Teachers using technology: the complexities of practice

John Monaghan

Teachers using technology: the complexities of practice

John Monaghan, University of Leeds

ABSTRACT *This paper focuses on high school mathematics teachers and their activities in technology-based lessons. It is a discursive paper that uses data from a teachers using technology project. The main aim is to present an holistic account of factors influencing teachers' practice. A secondary aim is present the integration of technology into lessons as a complex issue. Saxe's four parameter model of goal-linked practice is used to show how different dimensions of teachers' activities interrelate.*

Introduction

This paper focuses on high school mathematics teachers and what they do when they use technology with their classes. My main aim is to find an holistic way to examine practice from a conviction that the whole undertaking involves a fusion of many factors and analyses suffer if these factors are taken in isolation. A secondary aim is to react to claims that using technology in teaching is easy and that teachers using technology 'must' relinquish didactic roles and move to become facilitators. I examine the practice of ‘ordinary’ teachers. I use Saxe’s (1991) four parameter model to locate critical influences on practice and to explore the complexities of integrating technology into teaching. I use data from a project on teachers using technology to illustrate points, so, after a brief review of literature, I provide a short description of this project. I then outline Saxe’s model and examine teachers’ activities from the point of view of each parameter. I then focus on interrelationships between the parameters and compare planned goals with emergent goals in lessons. I end with comments on related approaches.

Teachers and technology

With regard to mathematics teachers using technology there is a sense in which the 1990s witnessed a progressive realisation that teachers teaching with technology is a complex issue. With regard to the professional literature the Mathematical Association (MA) in an early publication, state "Teacher exposition leads **naturally** to discussion between teacher and pupils with the computer display as a focus." (ibid., p18, my emphasis) A more recent publication adopts a more critical stance, e.g. "Inspection evidence consistently shows very little use of appropriate technology tools in mathematics teaching at all levels." (MA, 2002, p.5). With regard to the academic literature compare "In the implementation of computer-based laboratory explorations, the teacher must become a technical assistant, a collaborator, and a facilitator." (Heid, Sheets & Matras, 1990, p.195) with “The introduction of informatics in mathematics teaching works only when it is perceived as an answer to questions (even though unconscious) already present in teachers’ minds.” Bottino & Furinghetti (1996, p.132).

Research on mathematics teachers’ practices is a relatively recent phenomenon (Noss & Hoyles (1996, p.184)). With regard to technology, studies which acknowledge the importance of context have largely focused on teachers' beliefs, e.g. Moreira & Noss (1995), and forms of teacher knowledge, e.g. Lloyd & Wilson (1998). Such studies are important but they, by design, miss the 'wholeness' of teachers' practices. Kendal (2001) offers the most holistic account to date, to my knowledge, of teachers' practices in technology-based mathematics lessons. She focuses on both teachers and students and examines how teachers’ 'privileging' (Wertsch, 1991, p.124), teaching styles and attitudes, differentially affected students’ learning in computer algebra-based lessons but she only implicitly take practice as the central unit of analysis.

A project on teachers using technology

13 English mathematics teachers, none of whom had made extensive use of technology in their mathematics classes before, made a commitment to move to significant use of computers in one school year. The project explored teachers' lesson planning, classroom interactions, use of written support materials and areas of tension for teachers. The project aimed to be as natural as possible, i.e. teachers doing what they might have done even if they had not been in a project. We focused on technology tools: spreadsheets, graphic packages and calculators and algebra and geometry systems. Individual teachers chose the tool(s) they thought most appropriate for use with their classes. Teachers chose older classes, students aged 14-17 years, on the assumption that the tools would have the widest use in classes exposed to substantial amounts of algebra. Data collected included: observation of and accounts by teachers of their use of technology; weekly journal entry by teachers with lesson plans and materials; interviews; video-tapes (one lesson at the start of the year which did not involve technology and three lessons over the year which did involve technology).

Saxe's four parameter model

Saxe's (1991) model centres 'emergent goals' in terms of four parameters (see Figure 1). Saxe's emergent goals are little, and often unconscious, goals (must-do-this situations) that come into being and fade away.

> "Not only do individuals shape and reshape their goals as practices take form in everyday life, but they also construct goals that vary in character as a function of the knowledge that they bring into practices. ... Goals, then, are emergent phenomena, shifting and taking new forms as individuals use their knowledge and skills alone and in interaction with others to organize their immediate contexts." (ibid., 16-17)

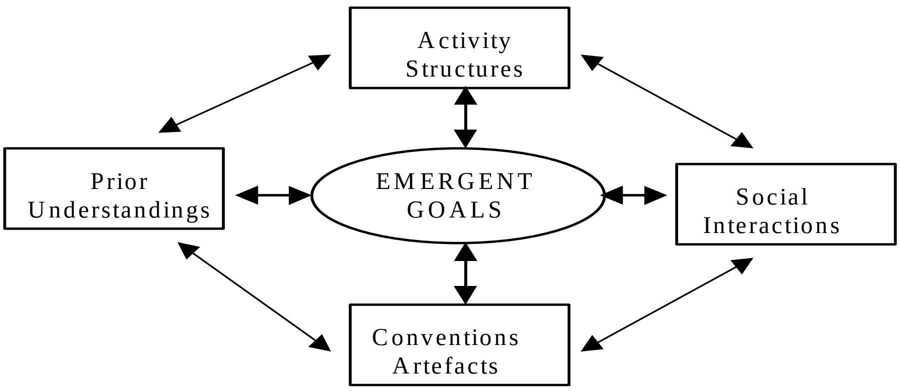

Figure 1 Saxe's four parameter model

Activity structures

Activity structures "consists of the general tasks that must be accomplished in the practice- and task-linked motives" (ibid., 17). Explicating exactly what a task in a mathematics lesson is a non-trivial undertaking. For the moment I simply note that teachers, in their specific school settings, come to know, through their identification with the practice in their school, what counts as a valid mathematical task in their school and that generating tasks for technology-based lessons is often problematic. A second aspect of activity structure is the 'activity cycle' of a lesson, which is not a Saxian construct and requires a few words by way of clarification. Magajna (2001, p.73), commenting on mathematics lessons, notes that "The observed task structure consists of several nested cycles. The most prominent level is the cycle of exercises and exercise-like pieces of theoretical explanations." The cycle of many mathematics lessons is often predictable and repetitive and technology lessons may take on a structure/cycle different to that of non-technology lessons.

Technology and non-technology lessons had different activity structures (tasks and cycles). All 13 observed non-technology lessons had a very similar cycle: teacher exposition and examples followed by students doing questions, which were similar to the teachers' examples, from a textbook. Lessons went through several of these cycles with answers to exercises given at the end of each cycle. Teachers did, however, interrupt the cycle, and provided further examples and/or questions, if they perceived that a number of students had misunderstood the work.

The tasks students engaged with in the observed non-technology lessons were textbook exercises. From the point of view of the teacher textbook tasks are 'safe' tasks, i.e. they are part of their established practice and teachers' activities around these tasks are justified through conforming to practice. The tasks and cycles of the technology-based lessons varied considerably over the teachers and, in most cases, over time. I will describe several approaches that more than one teacher adopted.

Three of the teachers clearly imitated the cycle of non-technology lessons. Two of these used graphic calculators. Exposition included instruction on keystrokes and tasks were 'closed'. Both teachers continued with this format in all three observed technology lessons. My interpretation of this was that they felt secure in paralleling established practice and were able to do this. The third teacher used a computer room which allowed her and the all the pupils to see each other. The room had a board and in the first observed technology lesson she instructed them in a manner (cycle and closed tasks) that was startlingly close to the observed non-technology lesson. She, however, changed this format in subsequent observed technology lessons, moving to 'open' tasks. The cycle of these subsequent lessons was common to many of the observed technology lessons of other teachers: short introduction to the task, worksheets which directed student activity, teacher assisting individuals/groups. All of the other teachers adopted this 'technology cycle' from the outset, though there was variation in the tasks set and in their manner of 'facilitating'.

The tasks set in technology-based lessons were, by and large, quite different to 'normal' tasks and 11 of the 13 teachers initially felt they could not employ textbooks as a resource in technology-based lessons. Some clearly intended this to be so as the teacher who stated that he wished to reduce exposition time, to relieve students from tedious calculations and have a stronger focus on concepts. There was a tendency with all the teachers, and very pronounced in some, to set more open tasks. Some teachers found that open tasks on a computer led their students to focus on the technology and the teachers felt an 'is this maths?' tension when their students attended to technological details at, in their opinion, the expense of the mathematics.

Prior understandings

Prior understandings are "understandings that individuals bring to bear on cultural practices both constrain and enable the goals they construct in practices" (Saxe, 1991, p.18). Mathematics teachers 'prior understandings' incorporates a range of beliefs, knowledge and social practices: how they view learning and teaching; what mathematics is to them and their mathematical and technological proficiency; how they plan their lessons. In reflecting on project teachers' practice with regard to this parameter I am aware of a certain fluidity and creativity in non-technology-based lessons and a degree of rigidity and domination by the technology in technology-based lessons. I elucidate my ideas below by noting commonalities and diversity.

The teachers had a clear understanding of how a normal lesson should unfold and although some wrote lesson plans most did not, “Without technology the lessons are kind of just there. I've got my own room and all my resources are in there so it tends to be what I feel like on the day.” – their knowledge of their teaching was tacit knowledge rather than articulate knowledge. Technology-based lessons, however, were planned in detail and this took a lot of time, especially early lessons. There is a straightforward explanation: their tacit understanding of ‘normal’ lesson was moulded in thousands of hours of practice but incorporating technology involved a rethink of this practice.

Teachers’ tacit goals in non-technology lessons were partially formed in relation to their use of a textbook. But teachers were flexible when learning problems appeared. Further to this there was no obvious ‘privileging’ of scientific calculator technology. In technology-based lessons textbooks were largely not used and student learning was largely directed by worksheets and dominated by a single technology (*Excel*, *Derive*, etc.). These lessons were usually less flexible than non-technology lessons. This was especially evident in the lessons where the computer room had to be booked in advance and there is a straightforward explanation: if you have booked a computer room, especially one without a board, then you use the computers! The dominance of the technology leads to emergent goals directed at 'surviving in the classroom'.

Finally prior understandings includes teachers’ subject knowledge. It was anticipated that this would have an impact on teachers’ practice but this impact, on reflection, appeared to be minimal. There were instances where teachers directed students to specific operations they were familiar with but there were no observed instances where, like Heid (1995), technology work revealed weaknesses in their mathematics.

Conventions and artefacts

Conventions and artefacts consist of “the cultural forms that have emerged over the course of social history” (Saxe, 1991, p.18). In the case of teachers using technology in their lessons an obvious artefact to consider is the software and hardware they use. But teachers also use (or do not use) written resources (textbooks and worksheets). The project showed differences in teachers’ practice with regard to these tools over technology and non-technology lessons and within technology lessons.

Software is too large a category to make general claims about. Project teachers’ experience was that specific software had a differential affect on the organisation of their teaching. A teacher who primarily used *Derive* with his class found using a computer graphing package (*Omnigraph)* much more like his ‘normal’ lessons. This had several dimensions. To use *Derive* he had to devote several lessons to attend to simple mastery of the commands and syntax but this was a five minute task with *Omnigraph*. Perhaps more important than this each differentially affected the way he interpreted the mathematics his students were doing. He viewed *Omnigraph* as a tool to do straightforward tasks that fitted in with his ‘normal’ lesson ideas. He viewed *Derive*, however, as a ‘monster’ that could do virtually everything and this forced him to completely re-interpret his lesson plans. This was a disquieting experience for him. A similar experience was evident with a teacher who primarily used *Excel* but who made some use of *Omnigraph*. Her lesson planning focused on mathematical ideas not particularly concerned with technology but techno-mathematical ideas became the focus of the lessons. One lesson focused on ratio. She set an investigation where three children were left money in a will to be distributed over a number of years in the ratio of their ages. The foci (emergent goals) in this lesson were on getting the spreadsheet cells right, not only the correct equation but a suitable cell format. She commented after the lesson that she was unhappy with this focus on ‘cell-arithmetic’.

Hardware also had a differential affect on the organisation of teaching. I comment on two aspects, the location of computers and graphic calculators vs computers. Project teachers with and without computers in their classes planned use and spontaneously used computers in different ways. Teachers who did not have computers in their class mainly planned lessons based on the computer or no use of the computer at all. This affected their lesson planning (both of the individual lessons and teachers’ long-term lesson schedules). Further to this teachers using computer rooms without a board for writing on generally devoted the last part of the lesson prior to the computer-based lesson to explaining what was to be done on the computers in the next lesson. At one level this may be a trivial change in teachers’ practice but, on another level, it seriously affected their practice. With regard to graphic calculators I restrict my comments to noting that the two teachers who made exclusive use of graphic calculators were the two teachers who made the least changes in their practice and the activity structure of their lessons – they taught from the front directing students’ keystrokes in much the same way that they otherwise directed their written mathematics from the board[1].

With regard to written resources all of the project teachers made considerable use of a textbook in their ‘normal’ lessons. All but two of the teachers initially felt that textbook work was inappropriate in technology-based lessons. As the year went on three other teachers found that they were able to use the textbook for technology-based work and another found that she could write worksheets based on textbook work.

Social interactions

There is commonality and diversity in the social interactions of teachers and students in mathematics classes. Wertsch’s (1998) characterisation of teacher-student discourse in instructional settings as organised around “sequences composed of *initiation* by the teacher, followed by a *reply* by the student, followed by an *evaluation* by the teacher” (ibid., p.69) applied to all observed non-technology classes. Within this commonality, however, teachers have diverse routines and diverse verbal and non-verbal ways of interacting with students. The big question here is does the use of technology affect social interactions in the classroom and, if so, in what ways?

As I began the project I suspected, that there would be a shift in teacher-student interactions and sought a data collection/analysis tool which would allow me to investigate interactions; the Systematic Classroom Analysis Notation (SCAN) (Beeby, Burkhardt & Fraser, 1979) appeared to suit my purposes. I summarise findings (see Monaghan (2001) for more details), note areas where marked differences were found and suggest reasons for these differences.

[1] Z Magajna (private correspondence) notes that Saxe's parameters are perhaps more dependent/related to declared or implicit ways of using technology than to the technology itself. Important questions here are: what are teachers attitudes to technology use in mathematics classes?; and how to different ways of regarding technology use in classrooms influence the parameters? These questions relate to issues concerning teachers' 'identity' (Wenger, 1998). I do not develop this here other than note that the tools teachers use in the classroom to do mathematics impinge on issues of identity. Lins (2000, 2002) work is also relevant here. She comments (Lins, 2000, p.52) that "technology is simultaneously independent of human action and yet irrelevant without it". In (Lins, 2002, p.58) she develops the concept of 'software of the teacher', i.e. that your *Cabri* and my *Cabri* might be (are) two distinct *Cabri*s.

In technology lessons teachers -	Reason for this
spent less time on whole class exposition	largely due to 6 of the teachers preparing their classes before they moved to the computer room
spent more time talking to two or more students	largely due to having to place 2 or more students to a computer
spent more time coaching or eliciting ideas from students	I do not have an obvious reason for this
spent less time explaining/ facilitating mathematical ideas	Due to foci on the technology
spent more time explaining/ facilitating technological ideas	No technology in non-technology lessons!
made more assertions	propensity for 6 of the teachers to move around the class attending to technical problems
gave more instructions	

What is remarkable here, with regard to other studies' claims that technology-based lessons result in qualitatively different teacher-student interactions, is the number of non-differences (this analysis does not suggest that teachers are taking on some new roles, e.g. consultant, fellow investigator) and that most of these differences between technology and non-technology lessons can be explained in very practical ways.

These global differences, however, hide subtle detail. I do not have space to consider all of these differences and I focus on the second one. Although this largely reflects the fact that the availability of computers forced students to work with two or more to a machine it is interesting to note that even when students worked in pairs in non-technology lessons the teacher talk was largely directed to one of the pair but in technology-based lessons the teacher talk was largely directed to all students around a computer. This appears to be an important general difference in technology lessons and interrelates with the fact that technology is often not just a tool for doing the mathematics but is also a medium for *expressing* the mathematics. A tool may be used in a task where the processes and product of the task are recorded on a sheet of paper or an artefact, e.g. a compass to draw a circle or to assist in making a polyhehron. In many mathematical software systems, however, the tool may not only perform mathematical actions but the product of these actions may recorded on the tool and this record may be the basis for student reflection on their actions. Further to this, when it acts as a medium in this way it is a shared medium for all using a specific computer. This is one reason why computers can be conducive to collaborative student work. This interrelates with the tasks set and can give the teacher an opportunity to set extension tasks. An instance of this in project teacher work occurred when a group of three students completed a task that produced variously positioned quadratic graphs on their computer screen. The teacher said, "Good, now reflect those graphs in the *x*-axis" and then walked away. This was more challenging task on a graph plotter than on paper and the teacher gave no guidance but the students did it.

To return to the big question posed above, the use of technology did affect social interactions in these classroom. Several aspects strike me as worthy of comment. First as I reflect on individual teachers (rather than global patterns of interaction) I am convinced that teachers who may be described as 'didactic' in non-technology lessons, remain didactic in technology lessons. Secondly, although there were some commonalities in non-technology lessons there was no common pattern to social interactions in all the observed technology lessons. Indeed, technology lessons were notable by their diversity. Thirdly, many of the noted differences in social interactions in technology lessons appear for very obvious reasons. Finally, my interpretation of the changes that occurred in technology lessons do not suggest that these teachers were on a developmental path towards adopting new roles such as fellow investigator.

Interrelations and goals

Interrelations between the parameters

Activity structures are intertwined with social interactions. This is manifest both in attempts to preserve established practice and in situations where established practice changes. The three teachers who imitated the cycle of non-technology lessons attempted to preserve established practice and social interactions. It could be argued that they wanted to remain in control. But it could also be argued, with a focus on activity-systems instead of a focus on teachers' volitions, that that this cycle was preserved because it embodied social interactions of practice which had become routinised. At the other extreme six teachers moved quickly around student pairs in computer rooms 'techno trouble shooting'. The activity cycle and the social interactions in these lessons were very different to those in teachers' non-technology lessons. The tasks teachers present to their students are also intertwined with social interactions and again there were instances of attempting to retain the status quo of established practice and being forced to move beyond established practice. The tasks teachers are used to giving to their students are, by and large, textbooks tasks which the teachers 'control'. Although 11 of the 13 teachers initially abandoned their text-books in technology lessons, the worksheet tasks they wrote retained this element of control (cf Laborde (2001, p. 299)), i.e. the power structure of the classroom remained.

This leads to links between the activity structure and the conventions and artefacts parameters. Textbooks and worksheets are artefacts (it is significant that textbooks are not produced by teachers whilst worksheets for technology lessons usually are). Textbooks, in non-technology lessons, and worksheets written for student use in technology-based lessons structure teacher (and student) activity in different ways (cf discussion above on cycles in technology and non-technology lessons). Another link between activity structure and conventions and artefacts is the way mathematics is written. Without technology teachers are, within the bounds of accepted mathematical practice, free to write mathematics as they want. With technology teachers must write mathematics as the software requires. In the case of the teacher using *Derive*, noted in the previous section, this led to lessons (and tasks) devoted to mastering the syntax of the system. In the case of *Excel* teachers designed tasks based on 'cell arithmetic'.

This last statement reveals links between the activity structure and prior understandings. Consider, for example, the teacher mentioned above who was uncomfortable with the focus on cell arithmetic, questioning 'is this maths?'. This question was legitimate for her because her prior understanding of mathematics was formed in a public understanding of what (school) mathematics is. In considering this issue it is hard to separate considerations of activity structures, artefacts and prior understanding. Tool use is intricately tied up with mathematics teachers 'being' or identity as mathematics teachers. Technology tools are not invested with the same social priority. So lessons that focus on how to use cell arithmetic in *Excel* or how to express an inverse function in *Derive* create legitimate tensions for teachers. But mathematics teaching is about teaching as well as mathematics and prior understandings of what teaching is are questioned when technology is used.

Although I have argued that claims that using technology turns teachers into facilitators and co-collaborators is a myth, teacher use of technology certainly does impact on social interactions. This impact does not result from the presence of an artefact, it is tied up with practice and change of practice and this is one reason why the interrelationship between the parameters of Saxe's model is important. What I have called 'techno trouble shooting' is linked with the positioning of the artefacts, teachers' technical/ mathematical/ pedagogical 'mastery and appropriation' (prior understandings) of the artefacts as mathematical tools. Diversity in changed practice is, to this way of thinking, an expectation of the use of technology by the teacher.

Teachers' goals and emergent goals

It would be somewhat repetitive to go over all the points above, so in the following I focus on tools and tasks and trace the implications with reference to one teacher. Digital technology is only one tool a teacher may use and, when used, it does not act in isolation but impacts on, and is impacted on by, use of other tools. Textbooks and worksheets are tools which emerged as having significant interrelations with technology use. Awareness of changes in practice from these different tools is an important factor to keep in mind given mathematics teachers dispositions towards the use of textbooks. This 'tool shift', textbooks to technology, interrelates with the activity structure (tasks and cycles) of lessons and may conflict with teachers' prior understandings of 'a good mathematics lesson', e.g. the teacher who was uncomfortable with the focus on cell arithmetic. What is interesting here is that she voluntarily planned this task and wrote a worksheet which resulted in a focus on cell arithmetic and this discomfort only emerged in practice because her emergent goals in the lesson were shaped by the need to get the spreadsheet cells right.

I take this further by focusing on teachers' views on the appropriateness of tasks and how specific tasks interrelate with other parameters in practice. I have commented that tasks set in technology-based lessons were different to ‘normal’ tasks. These tasks arose from many sources: books, courses, colleagues. Teachers planned and tried out these tasks on their own prior to lessons. I focus on goals in teacher planning and emergent goals in practice. The teacher referred to immediately above started by giving students structured tasks and then moved on to less structured work. Later she adapted tasks to reduce the number of printouts and made the tasks more prescriptive.

The variation in the structuredness of the tasks could be simply put down to the teacher learning from her mistakes. I accept that there is an element of 'trial and error' in any change in practice but locating the error and tracing its ramifications takes the analysis further. The 'error' in the early structured tasks was that they were too easy for the students. This is an understandable error, she did not know what level to pitch their lesson because it was new practice. The effect of this error was that many students finished their work midway through the lesson and sent their work to the printer. The computer room had a single slow printer and students' work had multiple pages. Her emergent goals in the second half of the lesson centred on managing both the printer queue and the behaviour of the students waiting for their work to be printed.

Related approaches

This account of teacher activity is motivated by a desire to find an holistic model. Werstch (1991) argues against analysing individual mental functioning in isolation and argues for analyses which are not limited by the boundaries of psychology, sociology or whatever. This Saxian approach shares with Wertsch an attempt to preserve

> as many dimensions of the general phenomenon under consideration as possible, thereby allowing one to move from one dimension to another without losing sight of how they fit together into a more complex whole. (ibid,. p.121).

Saxe's approach is essentially an activity theoretic approach. Both take human practice as central. Vygotsky (1978) develops a psychology which explains mental development through an analysis of the interaction of humans and the objects of their lived-in environment as mediated by cultural means. Vygotskian activity theory argues that all activity is culturally mediated activity which is consistent with Saxe's analysis.

The development of activity theory as expounded by Leont'ev (1978) sheds useful light on Saxe's goals and parameters and this account of mathematics teachers activities in technology-based lessons. I comment on Leont'ev's contribution with regard to actions, motives and goals (NB Leont'ev's goals are conscious, not emergent, goals). Leont'ev sees the basic components of activity as actions (processes) that realise activity, are generated by motives and are directed towards goals. Motives are central to Leont'ev's theory, they are the objects of activity (ibid., pp.62-63) and that which distinguishes one activity from another. Motives are to activity as goals are to actions. Leont'ev illustrates these ideas with a primitive hunter-gatherer example, an activity motivated by the need for food where a goal may be making trapping equipment. I now explore this with regard to the project teachers, a situation where motives are much less clear than in hunter-gatherer situations.

Saxe's parameters influence teachers' goals and actions but the parameters, with the possible exception of 'prior understandings', are not independent of the activity - indeed, they arise from the motive of the activity. Teachers' conscious goals are not a problematic issue and actions directed towards these goals may involve setting up the technology, providing the task on a worksheet, etc. Motives, however, are problematic and I think it is often not clear what the object of technology-based classroom mathematical activities are. Important questions here are 'Does the introduction of technology 'fit' with the motive of the classroom activity?' and 'Does the introduction of technology change the motive?'. The answer to the second question is an almost certain 'yes' - why use technology if the motive of classroom activity is unchanged? The answer to the first question varied across the teachers but whatever the answer the parameters are consistent with each other and with the motive of the activity. In the case of the teacher who asked 'is this maths?, the technology-based activity was not consistent with the teacher's understanding of the motive of the activity.

Further research

There are three important issues which require further research or consideration. (i) this 'holistic' account is not holistic in that students, who most definitely do feature in teachers' practice, are hardly considered here. (ii) the central issue of motives is underdeveloped in this account. (iii) the issue of the relationship between the parameters and teachers attitudes to, or ways of using, technology.

A potentially profitable area for future Anglo-French debate is the relationship between this approach and French work on instrumentation. Artigue (2002) argues that new needs emerge which are not easily recognised if the emergent goals are simply viewed in relation to techniques and praxeologies privileged by traditional pencil and paper mathematics. There are similarities and differences between these emergent needs and Saxe's emergent goals. Both concern unplanned foci of attention in practice due to tool-related transformation of practice but their theoretical positions differ. Saxe's emergent goals are at the centre of his theory and his parameters are constructs which aid an analysis of practice-linked goals. Instrumented techniques, and their epistemic and pragmatic values, however, are at the centre of Artigue's work and emergent needs contribute to her unravelling of the problematic status of instrumented techniques.

Acknowledgement The work reported on was supported by the ESRC, Award Reference Number R000222618. This paper is a shortened version of a paper that will appear in the *International Journal of Computers for Mathematical Learning*.

References

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.

Beeby, T., Burkhardt, H. & Fraser, R. (1979) *Systematic Classroom Analysis Notation for Mathematics Lessons*. Nottingham: Shell Centre for Mathematical Education.

Bottino, R. & Furinghetti, F. (1996) 'The Emerging of Teachers' Conceptions of New Subjects Inserted into Mathematics Programs: the case of informatics'. *Educational Studies in Mathematics*, **30**, 109-134.

Heid, M.K. (1995) 'The Interplay of Mathematical Understandings, Facility with a Computer Algebra Program, and the Learning of Mathematics'. *Proceedings of the 17th Annual Meeting of the N. American Chapter ofPME* (221-225). Columbus, OH.

Heid, M.K., Sheets, C. & Matras, M.A. (1990) Computer-enhanced Algebra: New Roles and Challenges for Teachers and Students'. pp.194-204 in T. Cooney (ed.), *Teaching and Learning Mathematics in the 1990s, NCTM 1990 Yearbook.* Reston,Va.: NCTM.

Kendal, M. (2001) *Teaching and Learning Introductory Differential Calculus with a Computer Algebra System*. PhD thesis, University of Melbourne.

Kiernan, C. (1992) 'The Learning and Teaching of School Algebra', pp. 390-419 in D.A. Grouws (ed.), *Handbook of research on mathematics teaching and learning*. New York: Macmillan.

Laborde (2001) 'Integration of Technology in the Design of Geometry Tasks with Cabri-Geometry'. *International Journal of Computers for Mathematical Learning*, **6**(3), 283-317.

Leont'ev, A. N. (1978) *Activity, Consciousness, and Personality*. Englewood Cliffs: Prentice-Hall.

Lins, B. (2000) 'The Importance of Premises: from an Essentialist to an Anti-essentialist view of ICT in Mathematics Education'. *British Society for Research into Learning Mathematics*, **20**(3), 49-53.

Lins, B. (2002) 'Towards New Trends on the Role of Users of Technology: a Look at Some Research Fields'. *British Society for Research into Learning Mathematics*, **22**(3), 55-60.

Lloyd, G. & Wilson, M. (1998) 'The Impact of a Teacher's Conception of Functions on His Implementation of a Reform Curriculum'.*Journal for Research in Mathematics Education*, **29**(3), 248-274.

Lumb, S., Monaghan, J. & Mulligan, S. (2000) 'Issues Arising when Teachers make Extensive Use of Computer Algebra'. *International Journal of Computer Algebra in Mathematics Education*, **7**(4), 223-240.

Magajna, Z. (2001) *Geometric Thinking in Out of School Contexts*, Doctoral Dissertation, School of Education. Leeds: University of Leeds.

Mathematical Association (1992) *Computer in the Mathematics Curriculum*. W. Mann & D. Tall (eds). Leicester: The Mathematical Association.

Mathematical Association (2002) *ICT and Mathematics: a guide to learning and teaching mathematics 11-19*. http://www.m-a.org.uk/education/teachers_teaching_with_technology/

Monaghan, J. (2000) '*Moving from occasional to regular use of ICT in secondary mathematics classes*'. http://www.regard.ac.uk/regard/home/index_html search on Monaghan.

Monaghan, J. (2001) 'Teachers' Classroom Interactions in ICT-based Mathematics Lessons'. pp.383-390 in M. van den Heuvel-Panhuizen (ed.) *Proceedings of the 25th Conference of the International Groups for the Psychology of Mathematics Education*, Vol. 3.

Moreira, C. & Noss, R. (1995) 'Understanding Teachers' Attitudes to Change in a Logomathematics Environment'. *Educational Studies in Mathematics*, **28**, 155-176.

Noss, R. & Hoyles, C. (1996) *Windows on Mathematical Meanings: Learning Cultures and Computers*. Dordrecht: Kluwer Academic.

Saxe, G. B. (1991) *Culture and Cognitive Development: Studies in Mathematical Understanding*. Hillsdale NJ: Laurence Erlbaum Associates.

Vygotsky, L.S. (1978) *Mind in Society*. Cambridge, MA: Harvard University Press.

Wenger, E. (1998) *Communities of Practice: Learning, Meaning, and Identity*. New York/Cambridge: Cambridge University Press.

Wertsch, J.V. (1991) *Voices of the Mind*. Cambridge, MA: Harvard University Press.

Wertsch, J.V. (1998) *Mind as Action*. New York/Oxford: Oxford University Press.