BUILDING PRACTICAL THEORIES FOR TECHNOLOGY INTEGRATION

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Secondary-school systems throughout the world are preoccupied with technology integration in subject teaching and learning. Advocacy of the educational use of new technologies often seems to suggest that their value is evident, their adoption urgent, their implementation unproblematic, and their impact transformative. However, the recent TIMSS-2003 studies show that technology integration is extremely rare in school Mathematics and Science, even when national curricula make reference to the use of computers, equipment is available for classroom use, and teachers have received recent training in technology integration in their subject. Drawing on studies of how mathematics and science teachers in England see technology use as contributing to their practice, this paper shows how established subject cultures – notably their pedagogical discourses and practices– shape the 'practical theories' that teachers bring to ICT use– illustrating this through a specific example of teachers' use of dynamic geometry software. These English studies of informally developed technology use by teachers are then compared with ideas emerging from French studies of project-based development of technology use. The paper concludes by arguing that the challenge of technology integration within an institutionalised community calls for a dialogic process of development in which current practice is sympathetically analysed and imaginatively reviewed in the light of speculative possibilities to produce viable new practical theories.

Introduction

Secondary-school systems throughout the world are preoccupied with 'technology integration'. The term implies extending the use of computer-based technologies beyond specialist courses and special projects into the everyday practice of mainstream schooling; indeed incorporating such technologies to the degree which currently characterises older information and communication technologies – such as classroom boards and exercise books; printed texts and reference materials, drawing instruments and physical apparatus.

Advocacy of the educational use of new technologies often seems to suggest that their value is evident, their adoption urgent, their implementation unproblematic, and their impact transformative. Reviewing over eighty years of such claims, Cuban (1989, 2001) has detected a recurring cycle governing the evolving reception of each new technology in which exhilaration then credibility give way to disappointment then blame. He reports that while new technologies have broadened classroom repertoires to a degree, they remain relatively marginal, and are rarely used for more than a fraction of the school week.

The Current State of Technology Integration in Mathematics and Science Education

For a recent snapshot of the integration of new technologies into mathematics and science teaching around the world, I have turned to the TIMSS-2003 studies (Mullis, Martin, Gonzalez, & Chrostowski, 2004a, pp. 248, 294; 2004b, pp. 266, 313). They present information (based on teacher reports) about the integration of various forms of computer usage, operationalised as use in 'about half of the lessons or more'. They also provide information about contextual factors such as whether or not computers were referred to in national subject

curricula, and the extent to which teachers had access to computers for their class lessons, and had participated (over the preceding two years) in professional development on technology integration in their subject. For the purposes of this paper, I have extracted the particulars of all those South-East Asian countries for which information is provided, and selected further countries that might be regarded as important comparators.

In Mathematics (Table 1), the profiles for individual countries indicate very low integration of the identified forms of technology use, as do the international averages (of all countries in the TIMSS survey, not just those selected here). Only one country (Korea) has a profile in which technology integration is not exceptionally rare (averaging 10% across the identified aspects of technology usage). Levels of reported availability of computer facilities for mathematics lessons are very variable, ranging from 5% to above 85%. It is not surprising to find that in those (3) countries (Indonesia, Malaysia and the Philippines) where levels of class access to computers are low (15% or below) and there is no reference to their use in national curricula, levels of reported integration are low. What is more striking are the low profiles of technology integration in those (4) countries (Australia, England, New Zealand and Singapore) where national curricula make reference to use of computers, and where many teachers (50% upwards) report access to computers and recent relevant training; indeed these profiles of integration are not markedly stronger than those in apparently less favourable circumstances.

Table 1
Computer Use in Mathematics Class – Grade 8 – TIMSS 2003

Country	Nat. Curriculum makes reference to using computers	Percentage of students whose teachers reported…					
		computers being available for use in class lessons	having had recent prof'nal dev'ment on IT integration	using computers in about half the class lessons or more for…			
				discovering principles and concepts	practicing skills and procedures	looking up ideas and information	processing and analyzing data
Australia	Yes	54	70	0	1	1	0
Chinese Taipei	Yes	29	81	0	0	1	1
England	Yes	66	63	1	5	2	1
Hong Kong SAR	No	39	79	0	0	1	3
Indonesia	No	11	21	1	2	1	1
Japan	Yes	86	27	2	1	1	1
Korea, Republic of	Yes	73	43	17	7	11	6
Malaysia	No	5	48	1	0	0	0
New Zealand	Yes	71	53	1	0	1	1
Philippines	No	10	44	2	2	3	2
Scotland	Yes	40	83	2	2	0	0
Singapore	Yes	67	88	3	4	3	3
United States		46	74	2	4	3	2
International Average		**32**	**43**	**2**	**2**	**2**	**2**

Turning to Science (Table 2), the degree of technology integration appears markedly higher in respect of *Looking Up Ideas and Information* (incidence from 5% to nearly 20% in over half the selected systems, and 6% averaged across all participating countries) than

other aspects within Science and all aspects within Mathematics (2% to 3% averaged across all participating countries). Indeed, all (6) of those countries (Australia, England, Hong Kong, New Zealand, Scotland and United States) where national curricula make reference to use of computers, and where many teachers (50% upwards) report access to computers and recent relevant training, register some degree of integration of using computers for *Looking Up Ideas and Information*. One country (again Korea) has a stronger and broader profile showing some degree of integration of all identified forms of technology usage, notably *Doing Scientific Procedures or Experiments* and *Studying Natural Phenomena Through Simulations* (at 32% and 28% respectively) which are barely represented elsewhere. One other country (United States) displays a similar degree of integration of *Practicing Skills and Procedures* and *Processing and Analyzing Data* (at around 10% and 12% respectively in both countries). Again, in those (3) countries (Indonesia, Malaysia and the Philippines) where levels of lesson access to computers are low (of order 15%) and there is no reference to their use in national science curricula, levels of reported integration are low, but not markedly lower than many countries apparently in more favourable circumstances.

The TIMSS 2003 studies tell us, then, that technology integration is extremely rare in mathematics and science, but they do not provide any explanation of why this should remain so even when national curricula refer to the use of computers, equipment is available for classroom use, and teachers have received recent training in technology integration in their subject. In the case of the system (Korea) where the strongest degree of technology integration was reported by teachers, a recent report (Jung, 2004) suggests that this reflects a switch to digital media for teacher presentation and student work, so that '*the Internet, networked computers and projection TVs that are provided in all… classrooms are used… to view various multimedia with the aim of motivating students, fostering understanding*

by accurately showing the contents of the lesson in the course of lesson development, have the students easily share their finished assignments with peers, and allow a systematic presentation of lesson conclusions'.

Table 2
Computer Use in Science Class – Grade 8 – TIMSS 2003

| Country | Nat. Curriculum makes reference to using computers | Percentage of students whose teachers reported… | | | | | | |
		computers being available for use in class lessons	having had recent prof'nal dev'ment on IT integration	doing scientific procedures or experiments	studying natural phenomena through simulations	practicing skills and procedures	looking up ideas and information	processing and analyzing data
Australia	Yes	74	64	1	0	3	6	4
Chinese Taipei	Yes	44	82	1	1	2	1	1
England	Yes	70	64	1	2	1	7	0
Hong Kong SAR	Yes	56	68	5	3	4	5	3
Indonesia	No	14	29	1	1	2	3	2
Japan	Yes	80	33	1	3	2	3	1
Korea, Republic of	Yes	86	44	32	28	11	16	12
Malaysia	No	14	53	3	1	1	3	2
New Zealand	Yes	48	52	1	1	1	4	1
Philippines	No	16	56	3	2	4	3	4
Scotland	Yes	68	68	1	0	2	6	1
Singapore	Yes	79	82	2	1	1	11	4
United States		72	80	3	3	8	19	12
International Average		38	45	2	2	3	6	3

In the United States, Cuban (1989, 2001) has suggested that disciplinary tradition, school organisation and external regulation encourage teachers to behave as academic specialists whose main concern is with curriculum coverage; the result is a gradual accumulation of incremental adaptations in which marginal uses of technology largely sustain existing classroom practices. This account resonates with studies which have examined the place of technology in classroom life as teachers live it. Kerr (1991) approached school teachers nominated by their principals as *'thoughtful users of technology, but not necessarily the first to try new approaches or the most enthusiastic'*. He asked these teachers to identify milestones that marked changes in how they thought about teaching. What he found was that technology figured in few of the responses to this question, and then only as one factor amongst several, never the first. Kerr then asked teachers to describe their current image of classroom activity and the place there for technology. In response, teachers did acknowledge the opening up of new teaching approaches, but they still stressed that technology played only a minimal role in their thinking about what happened in their classrooms. In summary, they *'saw themselves as teachers first and as users of educational technology a distant second'*. Nevertheless, Kerr also found signs that technology may provide more of a fulcrum for change than some teachers consciously realised. He identified it as playing a significant part in what he characterised as *'a measured development in their thinking about instruction, their role as teachers, and, most significantly, the look and feel of classrooms as the arenas where education takes place'*.

Teachers' Practical Theories of Successful Computer Use in Secondary Mathematics and Science

How, then, do mathematics and science teachers see technology use as contributing to their practice? Around five years ago, my research team interviewed departments (English as well as

Mathematics and Science) in a number of secondary schools in the Cambridge area. In the group interviews, teachers were asked to talk about examples, grounded in their own classroom experience, of what they regarded as successful use of computer-based tools and resources (colloquially referred to as ICT - information and communication technology) within their teaching. From this evidence, we built a cross-subject model summarising what could be described as their 'practical theories' of the classroom use of ICT. In the literature, 'practical theory' has been used in different ways (Deaney, Ruthven & Hennessy, in press); to refer to an explicit model of practice (Kroath, 1989; McIntyre, 1995) but also to the tacit, personal and situated facets of teacher cognition (Clark & Peterson, 1986; Munby, Russell & Martin, 2001). The task we set ourselves was to draw out and organise practitioner ideas as fully and explicitly as possible.

In each subject, similar ICT tools and resources were in use across the six schools. In Mathematics, all schools used spreadsheets, and most used Logo, and graphing tools, as well as courseware or Internet sites for revision and test preparation. In Science all schools used data logging facilities, multimedia resources and the Internet; and most also reported using spreadsheets, as well as courseware or Internet sites for revision and test preparation. Several themes emerged which were common to Mathematics and Science (Ruthven, Hennessy & Brindley, 2004).

Enhancing the Variety and Appeal of Classroom Activity

Teachers pointed to how use of ICT could bring variety to classroom activity, and enhance its appeal. ICT use was seen as *'being something different'*, *'making a change'*, *'adding another dimension'*, and –most frequently– as *'providing variety'*. There were suggestions of pupils *'enjoying seeing things done in a different way'* and welcoming *'a different teaching and learning style'*. Teachers emphasised the use of

ICT tools to make tasks less *'laborious'*, less *'tedious and repetitive'*, eliminating *'drudgery'*.

Effecting Working Processes and Improving Production

Teachers pointed to how use of ICT could facilitate and expedite routine parts of classroom activity, improving the pace of lessons, the productivity of pupils, and the quality of their work. Teachers emphasised the *'speed'* and *'ease'* of ICT-supported procedures, and the way in which they produced *'reliable'* and *'accurate'* results. Such use of ICT was *'time saving'* and *'kept the pace going'*.

Overcoming Pupil Difficulties and Building Assurance

Teachers pointed to how use of ICT could help to alleviate difficulties which many pupils experienced in writing, graphing and drawing by hand, allowing pupils to gain satisfaction and pride from creating *'work which is nicely presented'*, particularly by allowing them to correct and improve work, leaving no trace of changes. The immediacy of work with ICT also allowed pupils to *'get straight at it'*, and to *'get feedback immediately on how they're doing'* so that *'the ones who are nervous know'*.

Focusing on Overarching Issues and Accentuating Important Features

Teachers pointed to ways in which use of ICT could help to focus the attention of pupils on overarching issues, and to accentuate important features of situations under consideration. For example, computer graphing helped pupils to *'get over the stumbling block of actually drawing them in the first place [so that] they can actually see what they are and concentrate on that aspect'*. Likewise, it enabled teachers *'to offer clearer visual explanations'* which pupils *'accepted… because they'd seen it happening'*.

The theme of *Enhancing the variety and appeal of classroom activity* indicated that ICT use was still something out of the ordinary (for these teachers interviewed five years ago). The following themes each pointed primarily to enhancements of existing teaching and learning approaches. While the substance of teacher thinking had expanded to exploit technology use, that thinking remained strongly anchored in established models of classroom practice. Nevertheless, there was evidence of shifts in that practice. For example, mathematics teachers suggested that technology helped to create classroom conditions under which investigative work could be conducted more successfully, particularly with lower attaining pupils, making this form of classroom activity a more viable option. While, in one sense, such use of technology was simply assisting teachers to realise an established form of practice, what is significant is that they reported being able to employ this practice more effectively and extensively. At the same time, however, such use of technology was giving rise to unanticipated phenomena, such as tinkering by students, leading teachers to start to reconsider aspects of their practice. However, teachers did not feel able to consider more far-reaching changes in their practice. Despite an official policy of 'modernisation' promoting use of technology in the classroom, official policy emphasising 'standards' continued to define achievement in mathematics in terms of what students had traditionally been expected to do without access to technology (Hennessy, Ruthven & Brindley, 2005).

Other themes within the model pointed to important differences between subjects (Ruthven, Hennessy & Brindley, 2004).

Supporting Processes of Checking, Trialling and Refinement

In Mathematics but not Science, teachers pointed to ways in which use of ICT could support processes of checking, trialling and

refinement. In particular, they approved the interactive use of calculators to support 'trial and improvement' strategies in which predicted –often estimated– numeric and graphic solutions to problems were repeatedly tested and modified until acceptable. Teachers portrayed such activities as allowing pupils to *'do more investigative work' in which 'if something doesn't work, then they can try something else'.*

Broadening Reference and Increasing Currency of Activity

In Science but not Mathematics, teachers saw ICT use as broadening the range of classroom resources available, and increasing the currency and authenticity of schoolwork. They appreciated the way in which the Internet opened up access to 'all sorts of weird and wonderful stuff", including *'more modern, novel information', enabling students to 'develop a far wider understanding about the issues of science'.* (This difference between the subjects parallels the TIMSS-2003 findings of the greater integration by Science teachers of ICT use for Looking Up Ideas and Information). Teachers also highlighted how CD-ROM material brought 'the real thing' into the Science classroom, making it possible to *'see things which we can't replicate in the lab' or to 'extract data directly from video clips'.*

Fostering Pupil Independence and Peer Support

In English much more than Mathematics or Science, teachers identified a contribution of ICT use to creating opportunities for pupils to exercise greater independence, share their expertise, and provide mutual support. Given the opportunity, pupils could *'go off and do amazing things'* so that *'it does just feel that you're freeing them to do things that really show their potential'.* The wider sharing of expertise created *'all sorts of social networks with people helping each other'* in which pupils *'sorted things out as a group'.*

In effect, the differential concerns revealed by these themes shows how subject cultures –notably their pedagogical discourses and practices– shape practical theories of ICT use, making visible, giving form, and according value to particular issues and approaches. The prominence of pupil agency and collective activity in the culture of English teaching informs the particular attention of English teachers to *Fostering pupil independence and peer support.* Similarly, the predominance of a socially decontextualised view of the subject is reflected in Mathematics teachers' non-attention to *Broadening reference and increasing currency of activity.* Likewise, in Science, a methodical model of subject activity marginalises concern with *Supporting processes of checking, trialling and refinement.*

Teachers' Practical Theories of Dynamic Geometry Use in Establishing Angle Properties

In subsequent work, we looked more closely at particular practices of technology use in secondary school Mathematics and Science. We interviewed subject departments nominated as making good use of ICT in order to identify examples which teachers themselves regarded as particularly successful. We then followed some of these exemplars into the classroom, observing lessons and interviewing teachers about them. The use of dynamic geometry, for example, was singled out by around half the participating Mathematics departments. The most commonly mentioned type of use of dynamic geometry was in establishing the angle properties of a figure. Typical topics mentioned were: vertically opposite and supplementary angles; corresponding and alternate angles; angle sums of the triangle and other polygons; and angle properties of the circle ('the circle theorems'). Again we analysed salient issues raised by our observation and debriefing of lessons, identifying the following themes (Ruthven, Hennessy & Deaney, 2004, 2005).

Managing student experience of dynamic geometry

Teachers differed in the degree to which they gave students opportunities to use dynamic geometry systems (DGS) for themselves. Such decisions were shaped by teachers' assessments of immediate demands and eventual benefits, and particularly influenced by whether they saw educative potential in giving students direct experience of the mathematically disciplined character of DGS use. One teacher did not expect students to make any use of DGS. Describing the software as *'just a drawing program'*, he thought that his students *'would take a long time… to master the package'*, pointing to a *'huge scope for them making mistakes and errors'*, and arguing that *'the cost-benefit doesn't pay'* given that the examination curriculum *'just doesn't require that degree of investigation'.* Typically, however, teachers did give students direct experience of using DGS for themselves. Thus, while another teacher considered DGS to be *'quite a difficult piece of software'*, she aimed to ensure that her students did not *'have to be complicated by that'* so that they could *'just focus on what's happening mathematically'.* Normally her approach was to provide students with prepared figures to *'structure the work so they just have to move points'*, although she occasionally asked students to undertake *'very simple construction'* to help them *'see that the software works geometrically'.*
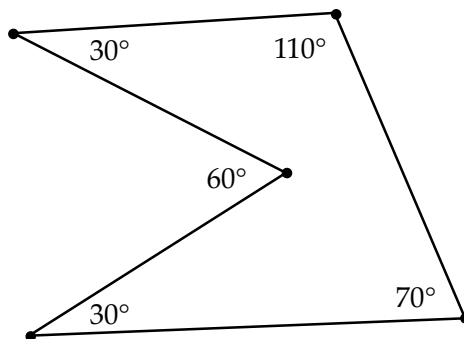
Figure 1. Screensnap of dynamic figure for examining polygon angle sums, displaying apparent anomalies of angle measurement and arithmetic computation.

Managing Apparent Mathematical Anomalies in Operation

Teachers also differed in how they handled situations where the behaviour of DGS diverged from expectation (as illustrated in Figure 1). Again, such decisions were influenced by whether teachers saw such situations as providing opportunities for mathematisation, and for instilling a critical attitude to computer results. The first teacher (of the two already mentioned) was careful to avoid exposing students to situations where the DGS displayed (by default) the measure not of the desired reflex angle but of its obtuse counterpart. For example, when he inadvertently dragged a polygon so that it contained a reflex angle, he reverted to an obtuse angle as soon as he realised what had happened. Tackling the same topic, however, the second teacher welcomed such situations as a stimulus for critical thinking: '*One of the key things that the kids learned [was] that you can't assume that what you've got in front of you is actually what you want… You have to look at it… and question it*'. Another type of anomalous result arose from numeric values being rounded. In the lessons on polygons, for example, episodes occurred where the sums

of angles appeared not to match the expected value exactly. Again, whereas the first teacher sought to smooth over such episodes, the second used them to promote deeper mathematisation.

The differing approaches of teachers to managing student experience of dynamic geometry and to handling apparent anomalies of operation can be interpreted as contrasting responses to instrumental aspects of technology integration (Guin, Ruthven & Trouche, 2005). The approach adopted by the first teacher in taking sole responsibility for use of the tool, remaining largely tacit about its operation, and smoothing over apparent anomalies, aims to *minimise* the instrumental demands on students, and to sustain an impression of congruity between dynamic pixel-and-pointer geometry and the institutional norms of static pencil-and-paper geometry. The approach adopted by the second teacher in carefully structuring students' opportunities to use the tool, focusing on those aspects of operation seen as promoting mathematisation, and responding to apparent anomalies in similar terms, aims to *optimise* instrumental demands on students in terms of their potential to make a knowledge-building contribution to wider mathematical development.

Using Dragging as a Means Of Generating Multiple Examples

In polygon-angle-sum lessons, the dynamic-geometry figures employed took the form of simple polygons with the measures of all angles marked (as illustrated in Figure 1). Here, dragging was treated as a means of generating several different examples of each type of polygon. Establishing the invariant angle sum of a triangle, one teacher introduced the idea that *'we've just picked four triangles at random and shown that that's true, and there's no way that could have happened by accident'*. He suggested that, for students, *'the fact they can see it changing as you're dragging and dropping it, makes [it] a bit more convincing for them'*, particularly since *'at one stage I got one of*

them to actually tell me where to stop… so it wasn't always me that was choosing it'. Using dragging as a means of generating examples appeals to an analogy between the movement of the dynamic figure from one static position to another and the replication of discrete figures in pencil-and-paper geometry; however, it also introduces a sense of sampling such figures from an extensive domain of possible examples.

Mediating Geometric Properties through Numeric Measures

In all the lessons observed, consideration of angle properties was mediated primarily by attention to their numeric measures. Sometimes properties were established directly by observing the stability under dragging of a single numeric measure (such as the sum of the angles of polygons with a particular number of sides). At other times properties were established more indirectly through identifying a pattern within sets of measures (such as the relation between the number of sides of a polygon and the sum of its angles) through forms of data-pattern generalisation. Indeed, lessons on polygon sums followed an inductive sequence, employing the familiar cases of triangles and quadrilaterals to introduce the approach, then proceeding to pentagons and later polygons. The angle sum of each type of polygon was established, building a table of values for successive polygons from which a pattern could be formulated.

Comments from teachers indicated that such approaches were already well established; through introducing the use of dynamic geometry they sought more efficient generation of data than was possible by hand. Indeed, this emphasis on mediating geometric properties through numeric measures, and on the use of measure patterns as a means of establishing such properties is consistent with the longstanding experimental and empirical orientation of

English school mathematics; the way in which the English national curriculum refers to this component not as *Geometry* but as *Shape, Space and Measures* conveys the extent to which that curriculum has been arithmetised. Where angle properties are concerned, the prominence of 'angle-chasing' computations in texts and tests testifies further to this trend. Likewise, the prevalence of data-pattern generalisation as an approach to mathematical 'investigation' in English secondary schools has been extensively documented.

Conceptualising the challenge of technology integration

Such assimilation of technology use to existing practice emerged across our study of Mathematics and Science. In particular, we found that ICT use is being strongly shaped by established school and subject cultures where little genuine investigation takes place and the pedagogic emphasis is on covering the syllabus in preparation for examination. In Science lessons, for example, we observed worksheet-driven simulation use and teacher-led data logging activity whereby expected relationships are simply verified, coupled with teaching of theory through teacher-controlled use of the interactive whiteboard (Hennessy, Deaney & Ruthven, in press; Hennessy, Wishart, Whitelock, Deaney, Brawn, la Velle, McFarlane, Ruthven, & Winterbottom, in press). In general, teachers reported that curriculum time constraints inhibited pupil use of data logging or pupil 'playing' with simulations. Occasionally, however some practitioners did show evidence of employing more interactive teaching methods in eliciting, testing and challenging pupils' own conceptions, and building knowledge through discussion and synthesis. Of course, it is also important to recall that the archetypical practice examined in our study had developed and spread through largely informal processes.

It is instructive to compare our English example of dynamic geometry use with a French study by Laborde (2001) in which secondary-school mathematics teachers, working as part of a larger project team which included mathematics education researchers and software developers, designed, trialled and revised a set of classroom scenarios. Laborde reported that integrating technology into teaching was a lengthy and fallible process, even in the favourable circumstances of a development project which afforded teachers direct contact with the design rationale for dynamic geometry and legitimised some relaxation of wider institutional norms. Moreover, she concluded not just that *'activities involving rich interactions with the students require time and the development of specific schemes of instrumentation',* but that *'they bring a new kind of perturbation with respect to the legitimacy of knowledge specific [to] technology'.*

Laborde characterises the evolution of the scenarios developed by teachers in terms of their progressively encompassing four different types of task. In the first type, dynamic geometry facilitates material aspects of a familiar task, such as the production of figures and measurement of their elements; such adaptations were prominent in the earlier English examples. In the second type, dynamic geometry assists mathematical analysis of a familiar task; an example (relevant to the problem of polygon angle-sums) would be the use of construction and dragging to underpin more strongly geometric analysis of the relationship between angles in a triangle (to be demonstrated in my conference presentation). In the third type of task, dynamic geometry substantively modifies a familiar task; an example would be the use of geometrical induction to establish the properties of polygon angle sums (to be demonstrated; see Figure 2). The final type covers tasks which could not be posed without dynamic geometry; an example would be the identification and construction of a dynamic figure with particular properties (to

be demonstrated). These speculative illustrations also point to ways in which current English approaches to using dynamic geometry to teach about angle properties could be extended to give more emphasis to visuo-spatial and logico-deductive aspects of geometrical reasoning (Ruthven, 2005).
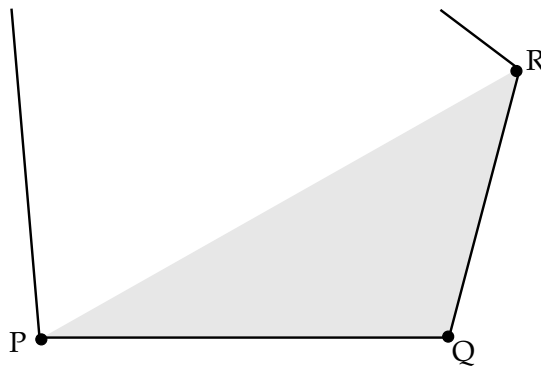

Figure 2. Screensnap of dynamic figure for approaching the angle sums of polygons through dynamic geometrical induction.

From reflection on similar experience in an experimental programme in which symbolic calculators were introduced to secondary mathematics classrooms, Artigue (2002) has proposed a general analysis of key issues which such initiatives must confront. She argues that schooling is still expected to reproduce a classical mathematical culture which predates modern computational tools. Consequently, such tools are seen primarily as pedagogical instruments for supporting the learning of a largely unchanged mathematics. Even within special projects, mathematical techniques

involving use of new technologies struggle to gain acceptance alongside established classical techniques which not only have an official status, but a didactical infrastructure which helps teachers to manage them in the classroom. There are established instructional sequences to introduce recognised classical techniques, and an accompanying theoretical discourse to frame them; in particular, these sequences enable students to gain varied experience of applying such techniques, and standardise and routinise their operation to a degree. A new technology can, of course, be assimilated to existing norms (and this is very typically what happens). Moving beyond the amplification of existing practice towards its reorganisation in response to the affordances of a new technology is considerably more challenging. In particular, no supporting didactical framework has yet been developed; hence, in the absence of officially recognised norms, rules and standards an unsystematic proliferation of possible new techniques takes place, although classroom or project participants can negotiate some form of localised order. Moreover, adequately establishing any such order typically calls for reference to an expertise and culture wider than that traditionally associated with school mathematics, extending into domains such as computer science, and taking account of developments in wider mathematical practice.
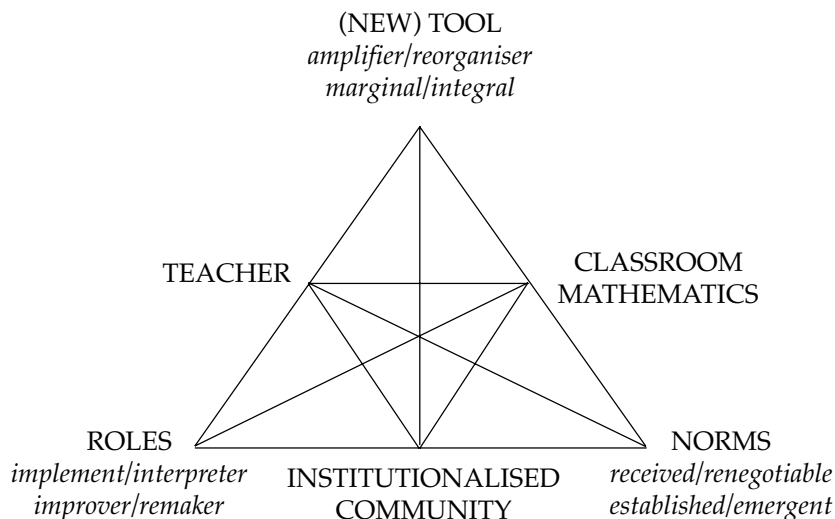
Figure 3. Key dialectics within the activity system framing the mediation of a (new) tool between teacher (as subject) and classroom mathematics (as object) in an institutionalised community.

An adapted form of activity-system model (Cole & Engeström, 1993) provides a convenient summary of these issues. The basic psychological triad within the model (forming the upper part of Figure 3) highlights dialectics relating to the ways in which a (new) tool can (come to) act as a mediational means between teacher (as subject) and classroom mathematics (as object). Firstly, such a tool can be conceived and employed as an amplifier of classroom mathematics in its already established form, or as a reorganiser of that mathematics to take on a qualitatively different form; indeed, as each in some ways (Dörfler, 1993). Laborde's typology of DGS-mediation –extending from material facilitation of familiar tasks to generation of distinctive tasks– illustrates such a spectrum of possibilities. Relatedly, only towards the reorganiser pole of this

spectrum does such mediation, and so use of the new tool, become (seen as) integral to classroom mathematics; towards the amplifier pole the tool's contribution to an otherwise unmodified mathematics remains (seen as) marginal, typically with any suggestion of user 'dependence' on the (incidentally convenient but ultimately dispensable) technology being excoriated.

The sociocultural extension to this triad (forming the lower part of Figure 3) acknowledges its framing by the teacher developmental roles and classroom mathematical norms of an institutionalised community. As shown by the English studies discussed earlier, a community which regards the teacher as implementer of a statutory curriculum rather than as interpreter of it, as improver of classroom mathematics within received norms rather than as remaker of that mathematics around renegotiated norms, will predispose forms of teacher thinking and classroom practice in which new tools are marginal amplifiers of established mathematics rather than integral reorganisers for emergent mathematics. Equally, Artigue's analysis points to the complex work required to renew the didactical infrastructure and renegotiate it institutionally in order to underpin the integration of a new tool into classroom mathematics. Formulating and realising models of technology-integrated mathematics education calls for collaborative investigation to develop viable practical theories through a dialogic process of development in which current practice is sympathetically analysed and imaginatively reviewed in the light of speculative possibilities and emergent priorities.

Note: This paper originated as a keynote address at the International Conference on Science and Mathematics Education (CoSMEd) 2005 on the theme of 'Bridging the Theory-Practice Gap in Science and Mathematics Education: The Challenge to Change'. It focuses specifically on the conference sub-theme of 'Bridging the Theory-Practice Gap through ICT'.

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*   All these Cambridge publications can be accessed at <http://www.educ.cam.ac.uk/istl/pub.html>.

†   The Korean presentation can be accessed at <http://www.mathlove.com/new3/notice/show.php?listno=3>.

§   Both TIMSS reports can be accessed at <http://timss.bc.edu/timss2003i/intl_reports.html>.