Teachers using technology: issues, problems and ways forward

John Monaghan, Centre for Studies in Science and Mathematics Education
University of Leeds Leeds LS2 9JT, UK

Introduction

I want to address problems and potential solutions that mathematics teachers face when they attempt to incorporate advanced algebraic technology in their teaching. As I am addressing a T^3 meeting I will deal with computer algebra system (CAS) technology such as that available on the TI-89 and TI-92.

I think it appropriate for a group that does not know me to say a little about my interests and work. For the last 13 years I have been a mathematics educator and my students are student teachers, mathematics undergraduates taking education modules and higher degree (Masters and Doctors) students who write dissertations on the teaching and learning of mathematics. My research interests centre on teaching and learning mathematics to 14-21 year olds with technology. Prior to my university work I was a school teacher for 10 years. I taught in schools for 11-18 year olds and I made considerable use of technology (that was in the 1980s). I have been 'doing research' for over 20 years. Until the mid-1990s my research was almost exclusively about how students understand mathematics. In the early 1990s I became interested in CAS and had a very productive partnership with some excellent teachers in my region. I became aware, however, that the excellence, the enthusiasm and the technical expertise of these teachers was a 'problem' in the sense that what worked for these teachers in their classes did not 'transfer' to most other teachers. I thus became interested in what 'ordinary' teachers do with technology in their classes.

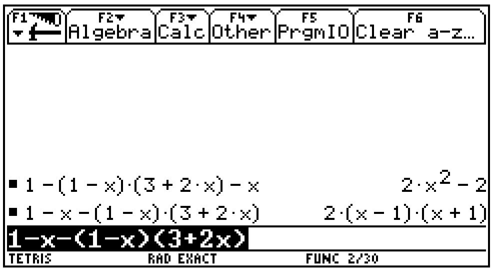
I would like to make it clear that the term 'ordinary teachers' is not a negative term to me. I am a teacher, I work with teachers, many of my friends are teachers, I like teachers and most teachers are 'ordinary teachers'. All I mean by 'ordinary teachers' here is the vast majority of (mathematics) teachers who are not technology enthusiasts or experts. The practices of these teachers needs to be understood if technology is to be an integral part of the future mathematics curriculum. I would like to illustrate this with a story from the ImpacT project (Watson, 1993). This two year project looked at technology practices of Elementary and High School teachers over a number of subjects. Some of the High School mathematics teachers made quite high use of technology. Some of the mathematics teachers who made the highest use of technology left their schools for jobs in other schools and when they did they left a 'hole'. The project claimed that technology activities are primarily dependent on individual teachers' initiatives and that these individuals do not reflect whole school mathematics teaching practices. This is something, I am sure, that most of us have experienced. It is certainly something I encountered in a recent survey of graphic calculator use in my city (Rodd & Monaghan, 2001). Here, for example, is a statement from the leader of a school's mathematics department, "We did have a member of staff who used one (a graphic calculator), she was quite keen and after she left we rather lost the impetus."

In the remainder of this paper/address I will provide a brief review of research on teaching high school mathematics with technology, go into greater depth on two studies of teaching calculus with CAS technology and end with considerations of the ways forward.

Research on teaching high school mathematics with technology

I am aware that many teachers reading this paper will not enjoy reading research papers and will also have difficulties obtaining obscure academic research journals. I have thus attempted to limit the number of references I make.

Over the last 20+ years there have been thousands of papers written about aspects of students learning mathematics with technology. Many of these, to my mind, present an over optimistic view of the advantages of using technology. With regard to learning in a CAS environment recent work by mainly French researchers (e.g. Lagrange, 1999; Artigue, 2001) has examined real classroom problems in learning 'techniques'. For example, a student needs to understand the expressions the CAS manipulates and then come to terms with how it manipulates them. The notion of equivalent expressions and the need for awareness of the different equivalent forms of an expression are important early considerations. A TI-92 user, for example, meets automatic simplification as soon as an expression is entered. The screen dump below displays an example of a puzzling automatic simplification phenomenon. Two equivalent expressions are 'simplified' in two different forms.



So a student cannot rely on automatic simplification to obtain the form s/he needs for an expression. She must consciously learn to use the items of the algebra menu (factor, expand, comdenom), to decide whether expressions are equivalent as well as anticipate the output of a given transformation on a given expression.

With regard to teaching, as opposed to learning, mathematics there are far fewer papers. Here again there are many that I would term over optimistic or prescriptive. For example Heid et al. (1990) state:

> In the implementation of computer-based laboratory explorations, the teacher must become a technical assistant, a collaborator, and a facilitator. ... the teacher will need refined skills as a discussion leader and as a catalyst for self-directed student learning.

This is a particularly strong statement chosen to make the point and the authors are clearly open to the charge of confusing an 'is' with an 'ought'.

Research papers directly addressing both teaching and CAS issues start from 1996. Zehavi (1996) focuses on in-service training where teachers work at problems at their own level, become aware of how technology can assist in their own mathematical thinking and then develop related materials at the student level. This model is partially incorporated into in-service training reported on by Lachambre & Abboud-Blanchard (1996). These authors also distinguish between four aspects of training: technical, scientific, cultural and professional. Heid (1995) and Zbiek (1995) show how computer algebra use can threaten teachers' perceived command of their subject knowledge and how teachers may bypass modes of effective teaching to ensure they exhibit a command of their subject knowledge to students in ICT lessons. In the next section of my talk I consider two fairly recent studies in some detail.

Two CAS studies in some detail

Lumb, Monaghan & Mulligan (2000)

Stephen and Steve were teacher-researcher members of a project *Moving from Occasional to Regular Use of Technology in Secondary Mathematics Classes*. The project aimed to explore: patterns of teaching and learning; teachers' preparation and use of resources; teachers and students' attitudes and teachers' confidence ˜ all over the course of one year. Stephen and Steve both used *Derive* with 16/17 year old Advanced level (A-level) classes. Stephen and Steve both teach in state schools in England, both have first class degrees in mathematics and they were in their second year of teaching when the project began. Both had spent a couple of hours playing with *Derive* on their own before the project began. Stephen's class had 9 students and Steve's had 15 students. These are fairly typical A-level class sizes. Stephen had a suite of PCs in his teaching room. Steve had to take his class to a PC computer suite on the other side of the school. Stephen's class studied pure mathematics (the focus for the *Derive* work).

Steve wrote
"My intention was to use *Derive* as a teaching aid to cover the pure maths syllabus. Getting through the syllabus content traditionally involves considerable teacher exposition and I was keen to find ways to reduce this proportion of time devoted to exposition. There is a myth that pure maths in England is largely taught as a set of algorithms. I thought a stronger focus on concepts might arise from *Derive* work. I expected that I would spend the majority of my time in the computer room. My primary resource was a textbook written specifically for the syllabus (which leads to the exam). The normal format in non-computer lessons was to explain topics myself and use the textbook for exercises. For the non-*Derive* work, I invariably used the text book. For the *Derive* work, I chose not to use the text book (although as time went on I did occasionally use it for examples). The main reason for not using the textbook for *Derive-based work* is that I wanted to use *Derive* as a 'teach yourself' tool. In other words, I wasn't going to stand at the blackboard and teach a topic – I wanted to write a set of worksheets that would hopefully do the job for me.

My early work with *Derive* with this class was far from positive. After an couple of lessons introducing *Derive* we worked on functions: curve sketching and transformations, e.g. given the graph of $y=f(x)$, sketch the graph of $y=f(x-2)+5$. I spent a lot of time on early lesson plans and writing worksheets (1 to 2 hours per lesson instead of 5 minutes for non-computer lessons). We all found input and output notation difficult at times. I found moving from my list of topics I could do with *Derive* to realising these with my class difficult. One reason for this was simply the extra time it took ˜ in the early weeks of the *Derive*-based work we spent nearly every lesson in the computer room and the students were getting anxious and bored. I had to limit computer use to those times when I felt it would be really beneficial. Reflecting on the reports of Heid (1995) and Zbiek (1995) the stress for me did not come from mathematical or technical concerns but from sensing that I was losing the interest and enthusiasm of the students.

My early worksheets were technology-focused, e.g. "Click and hold the left mouse button ..", and techno-maths focused, e.g. how to write $\sqrt{}(x^2-1)$.Worksheets, however, quickly became straight-maths-focused and appeared to conform with my 'teach yourself' intent. My lessons may be said to have worked well, but I still have reservations about them. As far as the functions topic was concerned, *Derive* was great - it even did the algebra for you. This brings up the issue of 'shouldn't the students be doing the algebra themselves, since they can't rely on *Derive* in an exam?' I suppose this isn't really a problem because the focus of the lessons was function transformations and it could be argued that the algebra could get in the way. *Derive* by-passed the 'hard slog' to enable a clearer vision of the results. With the calculus activities I encouraged them to write their results down in an orderly fashion but some, the lower attaining students, did not do this. So when they came to try to explain what they had found, they had no evidence to back up what they were trying to say. I need, too, to question the time taken ~ two double lessons to arrive at results which could be obtained in half this time without *Derive*. I need to question the time taken for the early function work too: was it worth the 2-3 weeks learning the initial syntax just to see nice graphs appear on the screen? Packages such as *Omnigraph* could have been used just as effectively but with only a fraction of the time. I ended the year questioning whether it was all worthwhile. I will probably use it again but as an occasional demonstration tool in the future.

Stephen wrote:
I wanted to use 'state of the art software' to follow the pure mathematics A-level module. I knew of, but was far from familiar with, *Derive* and it seemed an appropriate choice. I expected that I would also use graphic calculators, *Omnigraph* and Excel to support *Derive*-based work. I wanted my students to explore mathematics independently and I also wanted to increase their motivation to do mathematics. The project used the term 'regular use of ICT'. I'm not sure that is a useful expression. There were times during the project, for example when my project class were studying mechanics, when ICT use seemed inappropriate and we didn't use it at all. There were other times where we made really extensive use of ICT.

My primary resource for this course were textbooks designed for the modules but, with computer-based work, I wrote my own worksheets. I found writing worksheets the most time consuming aspect of being involved in the project. Knowing my frustration John lent me two very different books (Berry et al., 1993; Etchells et al., 1996). The first could be described as a traditional exposition of mathematics and the second as investigational. Although I used amended ideas from both books I did not find either particularly useful because they didn't fit in with the way I wanted to approach topics. I will try and explain my problems with them.

Berry *et al.* (1993) is not really a teacher's book as such - there are no lesson ideas, worksheets or anything directly useful. I found it useful though to work through it myself, discovering further capabilities of *Derive*, which I could then turn into ideas for lesssons. One particular example of this is using *Derive* to perform iterations. The ITERATE command is reasonably straightforward for the pupils to use once it had been explained to them, however it doesn't present answers in a quickly readable form. It is better to set up the iteration as a vector, so that each step of the iteration is numbered. This obviously makes the initial command more complex. The pupils had to copy it 'parrot fashion' and I had to highlight which numbers did what. Two students did then use this command with good effect in their coursework, although during the initial lessons other students were struggling to comprehend this command fully.

Etchells *et al.* (1996) is written specifically for teachers, full of lesson ideas. There are plenty of photocopiable worksheets, teacher notes and help sheets. Despite all this, I did not find it immediately useful. One reason is that I am teaching a modular course the calculus topics have been split into separate modules. There is a (necessary) tendency to teach for the exam. So, for example, the basic idea of differentiation occurs in the Pure Maths 1 module whereas the second derivative doesn't show up until the Pure Maths 2 module. Several of the worksheets in the book contained ideas which overlapped modules, and so were not appropriate until the later modules were being taught. Other activities in the book, which although they looked good, were not directly related to the topics being covered. One example of this is the activity 'Multiplying Straight Lines'. I believe this to be a worthwhile activity, but it is definitely an 'extra' and several of the ideas being beyond the immediate syllabus. (I have since used this as an 'end of term' activity but I found it easier with Omnigraph because I didn't need to keep switching from algebra to graph windows.)

Some reflections on Stephen & Steve's experiences
These reflections here are grouped into three categories: time, materials and *Derive*.

Time
Incorporating *Derive* into lessons involved considerable extra work/time: becoming basically competent with it; going through the syllabus and finding suitable topics; planning lessons in much greater detail than would normally be the case; writing and testing worksheets. This extra work was definitely biased towards the beginning of the course but it remained throughout the year. There is an argument that any new teaching resource involves extra effort on the teacher's part. We nevertheless believe that *Derive*, used as a regular resource, is at the upper end of the 'effort' scale for mathematics software.

Another time issue is time to get 'a feel' for how to use *Derive*. Going through the syllabus and finding suitable topics for *Derive* use is one thing, having a sense of how they might 'work' is another. There is an argument that this happens with any new development but we believe that *Derive* is at the upper end of the scale for mathematics software. Perhaps this is partially due to the enormous potential of *Derive* for this kind of mathematics. It is not just something, like a graph plotter, that does a specific task, it can do just about everything. This may be a selling point for *Derive* but, for the teacher, it can present real problems.

Materials
Steve commented that his early worksheets were technology-focused but that they then became mathematics-focused. We think this is a common pattern for teachers when they begin to use technology ˜ almost any technology. But once this hurdled is over, why continue using worksheets ˜ why not use the textbook? Steve claims that this resulted from a desire to use *Derive* as a 'teach yourself' tool. In Stephen's case he simply found that the textbook and *Derive* did not 'fit'. It is difficult to isolate reasons for this. It may arise from a desire to 'lead' students' use of *Derive* because it offers so much scope and the teacher wishes the students to go down a particular route they believe is beneficial to learning. It may also be because written mathematics and *Derive*-based mathematics are two different forms of mathematics. We return to the issue of the power of *Derive*, to leading students routes and to getting a feel for *Derive*-based mathematics. It is no more than an hypothesis but we think that teachers who plan to incorporate significant use of computer algebra in their teaching are presented with a re-evaluation of the mathematics they were taught and are familiar with. These re-evaluations are quite specific to the individual and someone else's 'route' is not easy to accommodate.

Derive
Project work suggested that spreadsheets and graphic applications have an immediacy which *Derive* and Sketchpad lack. 'Immediacy' is simply a term we use here. It has several levels of meaning.

- Software is immediate if you can use it quickly. *Derive* is not immediate in this sense. Both classes had to have several lessons devoted to learning to use *Derive* and further command-based learning was a feature of later lessons.
- Software is immediate if you can proceed with a task without getting caught up in technicalities. *Derive* is not immediate in this sense. For example, in one of Steve's lessons on functions it became necessary to specify inverse functions. $f^{-1}(x)$ does not

work. It is necessary to write $y = f(x)$ and rearrange to get x as a function of y. This caused the mathematical focus of the lesson to be put aside in order to focus on how to perform the technical operation.

- Software is immediate if its place in the mathematics being studied is clear. This level of immediacy is complex and intertwined with many person/situation-specific factors: the ‘transparency’ of the mathematics, the transparency of the software, the mathematical and software specific technical facility of the teacher and of the student and the size of the mathematical task. One of the problems with *Derive*, with respect to ‘transparency’ is its enormous potential ˜ its power appears to work against transparent usage.

Kendal and Stacey

Maragret Kendal and Kaye Stacey from Australia have written a number of papers based on Kendal’s PhD thesis (Kendal, 2001). In a recent paper (Kendal & Stacey, 2002) they report on two volunteer teachers, whom they call Teacher A and Teacher B, who used CAS on a TI-92 to teach approximately 22 lessons on introductory differential calculus to 16-17 year olds. They were both experienced teachers of mathematics, whose students had used graphics calculators in the classroom for several years. Kendal & Stacey reflected on three privileging characteristics of the teachers: teaching approach; purpose of technology use; and calculus content.

Privileging related to teaching approach

Teaching method: Teacher A’s focus was on teaching rules and strategies for carrying out procedures and during both interviews he talked primarily about routines to solve problems. In contrast Teacher B’s teaching emphasis was on understanding the concept of derivative. He gave the meaning to the symbolic derivative as gradient of a curve, often depicting the gradient of the tangent to the curve at a point using his outstretched arms to represent the tangent line (an enactive representation). He also encouraged the students to use visualization techniques to interpret mathematics, such as visualizing a graph where the tangent has slope zero. During the first interview he solved each problem several ways, explained his use of different representations, and convinced himself that his answer was appropriate. During the second interview he talked about conceptual understanding: ″Getting the tangent idea through to them, what the gradient actually represents, what the derivative actually represents, and the relationship between them - I think we’ve done that very nicely with the calculator.″

Teaching style: Teacher A adopted a teacher-centred style. He mostly lectured his students who were expected to copy down his lesson notes and lists of CAS key strokes. In contrast, Teacher B adopted a student-centred teaching style. He guided class discussions between ‘each student and teacher’ and ‘student and student’ and he encouraged the students to construct meaning for themselves. Thus, Teacher A’s teaching approach, which emphasized student performance and mastery of mathematical rules through teacher-centred lectures, is classified as ‘content-focused with an emphasis on performance’. Teacher B’s teaching approach, which emphasized conceptual understanding of content and student construction of meaning through student-centred class discussion, is classified as ‘content-focused with an emphasis on conceptual understanding’.

Privileging of calculus content

Teacher A focused almost exclusively on symbolic differentiation. However, during the second trial he expanded his teaching to include the calculation of derivatives at a point from graphical and the numerical representations of the function. This came about after the first interview when he realized that the students’ second trial assessment would involve all three representations, unlike the first trial assessment that was essentially symbolic.

During both trials, Teacher B consistently stressed the symbolic derivative and he used a graphical representation to give the symbolic representation meaning as discussed above. Although he personally demonstrated the ability to obtain an instantaneous rate of change at a point numerically (finding a rate of change or a difference quotient) during the first interview, he actively rejected teaching about difference quotients in the second trial. He explained this was because his students were a low-attaining group and would not cope with the three representations of derivative (i.e., he made changes to the calculus content he taught in response to knowledge of his second cohort of students).

The second aspect of privileging for content choice is whether students were encouraged to solve problems using CAS or by-hand. In both trials, Teacher A appeared comfortable for students to make their own choices about using or not using CAS; methods using CAS were demonstrated and students were free to use them. In contrast, Teacher B encouraged CAS for graphing only and actively discouraged it for symbolic procedures, especially in the second trial.

Privileging of technology use

In the first teaching trial, Teacher A regularly linked the CAS calculator to an overhead projector and frequently demonstrated symbolic procedures to the students and allowed them to use CAS freely. He avoided using graphs and tabular representations. In the second trial, he again used the overhead projector of the CAS screen in most lessons. He taught his students the additional CAS numerical and graphical differentiation routines, to obtain derivatives at a point. Teacher A showed little pedagogical CAS use in either trial. In the first interview, Teacher A reported one instance:

> ″I'd say, when you see these words [average rate of change] it means between two points, and when you see this word [instantaneous] that means at a point . . . [I am] giving them strategies . . . and we did it [used a dynamic graphing program] to understand the straight line against the curve.″

In the first teaching trial, Teacher B used the technology freely to draw graphs but he noticeably controlled student use of the CAS calculator for symbolic algebra procedures. In the second trial, he actually reduced his use of the CAS calculator so that functional use was discouraged. Only pedagogical use of the symbolic capability was encouraged. This occurred when he believed CAS use would promote understanding by providing data for exploratory activities. An example was when students used the CAS to build up a table of derivatives of polynomials from which the general rule for differentiating a polynomial could be induced. Teacher B maintained his emphasis on linking the symbolic and graphical representations to help the students attach meaning to the symbolic derivative.

> ″It's [the CAS] good for discovery because it takes a lot of the hack work out of the teaching for understanding but you still need to teach pen and paper skills. I think there are certain skills that the kids have to have, even if you can use the technology to do it. I think the kids have to have the [symbolic manipulation] skills as well, without the technology. I think that's essential for their understanding. It's not sufficient to just use the calculator, they have to have the understanding of what's behind it.″

Thus, during both trials, Teacher A used the CAS calculator primarily for functional purposes involving the three representations. Teacher B also used it functionally, (graphically but not symbolically), and pedagogically (graphically for illustrating the meaning of derivative and symbolically for pattern finding purposes). Although neither teacher changed their purpose for using the CAS calculator, they both used it in new ways in the second trial to accommodate the changed emphasis they gave to the representations (i.e, calculus content) as discussed in.

Kendal and Stacey ask how teachers with contradictory underlying beliefs will be able to change to accommodate new teaching practices that are incompatible with their beliefs? Alternatively, different teachers may be differentially successful with teaching approaches, so that maximizing effectiveness of teaching with CAS may be best achieved by advocating different styles for different teachers. This study has shown that the teachers were able to change the mathematical content they taught when the changes helped them better achieve their purpose for teaching. However it is anticipated that teachers will find it more difficult to change their teaching approach and purpose for use of CAS (privileging characteristics) without changing their beliefs about learning and, possibly, expanding their content knowledge.

Secondly, how does CAS become legitimized within the school culture? This is not a simple question, because it is not agreed what nature of use should be legitimized. Our two teachers drew their positions at least in part from the institutional position, which did not legitimize CAS. It will be very interesting to see if teachers make the changes more easily when CAS use has become institutionalized as in our new study, which examines the first cohorts of students in an examinations system where CAS is allowed (Stacey, McCrae, & Asp, 2000). However, there are deeper debates which arise when the institutional constraints do legitimize CAS, concerning what really constitutes doing mathematics and the right balance between by-hand and by-CAS algebraic skills from various viewpoints and the appropriateness of using CAS to compensate for inadequate algebraic skills. In addition, there is a lack of legitimacy that arises not from institutional constraint but from a need for new pedagogical content knowledge. In our study, the existing curriculum was enhanced by CAS, principally through its ability to improve understanding by enabling a multiple representations approach. Because the existing curriculum was unchanged there was no real need for the symbolic manipulation power of CAS – the mathematics stayed within the expected range of by-hand skills.

Implications: ways forward

I begin by thinking about ‘us and them’. ‘Us’ being teachers who embrace CAS technology and ‘them’ being teachers who do not. OK, this is stereotyping which is not a good thing to do, but I do it to make the point that what we may find natural, and maybe even easy, is not necessarily natural or easy for many teachers. If you consider that you work in isolation and that what you do in your classroom is your own business, then maybe these points about other teachers are not important to you. But if you work in a team or are responsible for teacher development, then I think it is crucial to consider the problems. I end with suggestions for what we need to do when working with other teachers (as colleagues or an course providers).

Avoid presenting technology as a remedy for the ills of current mathematics teaching and learning. This does not mean we should lose our enthusiasm but simply that we ‘get real’ and recognise that it isn’t a solution in itself and, where it can enhance teaching and learning, that it takes considerable effort.

Avoid prescriptions because there are always several ways to do things and what works for you may not work for someone else. The way to avoid presecriptions is to talk to people and consider their point of view. Ask them how they currently teach a topic and how they might teach it with, say, a TI-89. If they don’t know, then offer them alternative approaches and see what approach fits in with their way of thinking. This leads on to my next point.

Recognise that teachers differentially 'privilege' (Kendal & Stacey) teaching approaches, technology and mathematics. Related to this teachers see different 'routes' (Lumb, Monaghan & Mulligan) to knowledge for their students. In working with teachers there are two approaches we may take. We may respect that their route is best for them or we may wish to influence them to adopt our route. Whatever we do we need to understand their position.

Address the potential problem of using written resources, e.g. textbooks, with technology. Most teachers find it initially hard to coordinate the use of technology with use of textbooks, as the cases of Stephen and Steve illustrate. Hand in hand with this is being 'up front' that the early stages of using technology is likely to be very time consuming at a number of levels (becoming competent; finding suitable topics; planning lessons and getting 'a feel' for how to use the technology). If we do not anticipate these potential problems, then we risk teachers becoming frustrated and giving up using technology.

The future is a technological one but what technological future it will be will be largely created by teachers, 'us' and 'them'.

References

Artigue, M. (2001) 'Learning Mathematics in a CAS Environment: The Genesis of a Reflection about Instrumentation and the Dialectics between Technical and Conceptual Work'. pdf file http://ltsn.mathstore.ac.uk/came/events/freudenthal/theme1.html

Berry, J., Graham, E. & Watkins, A. (1993) *Learning Mathematics Through DERIVE*. Chichester: Ellis Horwood.

Etchells, T., Hunter, M., Monaghan, J., Pozzi, S. & Rothery, A. (1996) *Mathematical Activities with Computer Algebra*. Bromley: Chartwell-Bratt.

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

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.

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

Kendal, M. & Stacey, S. (2002) 'Teachers in transition: Moving towards CAS-supported classrooms'. To appear in *Zentralblatt für Didaktik der Mathematik*, Vol. 34 (5).

Lagrange, J-b (1999) 'A didactic approach of the use of CAS to learn mathematics'. pdf file available through http://ltsn.mathstore.ac.uk/came/events/weizmann/index.html

Rodd, M. & Monaghan, J. (2001) *The Leeds Graphic Calculator Project*. See http://edu.leeds.ac.uk/research/groups/cssme/graphCalc.html

Watson, D.M. (ed.) (1993) *The Impact Summary*, DFE and King's College London.

Zbiek, R.M. (1995) Her math, their math: an in-service teacher's growing understanding of mathematics and technology and her secondary students' algebra experience. *Proceedings of the 17th Annual Meeting of the N. American Chapter of PME* (221-225). Columbus,OH.