology, Pedagogy and Content Knowledge [TPACK] (Koehler & Mishra, 2009), represents an extension of the now classic conceptualisation of the types of knowledge and reasoning that underpin successful subject teaching (Wilson, Shulman & Richert, 1987). The core argument is that teachers develop a special type of "pedagogical content" knowledge (PCK) which is more than a simple combination of subject content knowledge and generic pedagogical knowledge. Typically this knowledge is developed through solving distinctive problems that arise in the course of teaching a particular topic. These problems raise considerations both of content and pedagogy, and solutions to them are typically not reducible to the logic of either knowledge domain alone. Moreover, while solutions to such teaching problems may become crystallised as stable professional knowledge, they may equally be subject to continuing adaptation and refinement, and they will vary between teachers and across teaching settings. Finally, for reasons both of ecological adaptation and cognitive economy, such knowledge is typically organised around prototypical teaching situations. For these reasons, the subsequent development of this line of work has been criticised for an unproductive focus on a logical demarcation of types of teacher knowledge rather than on its functional organisation (Ruthven, 2011a).

The idea of TPCK was introduced to draw attention to the way in which new technological resources reshape pedagogical knowledge, content knowledge and pedagogical content knowledge. Of course, there are already traditional forms of technology associated with established knowledge of these types, although the ways in which these technologies, such as those of written recording, routine computation and even didactic organisation, mediate thinking and action tend to be invisible to us because we take them so much for granted. It is not surprising, then, that this technological dimension is not recognised in the original PCK framework. However, the contemporary expansion in the technological media through which thinking, learning and teaching take place calls for corresponding evolution, even if still tentative, of teachers' knowledge of content, pedagogy and their interaction. The idea of TPACK seeks to make the need for such evolution visible by highlighting the existence of "intersections", according to the Venn-diagram metaphor (shown in Figure 1), between knowledge of technology and knowledge of pedagogy and/or content.

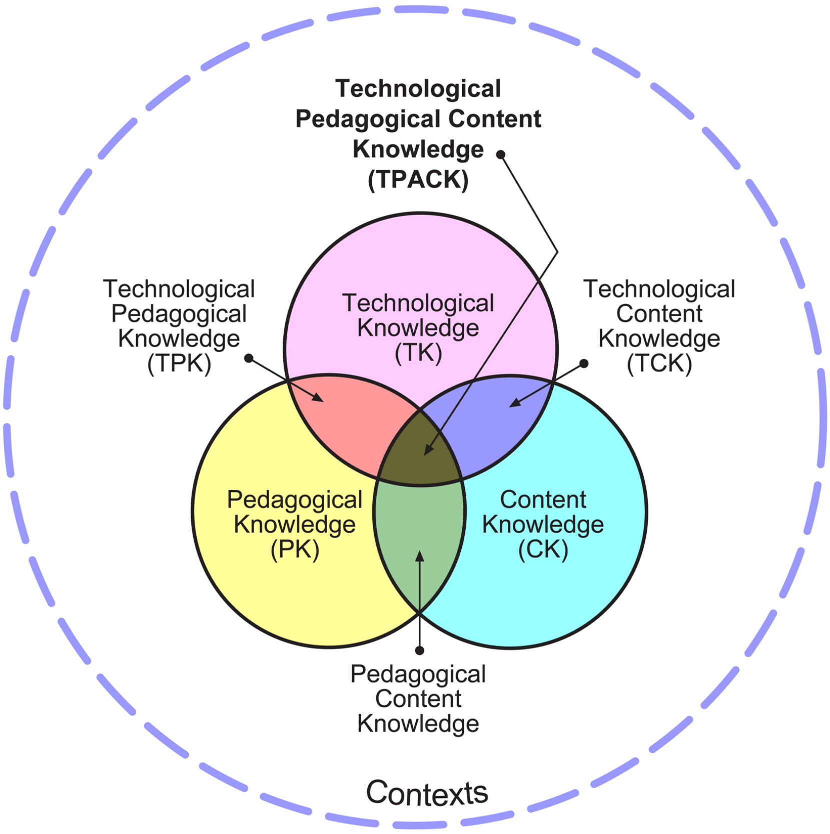

Figure 1: Venn-diagram metaphor for the TPACK model as shown at http://tpack.org/

There are, however, some ambiguities in the way in which TPACK is – and has been – used. First, the acronym is sometimes employed to focus attention on the whole system of two- and three-way interactions between these components (as when the standard figure is referred to as "the TPACK image"); at other times, the term is used to pick out the three-way intersection at the core (as is done within the version of the image shown in Figure 1) that might otherwise be referred to as TPCK (following the labelling pattern for the other intersections). Second, the character of the "intersections" or "interactions" between knowledge domains remains underanalysed, mirroring the differing strengths of definition found in current usages of pedagogical content knowledge (PCK): from a weak definition requiring no more than some simple combination of common knowledge of content with generic pedagogical knowledge, to a stronger definition that insists that PCK be underlain by some distinctive content-specific pedagogical reasoning. Third, there is a hierarchy implicit in the labelling rules under which content is more fundamental than pedagogy, and both of these than technology. In particular, under the strong definition, an unexamined amalgamation takes place of what might have been termed PTCK – pedagogical knowledge relating specifically to the development (by students) of particular forms of technological content knowledge – with what might have been termed TPCK – technological knowledge relating specifically to particular aspects of pedagogical content knowledge. Finally, there is ambiguity about the level at which the pedagogical and the technological are conceived: between a more concrete level at which knowledge is taken as relating to some particular pedagogy or technology, and a more reflexive meta-level at which these terms are reserved for knowledge about pedagogical or technological alternatives.

Table 1: Elaboration of TPACK components by Mishra and Koehler (2006)

Component	Elaborated characterisation
TK	Knowledge about standard technologies, such as books, chalk and blackboard, and more advanced technologies, such as the Internet and digital video. Includes: • the skills required to operate particular technologies • knowledge of operating systems and computer hardware • ability to use standard sets of software tools such as word processors, spreadsheets, browsers, and e-mail • knowledge of how to install and remove peripheral devices, install and remove software programs, and create and archive documents
TCK	Knowledge about the manner in which technology and content are reciprocally related. Includes: • knowledge of how technologies afford particular representations and flexibility in navigating across them • knowledge of the manner in which the subject matter can be changed by the application of technology
TPK	Knowledge of the existence, components, and capabilities of various technologies as they are used in teaching and learning settings, and conversely, knowing how teaching might change as the result of using particular technologies. Includes: • understanding that a range of tools exists for a particular task • ability to choose a tool based on its fitness and strategies for using the tool's affordances • ability to apply pedagogical strategies for use of technologies
TPCK	Emergent form of knowledge that goes beyond all three components (content, pedagogy, and technology). Includes: • understanding of the representation of concepts using technologies • pedagogical techniques that use technologies in constructive ways to teach content • knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face • knowledge of how technologies can be used to build on existing knowledge and to develop new epistemologies or strengthen old ones

Perhaps recognising some of these ambiguities, Koehler and Mishra have proposed more elaborated characterisations of those components of the model relating to technology (as shown in Table 1) which could serve to operationalise them more effectively (Mishra & Koehler, 2006; Koehler & Mishra, 2009). Nevertheless, some ambiguities remain. First, where technologies are content specific, such as dynamic algebra or geometry software, it can be particularly difficult to differentiate between TK and TCK. While knowledge of features and techniques that are generic to much software (such as the basic use of menus and pointers) clearly should be classed as TK, it can be hard to decide when knowledge becomes so content specific (such as the individual operations listed on menus and the particular functions for which the pointer is used) that it should be assigned to TCK. Likewise, given that understanding of certain types of representation forms part of CK, it is problematic to assign "understanding of the representation of concepts using technologies" in general to TPCK rather than TCK. There may be a risk of confusion here with the more specific usage of "representation" found in Shulman's original characterisation of pedagogical content knowledge, based on the idea that there are specifically "pedagogical" forms of representation, or specifically "didactical" organisations of representations, that go beyond those canonical forms of representation that form part of subject content knowledge. Indeed, pursuing the logic of Shulman's original argument, the constructs of CK, TK and TCK should be free of any specifically pedagogical aspect and applicable as much to the knowledge of students as that of teachers.

Turning more specifically now to mathematics, the US Association of Mathematics Teacher Educators (AMTE) has developed a Mathematics TPACK Framework (AMTE, 2009), organized around four major themes: designing and developing technology-enhanced learning experiences; facilitating technology-integrated instruction; evaluating technology-intensive environments; and continuing to develop professional capacity in mathematics TPACK. Just as the way in which T is interpreted in TPACK reflects a preoccupation with new digital technologies, the way in which P is interpreted here reflects a broadly neoprogressive orientation to pedagogy, a longstanding type of association (Cuban, 1989). By way of example, the second theme includes:

- Incorporat[ing] knowledge of learner characteristics, orientation, and thinking to foster learning of mathematics with technology;
- Facilitat[ing] technology-enriched, mathematical experiences that foster creativity, develop conceptual understanding, and cultivate higher order thinking skills;
- Promot[ing] mathematical discourse between and among instructors and learners in a technology-enriched learning community;
- Us[ing] technology to support learner-centered strategies that address the diverse needs of all learners of mathematics; and
- Encourag[ing] learners to become responsible for and reflect upon their own technology-enriched mathematics learning." (AMTE, 2009)

It seems, then, that both the "technological" and the "pedagogical" components of TPACK are open to narrower and broader interpretations: as highlighting, even valorising, a specific form of pedagogy or technology, or as acknowledging the existence of a range of pedagogies and technologies.

Let us turn now to an example of TPACK in use.

An example

Amongst a number of recent studies employing the TPACK framework to analyse the professional learning of teachers of algebra, I have chosen the one which makes use of the full system of TPACK categories. In this study of middle-school teachers participating in a professional development programme (Richardson, 2009), observational records of interactions and discussions between participants and entries extracted from their professional journals were classified as relating variously to TPK, TCK, PCK or TPCK. The study reports that it did not prove straightforward to demarcate these categories and indicates that they tended to acquire narrower operationalisations specifically related to the particular guiding rationale for the professional development programme. It appears, then that TPACK may have been more valuable as a holistic construct inspiring the professional development course than as a research tool for analysing the process or product of knowledge construction.

Within the programme, the novel technology (graphing calculator) was viewed as supporting greater emphasis on a particular representational medium (graphic figure). Accordingly, the guiding hypothesis for the professional development was that this technology provides an effective means of supporting deeper pedagogical engagement with the content ("To make meaning of certain problem situations, it is imperative that students model these situations graphically and use graphing to find solutions to these problems"). Inasmuch as this idea invokes interaction between considerations of technology, pedagogy and content, it could reasonably be classed as technological pedagogical content knowledge. The most developed algebraic example provided in the study report arose from a project session in which project teachers were asked to solve the inequality $2(x - 4) \geq {}^{3}/_{2}\,(2x + 1)$ using only symbolic, then only graphic, methods. This led to some teachers broadening what could be classed as their content knowledge of algebra (taken as transcending use of any particular tool system) beyond familiar symbolic methods ("to solve the inequality in algebraic form") to include unfamiliar graphic methods ("to solve the same inequality in graphic form"). Teachers also displayed what could be classed as technological content knowledge (taken as technology-specific content knowledge) relating to graphing with the two tool systems in play ("to graph… inequalities… by hand and with a graphing calculator").

Drawing on transcripts of discussion between participating teachers, the study seeks to identify what types of knowledge are under exchange and/or development, interleaving the resulting classification of specific contributions in terms of the TPACK framework:

> Teacher B: We already have the graphs. We need to figure out the answer.
>
> Teacher A: No…we already know the solution to the inequality. We found that using basic algebra. This is different. How can we verify it using only the graph? What strategy would you use to explain this to your students?
>
> [This is an example of the teacher's PCK. She explores ways to make this notion comprehensible to her students.]
>
> Teacher C: Let's start over. Graph the inequality on the Nspire. Well … I don't know how to graph it with the inequality.… But we can graph the two sides separately but on the same page.
>
> [This is an example of the teacher's TCK. She explores how to graph an inequality using a graphing device.]
>
> Teacher A: I'm not sure if that will help but at least we will be able to actually see the lines and move them to make one bigger than the other.
>
> [This is an example of the teacher's TCK. She understands technological content.]
>
> (Richardson, 2009)

The two suggestions embedded in this extract about where the exchange and/or development of technological content knowledge has been displayed by participating teachers are rather more persuasive than the one relating to pedagogical content knowledge. Teacher A's utterance ("What strategy would you use to explain this to your students?") certainly could be framing the emergent problem as being one of pedagogical content rather than plain content, but there is no clear indication of this framing being sustained; although, by taking "we" to serve as a projection onto "they" a later contribution ("I'm not sure if that will help but at least we will be able to actually see…") could be interpreted in such terms.

Likewise in the extract below, classing Teacher B's concluding contribution as technological pedagogical content knowledge involves a high level of inference from an anticipation of PCK ("So how would I explain this to my students?"), followed by a more reflexive expression of TCK ("The solution could be obtained quicker from the [calculator] graph than when we solved the inequality by hand in the beginning") that might be taken as appealing implicitly to some pedagogical notion of didactical time, before returning to what might represent crystallised PCK rather than just CK ("It makes so much sense. "Greater than" means…"). However, it is not clear why this utterance from Teacher B is taken as indicative of TPCK whereas that from Teacher A, which alludes specifically to content ("no matter how I move the lines, this part of this one is always on top of this one") is classed as TPK. It may be that these classifications draw on evidence beyond the transcript, as suggested by what appears to be categorisation of Teacher C's contribution as TCK on the basis of supporting observation rather than words spoken ("She understands how to use the graphing device to explore the effect altering either graph has on changing x values").

> Teacher A: Showing students this with computer software would be great. OK, so look … no matter how I move the lines, this part of this one is always on top of this one.
> [This is an example of the teacher's TPK. She understands that more than one technology tool exists to help students make connections between effects of manipulating graphs and solving inequalities.]
> Teacher C: Right. Yes. You are right. Well, that's what we need to know. Right? Look – values on this line are bigger than that line anytime x is at least…
> [This is an example of the teacher's TCK. She understands how to use the graphing device to explore the effect altering either graph has on changing x values.]
> Teacher B: … Negative 9 and a half. So how would I explain this to my students? The solution could be obtained quicker from the graph than when we solved the inequality by hand in the beginning. It makes so much sense. "Greater than" means "When is the left bigger than the right?"
> [This is an example of the teacher's TPCK. She reflects on how a teacher can show students how to perform the technological procedures and relate solving inequalities in a coherent way during her teaching.]
>
> (Richardson, 2009)

The example provided by this study suggests that trying to use the detailed TPACK framework to analyse naturally occurring teacher discourse is likely to founder because such utterances often provide insufficient evidence to draw inferences with confidence and to make clear discriminations about the character of the underlying knowledge in play or in the course of development. The framework might, however, prove more effective if it were employed to design a focused interview protocol and analyse the discourse arising from in-depth pursuit of specific aspects of teachers' knowledge.

Another recent study employed the TPACK framework to identify the developmental needs of a school-based lesson-study group. Over the course of two planning cycles, the researchers examined the group's evolving lesson plans for teaching the topic of systems of equations through making use of graphic calculators (Groth, Spickler, Bergner & Bardzell, 2009). Analysis of this evidence led to the researchers identifying various lines of development needed in the TPACK of the lesson-study group:

- how to use the graphing calculator as a means for efficiently comparing multiple representations and solution strategies;
- how to avoid portraying graphing calculators as black boxes;
- how to pose problems that expose the limitations of the graphing calculator.

In this study, it is notable that TPACK serves simply as a basic heuristic to raise questions about the interaction between technology, pedagogy and content in mathematics teaching, with the detailed framework of component intersections not used at all.

All in all, then, it seems that the idea of TPACK is used to signal the need to consider technological, pedagogical and epistemological aspects of the knowledge underpinning subject teaching and their interaction in general terms. Beyond that, the more detailed framework of TPACK components provides a rather coarse-grained tool for conceptualising and analysing teacher knowledge; one that generally needs to be supplemented by other systems of ideas to accomplish analysis to the depth required for effective professional development and improvement.

The Instrumental Orchestration framework

Core ideas

A further system of ideas that has attracted considerable interest as a means of analysing technology-mediated teaching and learning in mathematics is the "instrumental approach" (Artigue, 2002; Guin, Ruthven & Trouche, 2005). This approach was developed in cognitive ergonomics to study the typically non-propositional and action-oriented knowledge involved in making use of tools (Rabardel, 2002). The focus of the approach is on the process of "instrumental genesis" in which tool and person co-evolve so that what starts as a crude "artefact" becomes a functional "instrument" and the person who starts as a naive operator becomes a proficient user. It was taken up in mathematics education as a means of analysing developmental processes underpinning the introduction of digital technologies into teaching and learning. For the student learner, in particular, development of technological and mathematical proficiency are intertwined in the process of instrumental genesis. Although some aspects of its conceptual apparatus are rather convoluted, the broad thrust of the instrumental approach has proved valuable in highlighting these processes of co-evolution and so challenging the dissociation of conceptual and technical development characteristic of much neoprogressive thinking about mathematics teaching (Ruthven, 2002).

The extension of the instrumental approach through development of the idea of "instrumental orchestration" (Guin & Trouche, 2002; Trouche, 2004; 2005) seeks to address a central issue of technology integration in classroom teaching and learning: the management by the teacher of what could potentially be very disparate instrumental geneses on the part of individual students so as to ensure that technico-mathematical development within a class follows a more collective path by means of which emergent knowledge is socialised into a shared form aligned with wider conventions and practices. This calls for the teacher to "orchestrate" activity across the class with this collective development in mind. The idea of "instrumental orchestration", then, served for Trouche as a construct covering a range of mechanisms directed towards such collective knowledge-building. Each mechanism was characterised in terms of a particular "didactical configuration" – some disposition of tools within the classroom and allocation of user roles to participants – and the varied "exploitation modes" – the patterns of tool use and user interaction – that could be associated with it.

Table 2: Examples of instrumental orchestration from Trouche (2005)

Orchestration example	Didactical configuration	Exploitation modes
Customised calculator	Classroom calculators are "fitted out" with a guide affording three levels of study of the limit concept. These are designed to support the shift from a kinetic concept of limit to an approximative concept	Guide can be available always or only during a specific teaching phase. Students can use guide freely when available, or be constrained to follow the order of the levels. Components can be fixed, or updated in response to classroom lessons. Recording of steps of instrumented work, can be required, or not.
Sherpa student	A *sherpa* student operates a calculator projected to the whole class under the guidance of, and subject to checking and questioning by, the teacher, intended to provide a common reference in addressing the collective instrumental genesis of the class.	Calculators and projector off: work with pencil and paper only. Calculators and projector on: work strictly guided by the sherpa-student under the supervision of the teacher, with other students supposed to replicate the projected display on their own calculator. Calculators and projector on: students work freely but are able to view the work of sherpa-student Calculators on and projector off: students work without being able to view work of sherpa-student
Paired practicals	Each student is equipped with calculator and pencil and paper. Students work in pairs to solve an assigned problem. Each pair then has to explain and justify their reasoning and results, noting observations and dead-ends in a written research report.	Students can be free, or not, to form pairs. Students can be free, or not, to choose which one will write the research report. The teacher can offer help to students during the practical, or only at the end of it, or a week after. Written research reports can be handed in at the end of practical, or a week later. After reading students' research reports, the teacher can give a problem solution, or only give pointers to new strategies for students to pursue.
Mirror observations	Students work in pairs. While one pair tackles a mathematical task, another pair, guided by an observ-ation protocol, notes the actions carried out for later discussion and reflection.	May be used only exceptionally, or be a regular tool for regulation of students' tool-using activity. May fix, or not, the role of each student in the working pair (e.g. one can be in charge of the calculator, the other in charge of the report). Protocol can be modified according to the type of mathematical problem set.

The fullest account of the original construct of instrumental orchestration (Trouche, 2005) incorporates four examples (Table 2). It seems that it is the didactical configuration which represents the core feature of an orchestration with the exploitation modes indicating a range, even system, of didactical variables that underpin versatile use of the configuration in ways that can be tailored to a specific stage of a planned collective instrumental genesis. In particular, the system of exploitation modes may include options to not use the configuration (as in the first mode for 'Sherpa student'), or to use it only in some limited way. Nevertheless, the first of these examples ('Customised calculator') appears somewhat different in character from the other three. As Trouche points out, this first example involves adaptation of the tool itself, whereas the other three all attend to the organisation of activity and assignment of roles associated with use of the tool. Equally, the first example depends much more explicitly on analysis of what might be described as a specific "instrumental trajectory" of the class towards intended technico-mathematical learning outcomes, whereas this dimension is more implicit in the latter three examples. The most widely presented example has been that of the 'Sherpa student' (Guin & Trouche, 2002; Trouche 2004; Trouche, 2005), and so that has tended to become the prototype of an instrumental orchestration taken up by other researchers.

An example

A recent study has adapted the notion of instrumental orchestration to develop a typology of forms of organisation of classroom activity around use of a tool system (Drijvers, Doorman, Boon, Reed & Gravemeijer, 2010). The context for this study was one of trialling a teaching sequence at early-secondary school level on the concept of mathematical function. The researchers write that the sequence "aimed at the development of a rich function concept, whereby functions are conceptualised as input–output assignments, as dynamic processes of co-variation and as mathematical objects with different representations" (p. 216). Their design of a Java applet called Algebra Arrows (Fig. 2) matches this agenda.

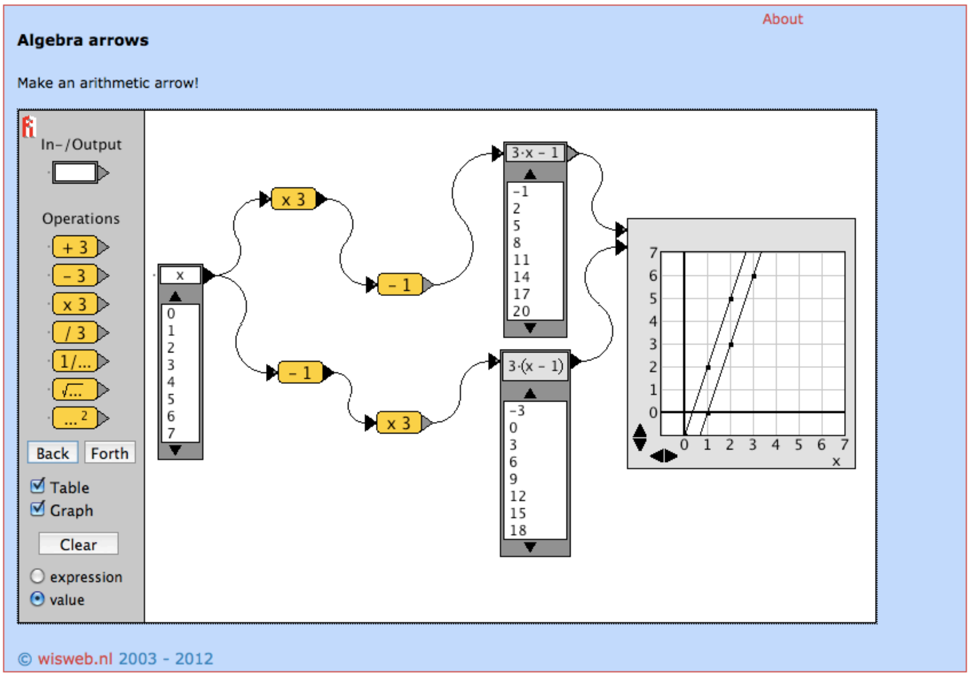

Figure 2: A screen display showing the Algebra Arrows tool in use

It is possible to implicitly discern the tool-adaptive form of instrumental orchestration (by analogy with Trouche's first example of the Customised calculator) in the didactical configuration of the applet to provide options to display or not display the Table and Graph components, affording the possibility of constraining lesson tasks so as to focus attention on particular types of representation and the relations between them. The applet is embedded in a Digital Mathematics Environment (DME) through which the tasks forming the teaching sequence are made available, and which allows students to access their work from any location, and the teacher to access this work in order to monitor progress and track development.

Table 3: Typology of whole-class instrumental orchestration from Drijvers et al. (2010)

Orchestration type	Didactical intention	Didactical configuration	Exploitation modes
Technical-demo	Demonstration by the teacher of techniques for using the tool	Provision to project DME Classroom arrangement allowing students to view the projected screen	Teacher employs new situation or their own solution or earlier student work as a point of departure
Explain-the-screen	Explanation by the teacher going beyond technique, involving mathematical content	Provision to project DME Classroom arrangement allowing students to view the projected screen	Teacher employs new situation or their own solution or earlier student work as a point of departure
Link-screen-board	Instruction by the teacher relating the representations of mathematics in different media	Provision to project DME Classroom arrangement allowing students to view both the projected screen and the board	Teacher employs new situation or their own solution or earlier student work as a point of departure
Discuss-the-screen	Discussion between teacher and students about what is happening on the screen	Provision to project DME and preferably to access student work Classroom arrangement allowing students to view the projected screen and favouring discussion	Teacher employs new situation or their own solution or earlier student work as a point of departure
Spot-and-show	Discussion between teacher and students in which student reasoning is brought to the fore through deliberate use of carefully chosen student work	Access to student work in the DME during lesson preparation Provision to project DME Classroom arrangement allowing students to view the projected screen	Teacher chooses earlier student work in advance of the lesson as a point of departure for the student to explain their reasoning, or for other students to give reactions, or for the teacher to provide feedback
Sherpa-at-work	Activity in which a sherpa-student uses the technology to present his or her work, or to carry out actions that the teacher requests	Provision to project DME Classroom arrangement enabling sherpa to use the projected tool and other students to view the projected screen and follow contributions of sherpa and teacher	Teacher has work presented or explained by the sherpa-student, or poses questions to the sherpa-student and asks them to carry out specific actions in the technological environment

However, in Drijver's study, the notion of "instrumental orchestration" is explicitly employed in the second activity-structuring sense to designate some particular organisation of classroom activity around use of a tool system (following the pattern of Trouche's last three examples). Thus, while Drijvers et al. take over Trouche's constructs of "didactical configuration" and "exploitation mode", these become more closely tied to concerns with the organisation of classroom activity around use of a tool. In particular, because Drijvers et al. wish to differentiate patterns of organisation, they take an "instrumental orchestration" to be the combination of a particular "didactical configuration" with a specific "exploitation mode". Equally, by characterising "exploitation mode" as "the way the teacher decides to exploit a didactical configuration for the benefit of his or her didactical intentions" (p. 215), Drijvers et al. give greater prominence to such intentions. Consequently, I have added "didactical intention" to "didactical configuration" and "exploitation mode" in summarising their typology (Table 3). Likewise, because Drijvers et al. are seeking to describe observed patterns, they report that they felt obliged to modify Trouche's definition of instrumental orchestration to acknowledge the way in which plans are elaborated and adapted in performance, through adding a further component:

> A *didactical performance* involves the ad hoc decisions taken while teaching on how to actually perform in the chosen didactic configuration and exploitation mode: what question to pose now, how to do justice to (or to set aside) any particular student input, how to deal with an unexpected aspect of the mathematical task or the technological tool, or other emerging goals. (Drijvers et al., 2010)

The development of the typology was influenced both by prior examples of instrumental orchestration that the developers included in the guidance materials for teachers (notably 'Sherpa-at-work' and 'Link-screen-board') and by templates identified through subsequent observation of teachers at work. While, in principle, it seems possible that there could be clashes within the typology – for example, if an episode revolved around the thinking displayed in a piece of work selected by the teacher ('Spot-and-show'), with that student nominated to act as the sherpa student ('Sherpa-student'), in effect a particular version of a more generic form ('Explain-the-screen'), in practice Drijvers et al. report that inter-rater reliability of the codings was good, although gradual shifts in classroom activity could create some difficulties of demarcation. Likewise, the researchers acknowledge that the range of orchestration types that emerged from the study might well have been conditioned by factors particular to the trialling situation

Nevertheless, developing this typology helped to identify overall patterns in classroom activity, and to pinpoint differences between the profiles of teachers, and between one teacher's enactments of the same sequence with different classes. While 'Technical-demo' was a common orchestration (in the sense both of being used by all teachers and frequently so), there were differences in the degree to which teachers made use of the more student-centred 'Discuss-the-screen', 'Spot-and-show' and 'Sherpa-at-work' orchestrations as opposed to the more teacher-led 'Explain-the-screen' and 'Link-screen-board'. This suggests that the way in which such expertise develops is also shaped by broader personal orientation to teaching mathematics.

Finally, this typology makes visible an important dimension of the professional knowledge that teachers participating in trialling had employed or developed in order to incorporate use of these digital technologies into their practice. In effect, these six orchestration types also represent the core of a collective system of professional expertise, making the typology of particular interest to teacher educators seeking to help teachers develop practical strategies for the organisation of classroom lessons using such digital technologies.

The Structuring Features of Classroom Practice framework

Core ideas

The Drijvers et al. study emphasises how integration of new technologies depends on teachers adapting and developing appropriate craft knowledge to underpin their classroom work. A third framework has been explicitly designed to support the identification and analysis of this type of teaching expertise. The Structuring Features of Classroom Practice framework (Ruthven, 2009) was devised by bringing a range of concepts from earlier studies of classroom organisation and interaction and of teacher craft knowledge and thinking to bear on this specific issue of technology integration. Thus this framework synthesises and extends concepts that have already proved valuable in analysing classroom practice (Table 4).

Table 4: Components of the Structuring Features framework

Structuring feature	Defining characterisation	Examples of associated craft knowledge related to incorporation of digital technologies
Working environment	Physical surroundings where lessons take place, general technical infrastructure available, layout of facilities, and associated organisation of people, tools and materials	Organising, displaying and annotating materials Capturing or converting student productions into suitable digital form Organising and managing student access to, and use of, equipment and other tools and materials Managing new types of transition between lesson stages (including movement of students)
Resource system	Collection of didactical tools and materials in use, and coordination of use towards subject activity and curricular goals	Establishing appropriate techniques and norms for use of new tools to support subject activity Managing the double instrumentation in which old technologies remain in use alongside new Coordinating the use and interpretation of tools
Activity structure	Templates for classroom action and interaction which frame the contributions of teacher and students to particular types of lesson segment	Employing activity templates organised around predict-test-explain sequences to capitalise on the availability of rapid feedback Establishing new structures of interaction involving students, teacher and machine and the appropriate (re)specifications of role
Curriculum script	Loosely ordered model of goals, resources, actions and expectancies for teaching a curricular topic including likely difficulties and alternative paths	Choosing or devising curricular tasks that exploit new tools, and developing ways of staging such tasks and managing patterns of student response Recognising and responding to ways in which technologies may help/hinder specific processes and objectives involved in learning a topic
Time economy	Frame within which the time available for class activity is managed so as to convert it into "didactic time" measured in terms of the advance of knowledge	Managing modes of use of tools so as to reduce the "time cost" of investment in student learning to use them or to increase the "rate of return" Fine-tuning working environment, resource system, activity structure and curriculum script to optimise the didactic return on time investment

The framework identifies five structuring features of classroom practice which shape the ways in which teachers integrate (or fall short of integrating) new technologies: working environment, resource system, activity structure, curriculum script, and time economy. The introduction of new technologies often involves changes in the *working environment* of lessons in terms of room location, physical layout, and class organisation, requiring modification of the classroom routines which enable lessons to flow smoothly. Equally, while new technologies broaden the range of tools and materials available to support school mathematics, they present the challenge of building a coherent *resource system* of compatible elements that function in a complementary manner and which participants are capable of using effectively. Likewise, innovation may call for adaptation of the established repertoire of activity formats that frame the action and interaction of participants during particular types of classroom episode, and combine to create prototypical *activity structures* or cycles for particular styles of lesson. Moreover, incorporating new tools and resources into lessons requires teachers to develop their *curriculum script* for a mathematical topic. This 'script' is an event-structured organisation of knowledge, forming a loosely ordered model of goals, resources and actions for teaching the topic, incorporating potential emergent issues and alternative courses of action; it interweaves mathematical ideas to be developed, appropriate topic-related tasks to be undertaken, suitable activity formats to be used, and potential student difficulties to be anticipated, guiding the teacher in formulating a suitable lesson agenda, and in enacting it in a flexible and responsive way. Finally, the introduction of new technologies may influence the *time economy* within which teachers operate, changing the 'rate' at which the physical time available for classroom activity can be converted into a 'didactic time' measured in terms of the advance of knowledge.

The status of this conceptual framework remains tentative. It prioritises and organises previously disparate constructs developed in earlier research, and has proved a useful tool for analysis of already available case-records. While it has been noted that "the differing provenance of the five central constructs raises some issues of coherence" (Ruthven 2011b, p. 97), such eclecticism is characteristic of the powerful intermediate theory that effective analysis of issues of teaching requires. However, further studies are now required in which data collection (as well as analysis) is guided by the conceptual framework, so that it can be subjected to fuller testing and corresponding elaboration and refinement. To adequately address issues of professional learning, such studies need to be longitudinal as well as cross-sectional, and to focus on teachers' work outside as well as inside the classroom. Likewise, the current reach of this conceptual framework is deliberately modest; it simply seeks to make visible and analysable certain crucial aspects of the incorporation of new technologies into classroom practice which other conceptual frameworks largely overlook.

An example

A study of teachers' use of graphing software to teach about algebraic forms at lower-secondary level used the Structuring Features of Classroom Practice framework to help identify various types of adaptation of teaching practices and development of craft knowledge associated with use of such technology through lesson observations supplemented by post-lesson interviews with teachers (Ruthven, Deaney & Hennessy, 2009).

In terms of *working environment*, many of the aspects observed were not specific to graphing software. Relocation of lessons from the normal classroom to the computer suite required teachers to modify their managerial routines, notably those concerned with handling the start of lessons, to include getting students seated appropriately, and their computer workstations and resources opened for use. Equally, adaptation was required to routines for securing the attention of students during periods of independent work, so as to make important points to the class as a whole. Teachers also had to develop fallback strategies to cope with any non-functioning of components of the technological infrastructure.

Typically the *resource system* for lessons consisted of graphing software and printed worksheets: the latter set out tasks and often provided a means of recording results by hand. Making students' use of graphing software functional required teachers to develop strategies to familiarise them with (and later to review) core techniques, and to allow students to explore (and then to share their discoveries of) a wider range of technical possibilities. Teachers themselves were developing expertise regarding the forms of technico-mathematical guidance that students might require: such as explaining how to enlarge a point to make it more visible, or how to enter x^2 in the equation editor; helping students to understand why their graph was a horizontal line rather than the expected sloping one (as a result of entering y=5+4 rather than y=5x+4), or a straight line rather than the expected curve (as a result of entering y=x+2^2 rather than y=$(x+2)^2$); prompting students to drag the displayed image to expose more of a particular graph, or to pursue the limiting trend of a graph.

In terms of *activity structures*, a distinctive type of activity format was emerging for individual or paired student work on a new type of 'target practice' task which capitalised on the interactivity of the software to centre investigative activity around a process of trial and improvement of posited solutions. For example, in two investigations of this type, students were tasked with using the software to find equations – of straight lines in the first investigation, quadratic curves in the second – passing through some specified point or pair of points. In a similar way, teachers had adapted a conventional whole-class exposition and questioning activity format to incorporate use the software to provide immediate feedback on student suggestions, for example through students "taking the stage" to use the projected computer to test their predictions.

These preceding elements of adaptation had all been interwoven into teachers' *curriculum scripts* for the topic of algebraic forms. At the core of these scripts, teachers had had to find or devise tasks (such as the 'target practice' type already alluded to) which productively employed graphing to investigate the topic of algebraic forms. On the basis of classroom experience of the ways in which these tasks played out in the classroom, teachers were both refining them and developing a repertoire of strategies to support students in tackling them, concerned with prompting strategic action and supporting mathematical interpretation. One example involved prompting students to zoom out on the displayed image of $0.00000009x^2 + x + 1$ to test whether it was a straight line (as it had appeared to be to students), then introducing the comparison with $0x^2 + x + 1$. Another example involved supporting a student who had graphed $x = -yx$ and wondered why it looked the same as $y = -1$, by helping him to rearrange and simplify the first equation. Such examples illustrate how a gradual accretion of teachers' expert knowledge, and its organisation within their curriculum script, takes place through their responding to, and reflecting on, classroom incidents. There was also evidence of certain technology-supported lines of questioning becoming invariant elements of teachers' curriculum scripts for the topic. A recurring pattern across one teacher's lessons arose when, after examining graphs of the form $y = x +$ c, she consistently posed the question "How would you draw the diagonal line going the other way… from top left to bottom right?" with a view to using the software to test student responses.

While they had to devote time for students to learn to graph both by hand and by machine, teachers reported that use of the software helped to ease and effect the production of graphs and so to accelerate such activity and elevate students' attention to focus on the mathematical relationships involved. In particular, teachers considered that having students make use of graphing software made investigative lessons much more viable. These changes in *time economy* had required corresponding adaptation of curriculum sequences on this topic and recalibration of their timing.

Commonalities, complementarities and contrasts between the frameworks

The title of this chapter refers to the "expertise" rather than the "knowledge" that underpins successful integration of digital technologies into everyday teaching practice. This is a deliberate choice to emphasise that – put another way – much of the knowledge that teachers use is "tacit" and resides in schemes of perception and action which they are typically unable to articulate, and may even be unaware of. Nevertheless, an important contribution that researchers can make to the enterprise of professional education and development is to identify such expertise and provide means of representing and analysing it. Typically they have done so by refining techniques of observation-based analysis supported by introspective interview that support inferences about such expertise. The resulting findings are particularly valuable when then taken up and used in teacher education for purposes of structuring and scaffolding the reflexive appropriation and development by teachers of the expertise that has been identified.

There are three conceptualisations of the relations between pairs of perspectives that I find particularly illuminating. The first relates to the contrasting models of knowledge or expertise underlying the Technological, Pedagogical and Content Knowledge framework and the Structuring Features of Classroom Practice framework. If we look back at the descriptors used for elements of TPACK (shown in Table 1), while the term "knowledge" predominates, there is also reference in the entries under TK to "skills" and "ability", under TPK to "ability" and "understanding", and under TPCK to "understanding and "techniques", indicating that the TPACK model does acknowledge such broader components of expertise. By comparison, the way in which the examples of "craft knowledge" are formulated in the Structuring Features model (shown in Table 4) frames these as practical competences without seeking to differentiate either between tacit and articulate knowledge or into technology-, pedagogy- and content-based categories. Perhaps, then, the crucial difference between these frameworks is that the organising concept for the TPACK model is one of epistemological demarcation between different classes of knowledge relevant to teaching, whereas the organising concept for the Structuring Features model is one of how material-cultural factors structure the functional organisation of teaching expertise.

The second illuminating comparison is between the Technological, Pedagogical and Content Knowledge framework and the Instrumental Orchestration framework. The forms of teaching expertise implied by the Instrumental Orchestration framework are those related to the management of the collective instrumental genesis of a class of students. Because this construct is used in a manner that emphasises the way in which development by students of mathematical content knowledge is, to some significant degree, intertwined with development of knowledge of the mediating technology, the process of classroom instrumental genesis is taken as having the growth of students' TCK at its core, even if some components of the knowledge to be developed might be classed as simple CK or TK alone. As well as this technological content knowledge linking topic and tool, the teacher must also have the pedagogical knowledge necessary to manage its development by students. This includes knowledge of how to coordinate the introduction and use of particular features of the tool with a task sequence capable of supporting an effective learning trajectory (as shown by the example of Trouche's 'Customised calculator' orchestration – which might be classed as TPCK) – and of how to exploit a range of more generic classroom configurations in enacting the various stages of such a sequence – (as shown by Trouche's other orchestrations which might be classed as TPK).

The third illuminating comparison is of the Instrumental Orchestration framework and the Structuring Features of Classroom Practice framework. The Structuring Features framework provides a more differentiated characterisation of several key aspects of Instrumental Orchestration. First, it highlights the matter of incorporating a new tool into the resource system (e.g. Establishing appropriate techniques and norms for use of new tools to support subject activity). Alongside that, there is the matter of adapting activity structures to better support the development and use of this tool (e.g. Establishing new structures of interaction involving students, teacher and machine and the appropriate (re)specifications of role). Finally, there is the matter of devising task sequences and associated narratives to incorporate use of the tool within the curriculum script for a topic (e.g. Choosing or devising curricular tasks that exploit new tools, and developing ways of staging such tasks and managing patterns of student response). Equally, the different types of instrumental orchestration identified by Drijvers et al. (shown in Table 3) all correspond – in the terms of the Structuring Features framework – to specific activity formats that exploit a particular resource (sub)system. However, Trouche's instrumental orchestration for development of the limit command (shown in Table 2) corresponds – in the terms of the Structuring Features framework – to customisation of a specific part of the resource (sub)system linked to development of an innovative pathway within the curriculum script for the topic. Moreover, the network of teaching possibilities for a topic that makes up the curriculum script – in the Structuring Features framework – underpins both the advance planning of a "lesson agenda" – linked to "didactical intention" in the Instrumental Orchestration framework – and its interactive enaction and adaptation by the teacher – linked to "didactical performance" in Drijver's extension of the Instrumental Orchestration framework.

In their current state, then, each of these three frameworks provides an overarching set of "top level" constructs that reflects a particular orientation towards the phenomenon of technology integration in subject teaching. By comparing these differing systems of base constructs I have sought to provide a more coordinated overview that shows how their different perspectives on technology integration in subject teaching are inter-related. I have also highlighted how each of these frameworks provides a more tentative listing of elements and examples at the more concrete level necessary to support the operational use of its main constructs as analytic tools. This points to a crucial need for fuller and more systematic investigation of the phenomenon of technology integration into subject teaching at this intermediate level. Indeed, close examination of each of the studies presented here as an example of the application of a particular framework in use has shown that it required supplementation by other ideas in order to generate illuminating findings. More intensive research work at this more concrete level could serve to better operationalise the existing frameworks or to fuel the development of a single more powerful one. My own view is that any more powerful framework is likely to be organised along functional lines closer to those of Instrumental Orchestration and Structuring Features, but in a way capable of incorporating intermediate level elements from all three existing frameworks. A synthesising framework of this type would provide an overarching system of constructs driven by the need to organise systematically a much richer and fuller inventory of the kinds of intermediate level elements that these three frameworks have started to identify.

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