Running head: Constituting Digital Tools and Materials as Classroom Resources

Title: Constituting Digital Tools and Materials as Classroom Resources: The Example of Dynamic Geometry

Author: Kenneth Ruthven

Affiliation: Faculty of Education, University of Cambridge, UK

Address for correspondence: University of Cambridge Faculty of Education, 184 Hills Road, Cambridge CB2 8PQ, UK

Mail: Kenneth Ruthven kr18@cam.ac.uk

Abstract: This chapter examines the appropriation of digital resources into the mainstream practice of secondary-school mathematics teaching, taking the particular example of dynamic geometry to illustrate this process. It highlights some crucial but often overlooked facets of the changes in teaching practice and teacher knowledge that accompany the constitution of digital tools and materials as classroom resources. First, the chapter demonstrates the interpretative flexibility surrounding a resource and the way in which wider educational orientations influence conceptions of its use. It does so by showing how such conceptions of dynamic geometry have shifted between pioneering advocates and mainstream adopters; and how these conceptions vary across such adopters according to their wider approaches to teaching mathematics. Second, the chapter outlines a conceptual framework intended to make visible and analysable the way in which certain structuring features shape the incorporation of new technologies into classroom practice. This conceptual framework is then used to examine the case of a teacher leading what – for him – is an innovative lesson involving dynamic geometry, and specifically to identify how his professional knowledge is being adapted and extended. This shows how the effective integration of new technologies into everyday teaching depends on a more fundamental and wide-ranging adaptation and extension of teachers' professional knowledge than has generally been appreciated.

Keywords: classroom teaching; craft knowledge; instructional practices; mathematics education; practitioner thinking; professional adaptation; teacher learning; teaching resources; technology integration

Chapter 5

Constituting Digital Tools and Materials as Classroom Resources: The Example of Dynamic Geometry

5.1 Introduction

This chapter examines the often unrecognised challenges that teachers face in seeking to make effective use of new mathematical tools and representational media in the classroom, highlighting several key facets of professional learning associated with overcoming these challenges. It focuses on the appropriation of digital tools and media as resources for the mainstream practice of secondary-school mathematics teaching, taking the particular example of dynamic geometry to illustrate this process. First, the chapter demonstrates the interpretative flexibility surrounding a resource and the way in which wider educational orientations influence conceptions of its use. It does so by showing how pedagogical conceptions of dynamic geometry have shifted between pioneering advocates and mainstream adopters; and how such conceptions vary across adopters according to their wider approaches to teaching mathematics. Second, the chapter outlines a conceptual framework intended to make visible and analysable the way in which certain structuring features shape the incorporation of new technologies into classroom practice. This conceptual framework is then used to examine the case of a teacher leading what – for him – is an innovative lesson involving dynamic geometry, and specifically to identify how his professional knowledge is being adapted and extended. This shows how the effective integration of new technologies into everyday teaching depends on a more fundamental and wide-ranging adaptation and extension of teachers' professional knowledge than has generally been appreciated.

5.2 The interpretative flexibility of educational resources

Studies of the social shaping of technology have drawn attention to the 'interpretative flexibility' through which the function and operation of a tool remain open to adaptation (MacKenzie & Wajcman, 1999). In particular, conceptions of a technology influence its non-adoption by potential users, or its appropriation by them in the light of their interests and circumstances; indeed, technologies may be taken up in ways which, in terms of the speculative intentions of their designers, appear as something of a misappropriation. The concept of 'innofusion', then, blurs the conventional technocratic model of development in proposing that innovation carries on throughout the process of diffusion, as a technology and its modalities of use become aligned with user concerns and adapted to use settings (Williams & Edge, 1996).

Contemporary educational studies adopt a similar perspective on curriculum materials and pedagogical guidance. Such resources have long provided a staple approach to influencing classroom practice. However, attempts to 'teacher proof' them, and the recurring failure of these efforts even more so, testify that teachers act as interpreters and mediators of them. This reflects a broader pattern in which the unfolding of innovation in education is shaped by the sense-making of the agents involved (Spillane, Reiser & Reimer, 2002). Teachers typically select, combine and adapt resources, and they necessarily incorporate them into wider systems of classroom practice (Ball & Cohen, 1996). Accordingly, conceptualisations of how resources are used have developed from rather limited views of teachers simply following or subverting them, to more sophisticated perspectives encompassing teacher interpretation of, and participation with, them (Remillard, 2005).

Interpretative flexibility became very apparent during the early development of geometry software. Originally intended to provide computer-supported analogues to established manual processes for the construction of figures, geometric software underwent a significant evolution with the recognition that, on a computer screen, such figures could be made dynamic, changing shape in response to the dragging of points or segments, but preserving their defining properties (Scher, 2000). Although the dragging operation rapidly became a defining feature of dynamic geometry software, its functional versatility and corresponding complexity were not anticipated, and are still in the process of being established (Arzarello, Olivero, Paola & Robutti, 2002; Laborde, 2001).

Equally, although dynamic geometry systems were developed with educational purposes in view, they were not initially devised with a particular pedagogical approach in mind (Scher, 2000). However, pioneering work quickly associated dynamic geometry with a pedagogical orientation in which such software served *"to create experimental environments where collaborative learning and student exploration are encouraged"* (Chazan & Yerushalmy, 1995: p. 8), so that *"mathematics becomes an investigation of interesting phenomena, and the role of the mathematics student becomes that of the scientist"* (Olive, 2002: p. 17). Nevertheless, evidence about how dynamic geometry has actually been taken up in schools offers an enigmatic picture. For example, a national survey conducted in the United States found an association between teachers nominating dynamic geometry as their most valued software and reporting skill-development as their main objective for computer use (Becker, Ravitz & Wong, 1999).

5.3 An English study of teacher constructions of dynamic geometry

A recent English study has thrown further light on the use of dynamic geometry in mainstream practice (Ruthven, Hennessy & Deaney, 2008). Much of the pioneering development of dynamic geometry systems has taken place in countries – notably France and the United States – which comparative studies show to have retained a strongly Euclidean spirit within their school geometry curriculum, resulting in greater attention to formalisation and systematisation, including an emphasis on proof (Hoyles, Foxman & Küchemann, 2001). The Euclidean lineage of dynamic geometry might be expected to fit poorly with a national curriculum which refers – as does the English one framing the practice studied – not to "*geometry*" but to *"shape, space and measures".* However, the scope to employ the software as a means of supporting observation, measurement and calculation resonates with the empirical style of English school mathematics, and such modalities of reasoning were found to be prevalent when dynamic geometry was used.

The study found echoes of the exploratory rhetoric of the software's advocates in teachers' suggestions that dynamic figures helped students to *"find out how it works without us telling them"*, or *"tell you the rule instead of you having to tell them"*, so that students were *"more or less discovering for themselves"* and could *"feel that they've got ownership of what's going on",* even if teachers might have to *"structure"*, *"hint"*, *"guide"*, or *"steer"* students towards the intended mathematical conclusion. Case studies identified a range of practical expressions of this idea. One case involved a strongly teacher-led, whole-class approach, in which dynamic presentation by the teacher was used to make it easier for students to *"spot the rule"* so that *"you're not just telling them a fact, you're allowing them to sort of deduce it and interact with what's going on"*. In the other cases, the classroom approaches involved more devolution to students, through investigations structured towards similarly preconceived mathematical results, with the teacher *"drawing attention to"*, *"flagging up"* and *"prompting"* them.

On the issue of students themselves making use of the software, classroom approaches were found to be based variously on avoiding, minimising, or capitalising on, the demands of using dynamic geometry. In the first case referred to above, the software was used only for teacher presentation on the grounds that *"it would take a long time… for [students] to master the package"* and *"the return from the time investment… would be fairly small"*, so that *"the cost benefit doesn't pay"*. In two further cases, the normal pattern was *“to structure the work so [students] just have to move points [on a prepared figure]”,* so that *“they don’t have to be complicated by that, they really can just focus on what’s happening mathematically*”. In the final case, getting students to construct their own dynamic figures was seen as a vehicle for developing and disciplining their geometrical thinking; using dynamic geometry was introduced to them in terms of: *“It’s not just drawing, it’s drawing using mathematical rules”.* Thus, the degree to which students were expected to make use of dynamic geometry was influenced by the extent to which this was conceived as promoting mathematically productive activity.

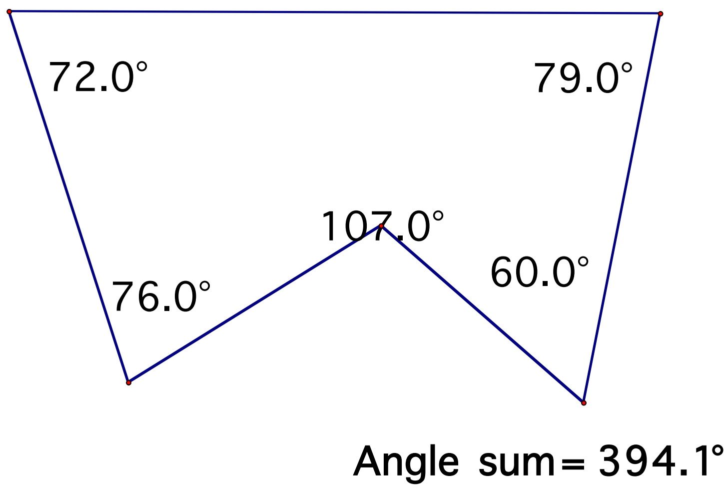

Figure 1: Dynamic geometry figure for establishing the angle sum of a pentagon

A related issue concerned handling the apparent mathematical anomalies which arise when dynamic figures are dragged to positions where an angle becomes reflex (with the associated problem of measurement), or where rounded values obscure an arithmetical relationship between measures (as featured in Figure 1). The potential for such situations to arise was considerable in the type of topic most widely reported as suited to dynamic geometry: the study of angle properties. For example, two of the case studies included a lesson on the angle sum of polygons (both employing a figure of the type shown in Figure 1). In the first case, the teacher took great care to avoid exposing students to apparent anomalies of these types, through vigilant dragging to avoid *“possibilities where students may become confused, or things that might cloud the issue”*. In the other case, the teacher actively wanted students to encounter such difficulties so as to learn *“that you can’t assume that what you’ve got in front of you is actually what you want, and you have to look at it… and question it”;* equally, resolving such situations was seen as serving *“to draw attention to… how the software measures the smaller angle, thus reinforcing that there are two angles at a point and [that students] needed to work out the other”*. Thus, approaches to handling these apparent mathematical anomalies were influenced by whether they were seen as providing opportunities to develop students' mathematical understanding, in line with a more fundamental pedagogical orientation that saw analysis of discrepancies as supporting learning.

This study, then, highlights several noteworthy aspects of the interpretative flexibility of dynamic geometry. First it shows that the forms of guided discovery that dynamic geometry is typically used to support in English classroom practice, as well as the empirical and arithmetical modes of reasoning associated with them, are very different from the types of mathematical enquiry and modes of mathematical reasoning envisaged by the original proponents of the software. Equally, it shows how differing approaches to staging guided discovery, and organising the associated software use, reflect varied interpretations of the functionality for students of dynamic geometry, shaped by contrasting conceptions of what it means for students to learn mathematics.

These case studies were carried out in mathematics departments that were professionally well regarded for their use of digital technologies. Even in these departments, the exposure of any one class to dynamic geometry was of the order of a handful of lessons each year. Moreover, when the software was used, teachers largely sought to minimise disruption to customary patterns of classroom activity. Indeed, research on how teachers make use of the interactive whiteboards now widely available in English classrooms reports that software such as dynamic geometry is generally rejected as over-complex or used only in limited ways (Miller & Glover, 2006). Such observations suggest that, it is not just the way in which teachers conceptualise dynamic geometry as a teaching resource that influences their response to it, but more basic concerns about how to realise its incorporation within a viable classroom practice.

5.4 Structuring features of classroom practice

Such concerns are often overlooked in educational reform, and with them the craft knowledge that underpins everyday classroom practice (Brown & McIntyre, 1993; Leinhardt, 1988). In particular, much proposed innovation entails modification of the largely reflex system of powerful schemes, routines and heuristics that teachers bring to their classroom work, often tailored to their particular circumstances. The conceptual framework that I will now develop focuses, then, on the functional organisation of a system of (often tacit) pedagogical craft knowledge required to accomplish concrete professional tasks. (Consequently this framework does not directly consider the subject disciplinary knowledge required of the teacher, although this too plays a part).

This section will introduce five key structuring features of classroom practice and show how they relate to the constitution of digital tools and materials as classroom resources: working environment, resource system, activity format, curriculum script, and time economy.

5.4.1 Working environment

Making use of computer-based tools and materials in teaching often involves changes in the **working environment** in which lessons are conducted; namely, the physical surroundings where lessons take place, their general technical infrastructure, and the social organisation associated with them.

In many schools, lessons have to be relocated from the normal classroom to a dedicated computer suite in order to make machines available in sufficient numbers for students to work with them. Such use entails disruption to normal working practices and makes additional organisational demands on the teacher (Jenson & Rose, 2006; Ruthven, Hennessy & Deaney, 2005). Well-established routines which help lessons to start, proceed and close in a timely and purposeful manner in the regular classroom (Leinhardt, Weidman & Hammond, 1987) have to be adapted to the computer suite. The alternative of providing sets of handheld devices or laptop computers in the ordinary classroom raises similar organisational issues. For example, teachers report having to develop classroom layouts that assist them to monitor students' computer screens, as well as classroom routines to forestall distraction, such as having students push down the screens of their laptops during whole-class lesson segments (Zucker & McGhee, 2005).

More recently, there has been a trend towards provision of digital projection facilities or interactive whiteboards in ordinary classrooms. Their attraction to many teachers is that they require fewer modifications to the customary working environment of lessons (Jewitt, Moss & Cardini, 2007; Miller & Glover, 2006). Such facilities can be treated as a convenient enhancement of a range of earlier display and projection devices, and allow a single classroom computer to be managed by teachers on behalf of the whole class.

5.4.2 Resource system

New technologies have broadened the types of subject- and topic-specific resources available to support school mathematics. Educational suppliers now market textbook schemes alongside exercise and revision courseware, concrete apparatus alongside computer microworlds and environments, manual instruments alongside digital tools. The collection of mathematical tools and materials in classroom use constitutes a **resource system** which depends for its successful functioning on their being used in a co-ordinated way aligned with educational goals (Amarel, 1983).

Studies of the classroom use of computer-assisted instructional packages have attributed strong take-up of particular materials to their close fit with the regular curriculum and their flexibility of usage (Morgan, 1990). Equally, teachers report that they would be much more likely to use technology if ready-to-use resources were readily available to them and clearly mapped to their scheme of work (Crisan, Lerman & Winbourne, 2007). An important factor here is the limited scope that many digital materials offer for the teacher customisation characteristic of the use of other resources, and recognition of this has encouraged developers to offer greater flexibility to teachers. However, whatever the medium employed, teachers need to acquire knowledge in depth of materials in order to make effective use of them and to integrate them successfully with other classroom activity (Bueno-Ravel & Gueudet, 2007; Abboud-Blanchard, Cazes & Vandebrouck, 2007).

Something close to the textbook – even if taking a digitised form – remains at the heart of the resource system in many classrooms, valued for establishing a complete and coherent framework within which material is introduced in an organised and controlled way, appropriate to the intended audience. Indeed, one common use of interactive whiteboards in classrooms is to project and annotate textbook pages or similar presentations (Miller & Glover, 2006). More broadly, educational publishers are seeking increasingly to bundle digital materials with printed textbooks, often in the form of presentations and exercises linked to each section of the text, or applets providing demonstrations and interactivities. Such materials are attractive to many teachers because they promise a relatively straightforward and immediately productive integration of old and new technologies.

Textbook treatments of mathematical topics necessarily make assumptions about what kinds of tools will be available in the classroom. Nowadays, it is increasingly assumed that some kind of calculator will be available to students. If well designed, textbooks explicitly develop the calculator techniques required and establish some form of mathematical framing for them. However, it is rare to find them taking account of other digital mathematical tools. Here, textbook developers face the same problems as classroom teachers. In the face of a proliferation of available tools, which should be prioritised? And given the currently fragmentary knowledge about bringing these tools to bear on curricular topics, how can a coherent use and development be achieved? Such issues are exacerbated when tools are imported into education from the commercial and technical world. Often, their intended functions, operating procedures, and representational conventions are not well matched to the needs of the school curriculum.

5.4.3 Activity format

The processes of classroom teaching and learning are played out within recurring patterns of teacher and student activity. Classroom lessons can be segmented according to recognisable **activity formats**: generic templates for action and interaction which frame the contributions of teacher and students to particular types of lesson segment (Burns & Anderson, 1987; Burns & Lash, 1986). The crafting of lessons around a succession of familiar activity formats and their supporting classroom routines helps to make them flow smoothly in a focused, predictable and fluid way (Leinhardt, Weidman & Hammond, 1987), permitting the creation of prototypical **activity structures** or **activity cycles** for lessons as a whole.

Monaghan (2004) studied secondary teachers who had made a commitment to move from making little use of ICT in their mathematics classes to making significant use. For each participating teacher, a *"non-technology"* lesson was observed at the start of the project, and further *"technology"* lessons over the course of the year. Monaghan found that technology lessons tended to have a quite different activity structure. In all the observed non-technology lessons, teacher-led exposition including the working-through of examples was followed by student work on related textbook exercises. Of the observed technology lessons, only those which took place in the regular classroom using graphic calculators displayed this type of structure. Most of the technology lessons focused on more open tasks, often in the form of investigations. These featured an activity structure consisting typically of a short introduction to the task by the teacher, followed by student work at computers over most of the session. Both types of technology lesson observed by Monaghan appear, then, to have adapted an existing form of activity structure: less commonly that of the exposition-and-practice lesson; more commonly that of the investigation lesson.

Other studies describe classroom uses of new technologies that involve more radical change in activity formats, and call for new classroom routines. For example, to provide an efficient mechanism through which the teacher can shape and regulate methods of tool use, Trouche (2005) introduces the role of *"sherpa student"*, taken on by a different student in each lesson. The sherpa student becomes responsible for managing the calculator or computer that is being publicly projected during whole-class activity; what is distinctive about this activity format is the way in which it is organised around the teacher guiding the actions of the sherpa student, or opening them up for comment and discussion by the remainder of the class; the particular function it serves is in providing a mechanism by which the teacher can manage the collective development of techniques for using the tool. A new activity format of this type calls, then, for the establishment of new classroom norms for participation, and the adaptation of existing classroom routines to support its smooth functioning.

5.4.4 Curriculum script

In planning to teach a particular topic, and in conducting lessons on it, teachers draw on (evolving) knowledge gained in the course of their own experience of learning and teaching that topic, or gleaned from available curriculum materials. Such knowledge is organised as a **curriculum script**, where 'script' is used in the psychological sense of a form of event-structured organisation: a loosely ordered model of relevant goals and actions that guides teachers' handling of the topic, and includes variant expectancies of a situation and alternative courses of action (Leinhardt, Putnam, Stein & Baxter, 1991). A curriculum script interweaves ideas to be developed, tasks to be undertaken, representations to be employed, and difficulties to be anticipated in the course of teaching that topic, and links these to relevant aspects of working environment, resource system, and activity structure.

Teachers frequently talk about the use of new technologies in terms which appear to involve the adaptation and extension of established curriculum scripts (Ruthven & Hennessy, 2002). For example, they talk about a new technology as a means of improving existing approaches to a topic, suggesting that it serves as a more convenient and efficient tool for supporting specific mathematical processes, or provides a more vivid and dynamic presentation of particular mathematical properties. Nevertheless, it is easy to underestimate the host of small but nuanced refinements which existing curriculum scripts require in order even to assimilate a new technology, let alone adapt the approach taken to a mathematical topic in the light of fresh insights gained from using the technology to mediate it.

When teachers participate in development projects, they experience pressure (often self-administered) to use technology more innovatively. Monaghan (2004) reports, for example, that teachers had difficulty in finding resources to help them devise and conduct technology lessons on an investigative model. Consequently, they were obliged to plan such lessons at length and in detail, and then found themselves teaching rather inflexibly. The extent and complexity of such adoption is still greater when 'imported' technologies need to be aligned with the school curriculum. Monaghan compares, for example, the relative ease with which new lessons could be devised around the use of graphware specifically devised for educational use, with the much greater demands of appropriating ‘imported’ computer algebra systems to curricular purposes. These challenges become particularly severe in an educational culture, such as the French one, which emphasises a rigorous articulation of mathematical ideas and arguments (Artigue, 2002; Ruthven, 2002)

5.4.5 Time economy

The concept of *time economy* (Assude, 2005) focuses on how teachers seek to manage the *“rate”* at which the physical time available for classroom activity is converted into a *“didactic time”* measured in terms of the advance of knowledge. Although new tools and materials are sometimes represented as displacing old to generate a time bonus, it is more common to find a *double instrumentation* in operation, in which old technologies remain in use alongside new. In particular, old technologies may make an epistemic, knowledge-building contribution as much as a pragmatic, task-effecting one (Artigue, 2002). This double instrumentation means that new technologies often give rise to cost additions rather than to cost substitutions with respect to time. Thus a critical concern of teachers is to fine-tune resource systems, activity structures and curriculum scripts to optimise the rate of didactic return on the time investment (Bauer & Kenton, 2005; Crisan et al., 2007; Smerdon et al., 2000). A critical issue is what teachers perceive as the mathematical learning that results from students using new tools. As noted in the earlier discussion of dynamic geometry, teachers are cautious about new tools which require substantial investment, and alert for modes of use which reduce such investment or increase rates of return.

These concerns to maximise the time explicitly devoted to recognised mathematical learning are further evidenced in the trend to equip classrooms with interactive whiteboards, popularised as a technology for increasing the pace and efficiency of lesson delivery, as well as harnessing multimodal resources and enhancing classroom interaction (Jewitt et al., 2007). Evaluating the developing use of interactive whiteboards in secondary mathematics classrooms, Miller & Glover (2006) found that teachers progressed from initial teaching approaches in which the board was used only as a visual support for the lesson, to approaches where it was used more deliberately to demonstrate concepts and stimulate responses from pupils. In the course of this development, there was a marked shift away from pupils copying down material from the board towards use *“at a lively pace to support stimulating lessons which minimise pupil behaviour problems”* (p. 4). However, in terms of the type of mathematical resource used with the board, there was little progression beyond textbook type sources and prepared presentation files; more generic mathematical resources such as spreadsheet, graphing and geometry programs were rejected by teachers as over-complex or used by them only in limited ways.

5.5 Practitioner thinking and professional learning in an innovative lesson

The conceptual framework sketched in the last section will now be used to analyse the practitioner thinking and professional learning surrounding one of the lessons from the earlier study of classroom practice incorporating dynamic geometry use (Ruthven, Hennessy & Deaney, 2008). In the original study, this specific nomination was followed up not only because the teacher concerned had talked lucidly about his experience of teaching such a lesson for the first time, but because he displayed particular awareness of the potential of dynamic geometry for developing visuo-spatial and linguistic aspects of students' geometrical thinking. Thus this case was chosen for investigation as a prospectively interesting outlier where a teacher appeared to be developing a form of classroom practice more consonant with the style of dynamic geometry use envisaged by its protagonists. Because the teacher was unusually expansive in interview, touching on a range of aspects of practitioner thinking and professional learning, this case was also particularly suited to further analysis in terms of the structuring features identified in the conceptual framework outlined in the previous section. Nevertheless, it should be borne in mind that the original study was not designed or conducted with this conceptual framework in mind; rather, it has provided a subsequently convenient means of exploring application of the framework to a concrete example.

5.5.1 Orientation to the lesson

When initially nominating a recent lesson as an example of successful practice, the teacher explained that it had been developed in response to improved technology provision in the mathematics department, notably the installation of interactive whiteboards in ordinary classrooms. He reported that the lesson (with a class in the early stages of secondary education) had started with him explicitly constructing a triangle, and then the perpendicular bisectors of its edges. The focus of the investigation which ensued had been on employing dragging to examine the idea that this construction might identify the 'centre' of a triangle.

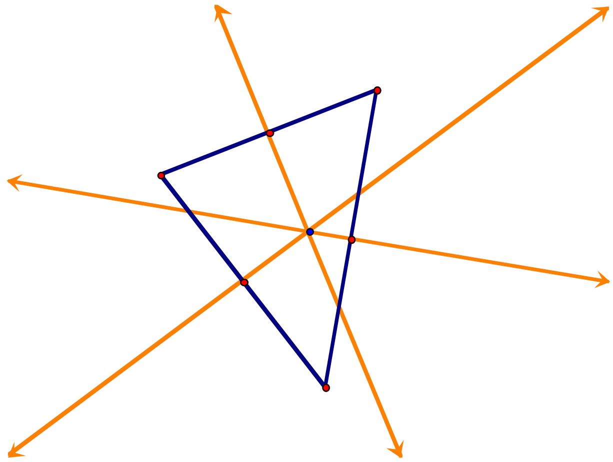

Figure 2: The basic dynamic figure employed in the investigative lesson

According to the teacher, one particularly successful aspect of the lesson had been the extent to which students actively participated in the investigation. Indeed, because of the interest and engagement shown by students, the teacher had decided to extend the lesson into a second session, held in a computer room to allow students to work individually at a computer. For the teacher, the ready recall by students in this second session of ideas from the earlier session was another striking aspect of the lesson's success. In terms of the specific contribution of dynamic geometry to this success, the teacher noted how the software supported exploration of different cases, and overcame the manipulative difficulties which students encountered in using classical tools to attempt such an investigation by hand. But the teacher saw the contribution of the software as going beyond ease and accuracy; using it required properties to be formulated precisely in geometrical terms.

These, then, were the terms in which this earlier lesson was nominated as an example of successful practice. We followed up this nomination by studying a lesson along similar lines, conducted over two 45-minute sessions on consecutive days with a Year 7 class of students (aged 11-12) in their first year of secondary education.

5.5.2 Working environment

Each session of the observed lesson started in the normal classroom and then moved to a nearby computer suite where it was possible for students to work individually at a machine. This movement between rooms allowed the teacher to follow an activity cycle in which working environment was shifted to match changing activity format. Even though the computer suite was, like the teacher's own classroom, equipped with a projectable computer, starting sessions in the classroom was expedient as doing so avoided disruption to the established routines underpinning the smooth launch of lessons.

Moreover, the classroom provided an environment more conducive to sustaining effective communication during whole-class activity and to maintaining the attention of students. Whereas in the computer suite each student was seated behind a sizeable monitor, blocking lines of sight and placing diversion at students' fingertips, in the classroom the teacher could introduce the lesson *"without the distraction of computers in front of each of them"*.

It was only recently that the classroom had been refurbished and equipped, and a neighbouring computer suite established for the exclusive use of the mathematics department. The teacher contrasted this new arrangement favourably in terms of the easier and more regular access to technology that it afforded, and the consequent increase in the fluency of students' use. New routines were being established for students opening a workstation, logging on to the school network, using shortcuts to access resources, and maximising the document window. Likewise, routines were being developed for closing computer sessions. Towards the end of each session, the teacher prompted students to plan to save their files and print out their work, advising them that he'd *"rather have a small amount that you understand well than loads and loads of pages printed out that you haven't even read"*. He asked students to avoid rushing to print their work at the end of the lesson, and explained how they could adjust their output to try to fit it onto a single page; he reminded them to give their file a name that indicated its contents, and to put their name on their document to make it easy to identify amongst all the output from the single shared printer.

5.5.3 Resource system

The department had its own 'schemes of work' (a term used in English schools for a written schedule of topics to be taught to particular year-groups, that usually includes suggestions for resources to be used) with teachers encouraged to explore new possibilities and report to colleagues. This meant that teachers were accustomed to integrating material from different sources into a common scheme of work. However, so wide was the range of computer-based resources currently being trialled that our informant (who was head of department) expressed concern about incorporating them effectively into departmental schemes, and about the demands of familiarising staff and students with such a variety of tools.

In terms of coordinating use of old and new technologies, work with dynamic geometry was seen as complementing established work on construction with classical manual tools, by strengthening attention to the related geometric properties. Nevertheless, the teacher felt that old and new tools lacked congruence, because certain manual techniques appeared to lack computer counterparts. Accordingly, old and new were viewed as involving different methods and having distinct functions. While ruler and compass were seen as tools for classical constructions, dynamic software was *"a way of exploring the geometry"*. Equally, some features of computer tools were not wholly welcome. For example, the teacher noted that students could be deflected from the mathematical focus of a task, spending too much time on cosmetic aspects of presentation. During the lesson the teacher had tried out a new technique for managing this, by briefly projecting a prepared example to show students the kind of report that they were expected to produce, and to illustrate appropriate use of colour coding. In effect, by showing students to what degree, and for what purpose, he regarded it as legitimate for them to *"slightly adjust the font and change the colours a little bit, to emphasise the maths, not to make it just look pretty"*, the teacher was developing sociomathematical norms (Yackel & Cobb 1996) for using the new technology, and developing a classroom strategy for establishing these norms.

5.5.4 Activity format

Each session of the observed lesson followed a similar activity cycle, starting with teacher-led activity in the normal classroom, followed by student activity at individual computers in the nearby computer suite, with this change of rooms during sessions serving to match working environment to activity format. Indeed, when the teacher had first nominated this lesson, he had remarked on how it combined a range of activity formats – *"a bit of whole class, a bit of individual work and some exploration"* – to create a promising lesson structure; one that he would *"like to pursue because it was the first time [he]'d done something that involved quite all those different aspects".*

In discussing the observed lesson, however, the teacher highlighted one aspect of the model which had not functioned as well as he would have liked: the fostering of discussion during individual student activity. He identified a need for further consideration of the balance between opportunities for individual exploration and for productive discussion, through exploring having students work in pairs. At the same time, the teacher noted a number of ways in which the computer environment helped to support his own interactions with students within an activity format of individual working. Such opportunities arose from helping students to identify and resolve bugs in their dynamic geometry constructions. Equally, the teacher was developing ideas about the pedagogical affordances of text-boxes, realising that they created conditions under which students might be more willing to consider revising their written comments because this could be done with ease and without his interventions being seen by students as *“ruin[ing] their work”* by spoiling its presentation. This was helping him to achieve his goal of developing students’ capacity to express themselves clearly and precisely in geometrical terms through refining their statements of properties.

5.5.5 Curriculum script

The observed lesson followed on from earlier ones in which the class had undertaken simple classical constructions with manual tools: in particular, using compasses to construct the perpendicular bisector of a line segment. Further evidence that the teacher’s curriculum script for this topic originated prior to the availability of dynamic geometry was his reference to the practical difficulties which students encountered in working by hand to accurately construct the perpendicular bisectors of a triangle. His evolving script now included knowledge of *“unusual”* and *“awkward”* aspects of software operation liable to *“cause[] a bit of confusion”* amongst students, but also of how such difficulties might be turned to advantage in reinforcing the mathematical focus of the task so that *“sometimes the mistakes actually helped”*.

Equally, the teacher’s curriculum script anticipated that students might not appreciate the geometrical significance of the concurrence of perpendicular bisectors, and incorporated strategies for addressing this, such as trying *“to get them to see that… three random lines, what was the chance of them all meeting at a point”.* This initial line of argument was one already applicable in a pencil and paper environment. Later in the interview, however, the teacher made reference to another strategy which brought the distinctive affordances of dragging the dynamic figure to bear on this issue: *“When I talked about meeting at a point, they were able to move it around”*. Likewise, his extended curriculum script depended on exploiting the distinctive affordance of the dynamic tool to explore how dragging the triangle affected the position of this ‘centre’.

This suggests that the teacher’s curriculum script was evolving through experience of teaching the lesson with dynamic geometry, incorporating new mathematical knowledge specifically linked to mediation by the software. Indeed, he drew attention to a striking example of this which had arisen from his question to the class about the position of the ‘centre’ when the triangle was dragged to become right angled. The lesson transcript recorded:

Teacher: What’s happening to the [centre] point as I drag towards 90 degrees? What do you think is going to happen to the point when it’s at 90?…

Student: The centre’s going to be on the same point as the midpoint of the line.

Teacher [with surprise]: Does it always have to be at the midpoint?

[Dragging the figure] Yes, it is! Look at that! It's always going to be on the midpoint of that side.… Brilliant!

Reviewing the lesson, the teacher commented that this property hadn't occurred to him; he *"was just expecting them to say it was on the line".* Reacting to the student response he reported that he looked at the figure and *"saw it was exactly on that centre point",* and then *"moved it and thought… of course it is!".* What we witness here, then, is an episode of reflection-in-action through which the teacher's curriculum script for this topic has been elaborated.

5.5.6 Time economy

In respect of the time economy, a very basic consideration of physical time for the teacher in this study was related to the proximity of the new computer suite to his normal classroom. However, a more fundamental feature of this case was the degree to which the teacher measured didactic time in terms of progression towards securing student learning rather than pace in covering a curriculum. At the end of the first session, he linked his management of time to what he considered to be key stages of the investigation: *"the process of exploring something, then discussing it in a quite focused way as a group, and then writing it up*", in which students moved from being *"vaguely aware of different properties"* to being able to *"actually write down what they think they've learned."*

A further crucial consideration within the time economy is investment in developing students' capacity to make use of a tool. As noted in the larger study from which this case derives, teachers were willing to invest time in developing students' knowledge of dynamic geometry only to the extent that they saw this as promoting their mathematical learning. This teacher was unusual in the degree to which he saw working with the software as engaging students in disciplined interaction with a geometric system. Consequently, he was willing to spend time to make them aware of the construction process underlying the dynamic figures used in lessons, by *"actually put[ting] it together in front of the students so they can see where it's coming from."* Equally, this perspective underpinned his willingness to invest time in familiarising students with the software, recognising that it was possible to capitalise on earlier investment in using classical tools in which *"doing the constructions by hand first"* was a way of *"getting all the key words out of the way."* As this recognition of a productive interaction between learning to use old and new technologies indicates, this teacher took an integrative perspective on the double instrumentation entailed. Indeed, this was demonstrated earlier in his concern with the complementarity of old and new as components of a coherent resource system.

5.6 Discussion

Although only employing a dataset conveniently available from earlier research, the case study presented in this chapter starts to illuminate the professional adaptation on which the constitution of digital tools and materials as classroom resources depends. While the status of the conceptual framework that has been used to identify structuring features of classroom practice must remain 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. It has potential to be employed not just in relation to secondary mathematics teaching, but to other school phases and curricular areas, and to other types of resource; indeed, much of the earlier research from which the various central concepts have been drawn has such a range.

At the same time, however, the differing provenance of the five central constructs raises some issues of coherence. The original construct of curriculum script, for example, is very clearly psychologically based, focusing on individual knowledge schemes. One might also add that the term 'script' (originating in a psychological metaphor for memory structures) risks failing to convey the sense intended here of an organised repertoire of potential actions and interactions for teaching a topic as opposed to a specific sequence. By contrast, the construct of working environment may appear to refer to a material situation independent of the teacher. However (as suggested by Adler in Chapter 1), a more adequate theorisation takes a structuring feature as being constituted not just by an existing system of contextual constraints but by teachers' interpretation of these and adaptation to them. Moreover, this co-constitution takes place on the social plane as well as the individual; indeed, these planes interact inasmuch as individual adaptation to such constraints is subject to a degree of socialisation, while the corresponding social norms evolve by virtue of a wider cultural appropriation of what originated as innovative microgenetic adaptations on a very local scale.

Thus, while each of these structuring features of working environment, resource system, activity format, curriculum script, and time economy are anchored in a particular form of constraint under which the work of teaching takes place, these constraints do not wholly condition practice, but interact and afford some degree of adaptation. For example, in the case study detailed in this chapter, the proximity of the teacher's normal classroom to the computer classroom afforded him the option to move between them as the location for the lesson. Moreover the way in which he exercised this option was guided by his assessment of the suitability of the two locations for different activity formats. This, in turn, permitted the teacher to develop a new type of activity structure covering each session as a whole, efficient in terms of time economy, and providing what he considered a promising structure for an investigative lesson to capitalise on student use of digital resources. In terms of the specific digital resource in play, dynamic geometry, the teacher established a resource system in which this software fulfilled complementary functions to classical tools, each supporting particular aspects of students' learning of mathematics, and so justifiable in terms of time economy. Finally, the teacher's curriculum script for the topic was evolving, through adaptation and extension of an investigative task previously carried out without digital tools, the associated activity formats, and corresponding refinement of his knowledge about supporting the interactive development of mathematical ideas.

Acknowledging the concern of Section 4 of this book with the collaborative use of resources, the collective role of the school department in fostering teachers' professional learning was not a focus of this case study. In this department, however, it was clear that the internally developed schemes of work provided a key means of prompting the spread between teachers of new teaching ideas, often supported by self-devised materials. Nevertheless, the teacher had not yet reached the point at which this particular teaching sequence could be incorporated in the relevant departmental scheme. Indeed this case illustrates the *bricolage* which typifies the process of appropriating a new tool in the absence of well established professional practice; a bricolage which, in the English educational system at least, is often left to the individual teacher rather than organised collectively. Likewise, the teaching sequence studied in this chapter was far from being captured in documented form. Although he had prepared a worksheet to remind his students of certain pieces of advice for their work, the teacher was generally rather sceptical of the value of such aids: *"I don't like pre-prepared worksheets"; "Normally I don't use worksheets very much at all".* This arose from his strong valorisation of the explicit collective (re)construction of mathematical situations: *"I always like to start with a blank page and actually put it together in front of the students so they can see where it's coming from*". For him, it was this interactivation of a teaching sequence (guided by his curriculum script) that lay at the centre of his teaching. Under these conditions, then, this new teaching sequence might be expected to eventually be shared with colleagues more through observation or simulation of a lesson than by the reading or following of a documentary reification of this professional knowledge.

This prompts comparison of the ideas developed in this chapter with those of other chapters in this book, notably those chapters in Sections 1 and 3 that focus on the integration of digital tools and materials into everyday mathematics teaching. In terms of the core idea of 'resource' itself, following the concrete sense in which that term is widely used within the teaching profession, the focus of this chapter is on material 'resources' in classroom use, whereas, as Gueudet & Trouche note in Chapter 2, they use the term more loosely to cover any teacher resource, material and non-material.

Another significant contrast between the conceptual framework used in this chapter and that of Gueudet and Trouche lies in the central metaphor employed to capture the organisation, retrieval and exchange of professional knowledge. For Gueudet & Trouche, this is the 'document'; in the conceptual framework employed in this chapter it is the 'script'. Although neither Gueudet & Trouche nor myself are entirely happy with our respective metaphors, they do point to an important contrast in modalities of memory and thought, similar to that discussed by Proust in Chapter 9. This may well reflect divergences of professional practice and values between educational systems, notably as these bear on the planning of lessons. Such divergences might be linked, for example, to differing types of evidence used for professional accountability (lesson planning, for example, as against student progression) and models of lesson process (establishing disciplinary narrative, for example, as against ensuring curricular coverage), as well as intensity of work (with contrasting expectations as regards lesson preparation reflecting very different volumes of teaching and other duties required of teachers).

Relatedly, although Gueudet & Trouche note in Chapter 2 how a teacher's curriculum script serves particularly to guide the decisions that the teacher takes in class, it is important to emphasise that this script also plays a crucial part in pre-active planning of a lesson agenda, and in post-active reflection on (and learning from) a lesson (Leinhardt et al., 1991). Indeed, I would hypothesise that every 'document' expresses elements of some underlying 'script'. Nevertheless, it is important to acknowledge the part that the use and adaptation of documentary materials may play in supporting and developing the personal curriculum scripts of teachers, particularly those whose subject knowledge is modest (as noted by Pepin in Chapter 7).

In Chapter 14, Drijvers raises the question of how the conceptual framework used in this chapter relates to the construct of instrumental orchestration. In terms of the concrete instrumental orchestrations that Drijvers describes, the answer is simple: each corresponds to a particular type of activity format centred on a specific use of one or more tools. More broadly, as described by Drijvers, didactical configuration and exploitation mode are features of what is commonly referred to within research on teacher thinking and planning as pre-active teaching, and didactical performance is likewise an aspect of interactive teaching (Clark & Peterson, 1986). In terms of the structuring features of classroom practice identified by the conceptual framework employed in this chapter, didactical configuration concerns organisation of the working environment as well as some more generic aspects of the functioning of the resource system; exploitation mode relates to more topic-specific aspects of the functioning of the resource system as well as to the tool mediation of processes within the curriculum script; and didactical performance relates to the way in which the curriculum script guides interactive teaching.

Drijvers notes that the conceptual framework presented in this chapter is a more generic one, not specifically tied to the integration of technological resources in the way that the orchestration framework is. Arguably these qualities are complementary. Indeed, an important conceptual weakness, both of advocacy for technology integration and research into it, has been lack of attention to the broader situation in which ordinary teachers find themselves (Ruthven & Hennessy, 2002; Lagrange, 2008). It is in this spirit that the conceptual framework used in this chapter has been developed by synthesising observations from recent studies of technology use, particularly in school mathematics, in the light of earlier conceptualisations of classroom teaching and situated teacher expertise.

Turning to future development of the conceptual framework presented in this chapter, other insights have already been gained through a parallel analysis of mathematics teachers' appropriation of graphing software (Ruthven, Deaney & Hennessy, 2009). However, further studies are now required in which both data collection and analysis are guided by the conceptual framework, so that it can be subjected to fuller testing and corresponding elaboration and refinement. If they are 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. By providing a system of constructs closer to the lived world of teacher experience and classroom practice, it may prove able to fulfil an important mediating function, allowing insights from more decontextualised theories to be translated into classroom action, and serving to draw attention to practical issues neglected in such theories.

Acknowledgements

Particular thanks are due to the teacher colleague featured in the case study; to Rosemary Deaney who carried out the fieldwork for it; and to the UK Economic and Social Research Council which funded the associated research project.

This chapter draws on and develops ideas and material from two earlier publications (Ruthven, 2009; Ruthven, 2010). These publications drew, in turn, on papers discussed at the CERME conferences in 2007 and 2009, in the RME and TACTL SIGs at the AERA conference in 2009, and at the CAL conference in 2009.

References

Abboud-Blanchard, M., Cazes, C., & Vandebrouck, F. (2007). Teachers' activity in exercises-based lessons. Some case studies. In D. Pitta-Pantazi & G. Philippou (Eds.), *Proceedings of the Fifth Congress of the European Society for Research in Mathematics Education* (pp. 1826-1836). Larnaca: CERME-5. Accessed at http://ermeweb.free.fr/CERME5b/WG9.pdf.

Amarel, M. (1983). Classrooms and computers as instructional settings. *Theory into Practice,* 22, 260-266.

Artigue, M. (2002). Learning mathematics in a CAS environment: The genesis of a reflection about instrumentation and the dialectics between technical and conceptual work. *International Journal of Computers for Mathematical Learning,* 7(3), 245-274.

Arzarello, F., Olivero, F., Paola, D., & Robutti, O. (2002). A cognitive analysis of dragging practises in Cabri environments. *Zentralblatt fur Didaktik der Mathematik* [now known as *ZDM: The International Journal on Mathematics Education],* 34(3), 66-72.

Assude. T. (2005). Time management in the work economy of a class. A case study: Integration of Cabri in primary school mathematics teaching. *Educational Studies in Mathematics,* 59(2), 183-203.

Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is –or might be– the role of curriculum materials in teacher learning and instructional reform. *Educational Researcher,* 25(9), 6-8 & 14.

Bauer, J., & Kenton, J. (2005). Towards technology integration in schools: Why it isn't happening. *Journal of Technology and Teacher Education,* 13(4), 519-546.

Becker, H., Ravitz, J. & Wong, Y. (1999). Teacher and Teacher-Directed Student Use of Computers, Teaching, Learning, and Computing: 1998 National Survey Report #3. Centre for Research on Information Technology and Organizations, University of California Irvine. Accessed at http://www.crito.uci.edu/TLC/FINDINGS/.../REPORT_3_PDF_REV.PDF.

Brown, S., & McIntyre, D. (1993). *Making Sense of Teaching.* Buckingham: Open University Press.

Bueno-Ravel, L., & Gueudet, G. (2007). Online resources in mathematics: Teachers' genesis of use. In D. Pitta-Pantazi & G. Philippou (Eds.), *Proceedings of the Fifth Congress of the European Society for Research in Mathematics Education* (pp. 1369-1378). Larnaca: CERME-5. Accessed at http://ermeweb.free.fr/CERME5b/WG9.pdf.

Burns, R. B., & Anderson, L. W. (1987). The activity structure of lesson segments. *Curriculum Inquiry,* 17(1), 31-53.

Burns, R. B., & Lash, A. A. (1986). A comparison of activity structures during basic skills and problem-solving instruction in seventh-grade mathematics. *American Educational Research Journal,* 23(3), 393-414.

Chazan, D., & Yerushalmy, M. (1995). Charting a course for secondary geometry. In R. Lehrer & D. Chazan (Eds.) *New Directions in the Teaching and Learning of Geometry.* Hillsdale NJ: Lawrence Erlbaum.

Clark, C. M., & Peterson, P. L. (1986). Teachers' thought processes. In M. Wittrock (Ed.) *Handbook of Research on Teaching*, 3rd edition (pp. 255-96). New York: Macmillan.

Crisan, C., Lerman, S., & Winbourne, P. (2007). Mathematics and ICT: a framework for conceptualising secondary school teachers' classroom practices. *Technology, Pedagogy and Education,* 16(2), 21-39.

Hoyles, C., Foxman, D., & Küchemann, D. (2001). *A comparative study of geometry curricula.* London: Institute of Education.

Jenson, J., & Rose, C. B. (2006). Finding space for technology: Pedagogical observations on the organization of computers in school environments. *Canadian Journal of Learning and Technology* 32(1). Accessed at http://www.cjlt.ca/index.php/cjlt/article/view/59/56.

Jewitt, C., Moss, G., & Cardini, A. (2007). Pace, interactivity and multimodality in teachers' design of texts for interactive whiteboards in the secondary school classroom. *Learning, Media and Technology,* 32(3), 303-317.

Laborde, C. (2001). Integration of technology in the design of geometry tasks with Cabri-Geometry. *International Journal of Computers for Mathematical Learning,* 6(3), 283-317.

Lagrange, J.-B. (2008). 'Ordinary' teachers using technology: concerns, theoretical approaches, case studies. Regular lecture at ICME-11. Abstract accessed at http://icme11.org/node/1441.

Leinhardt, G. (1988). Situated knowledge and expertise in teaching. In J. Calderhead (Ed.) *Teachers' Professional Learning* (pp. 146-168). London: Falmer.

Leinhardt, G., Putnam T., Stein, M. K., & Baxter, J. (1991). Where subject knowledge matters. *Advances in Research in Teaching,* 2, 87-113.

Leinhardt, G., Weidman, C., & Hammond, K. M. (1987). Introduction and integration of classroom routines by expert teachers. *Curriculum Inquiry,* 17(2), 135-176.

MacKenzie, D., & Wajcman, J. (Eds.) (1999). *The Social Shaping of Technology* (Second Edition). Buckingham: Open University Press.

Miller, D., & Glover, D. (2006). Interactive whiteboard evaluation for the Secondary National Strategy: Developing the use of interactive whiteboards in mathematics: Final report. Keele: Keele University. Accessed at http://nationalstrategies.standards.dcsf.gov.uk/node/96272.

Monaghan, J. (2004). Teachers' activities in technology-based mathematics lessons. *International Journal of Computers for Mathematical Learning,* 9(3), 327-357.

Morgan, C. (1990). Carry on SMILEing. *Micromath,* 6(3), 14-15.

Olive, J. (2002). Implications of using dynamic geometry technology for teaching and learning. In M. Saraiv, J. Matos, & I. Coelho (Eds.) *Ensino e Aprendizagem de Geometria*. Lisbon: SPCE. Accessed at http://www.spce.org.pt/sem/JO.pdf.

Remillard, J. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research,* 75(2), 211-246.

Ruthven, K. (2002). Instrumenting mathematical activity: Reflections on key studies of the educational use of computer algebra systems. *International Journal of Computers for Mathematical Learning,* 7(3), 275-291.

Ruthven, K. (2009). Towards a naturalistic conceptualisation of technology integration in classroom practice: The example of school mathematics. *Education & Didactique,* 3(1), 131-149.

Ruthven, K. (2010). Constituer les outils et les supports numériques en ressources pour la classe. In G. Gueudet & L. Trouche (Eds.), *Ressources vives, le travail documentaire des professeurs en mathématiques* (pp. 183-199). Rennes: Presses Universitaires de Rennes/Institut National de Recherche Pédagogique.

Ruthven, K., Deaney, R., & Hennessy, S. (2009). Using graphing software to teach about algebraic forms: A study of technology-supported practice in secondary-school mathematics. *Educational Studies in Mathematics,* 71(3), 279-297.

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(1), 47-88.

Ruthven, K., Hennessy, S., & Deaney, R. (2005). Incorporating Internet resources into classroom practice: Pedagogical perspectives and strategies of secondary-school subject teachers. *Computers and Education,* 44(1), 1-34.

Ruthven, K., Hennessy, S., & Deaney, R. (2008). Constructions of dynamic geometry: a study of the interpretative flexibility of educational software in classroom practice. *Computers and Education,* 51(1), 297-317.

Scher, D. (2000). Lifting the curtain: The evolution of the Geometer's Sketchpad. *The Mathematics Educator,* 10(1), 42-48.

Smerdon, B., Cronen, S., Lanahan, L., Anderson, J., Iannotti, N., Angeles, J., & Greene, B. (2000). *Teachers' tools for the 21st century: A report on teachers' use of technology.* Washington DC: US Department of Education, National Center for Education Statistics. Accessed at nces.ed.gov/pubs2000/2000102.pdf.

Spillane, J. P., Reiser, B. J., & Reimer, T. (2002). Policy implementation and cognition: Reframing and refocusing implementation research. *Review of Educational Research,* 72(3), 387-431.

Trouche, L. (2005). Instrumental genesis, individual and social aspects. In D. Guin, K. Ruthven, & L. Trouche (Eds.), *The didactical challenge of symbolic calculators: turning a computational device into a mathematical instrument* (pp. 197-230). New York: Springer.

Williams, R. & Edge, D. (1996). The social shaping of information and communications technologies. *Research Policy*, 25(6) 856-899.

Yackel, E., & Cobb, P. (1996). Sociomathematical norms, argumentation, and autonomy in mathematics. *Journal for Research in Mathematics Education, 2*7(4), 458-477.

Zucker, A., & McGhee, R. (2005). A study of one-to-one computer use in mathematics and science instruction at the secondary Level in Henrico County public schools. Menlo Park CA: SRI International. Accessed at ubiqcomputing.org/FinalReport.pdf.