Technology-Enriched Mathematics Learning: What is the Teacher's Role?

Merrilyn Goos

m.goos@uq.edu.au

The University of Queensland, Australia

Abstract

Previous research on computers and graphics calculators in mathematics education has looked at effects on curriculum content and students' mathematical achievement and attitudes, but less attention has been given to the ways in which teachers integrate technology into their pedagogical practice or to how teachers learn to teach with technology. This observation is critical in the current context of educational policy making, where it is assumed – often incorrectly – that supplying schools with hardware and software will increase teachers' use of technology and encourage more innovative teaching approaches. This paper reports on a research program that aimed to develop better understanding of how and under what conditions Australian secondary school mathematics teachers learn to effectively integrate technology into their practice. The research adapted Valsiner's concepts of the Zone of Proximal Development, Zone of Free Movement and Zone of Promoted Action to devise a theoretical framework for analysing relationships between factors influencing teachers' use of technology in mathematics classrooms. The framework is used to analyse case studies of a novice teacher and an experienced teacher in different school settings.

Introduction

Mathematics, science and technology education in Australia are currently experiencing major impetus for innovation and reform. The Australian Government's policy statements on educational innovation and teacher quality (Commonwealth of Australia, 2001, 2003) emphasise that Australia's future lies in its potential as a knowledge-based society built on the intellectual capabilities and creativity of its people. Teachers and students are expected to become partners in a learning society underpinned by science and mathematics and successful schools are portrayed as those drawing on the resources of technology to facilitate learning.

Throughout Australia there are moves to encourage – and in some cases mandate – the integration of digital technologies into school education through curriculum initiatives, funding for infrastructure, and the development of professional standards for teachers. In the current context of educational policy making it seems to be assumed that supplying schools with hardware and software will increase teachers' use of technology and encourage more innovative teaching approaches that produce improved learning outcomes for students. Yet internationally there is research evidence that that improving teachers' access to educational technologies has not, in general, led to increased use or to movement towards more learner-centred teaching practices (Cuban, Kirkpatrick & Peck, 2001; Wallace, 2004).

Windschitl & Sahl (2002) have identified two factors that appear to be crucial to the ways in which teachers might embrace, ignore, or resist technology. First, teachers' use of technology is influenced by their beliefs about learners, about what counts as good teaching in their institutional culture, and about the role of technology in learning. Second, school structures – especially those related to the organisation of time and resources – often make it difficult for teachers to adopt technology-related innovations. Clearly, there is a need to re-think assumptions about relationships between access to technology and its use by teachers. This paper describes a framework for explaining interactions between pedagogical knowledge and beliefs, school structures and other institutional constraints, and professional learning opportunities. The framework is used to analyse examples of teachers' use of technology in secondary school mathematics drawn from a series of socioculturally oriented research studies carried out in Australian schools.

Theoretical Framework

For some time education researchers have recognised the potential for mathematics learning to be transformed by the availability of technology resources such as computers, graphics calculators, and the internet (see Arnold, 2004; Forster, Flynn, Frid & Sparrow, 2004; Goos & Cretchley, 2004 for recent reviews of Australasian research). These technologies offer new opportunities for students to communicate and analyse their mathematical thinking by enabling fast, accurate computation, collection and analysis of data, and exploration of the links between numerical, symbolic, and graphical representations (Hennessy, Fung & Scanlon, 2001). In Australia and internationally, teacher organizations recommend giving priority to the use of technologies as natural media for mathematics learning, while recognising that effective support for teachers is a key ingredient in exploiting technology to enhance learning (Morony & Stephens, 2000; National Council of Teachers of Mathematics, 2000).

Although every Australian state and territory has now developed mathematics syllabuses and assessment regimes that mandate the use of technology (e.g., Queensland Studies Authority, 2000), the support that teachers need for meaningful technology integration is often lacking. A recent survey of secondary mathematics teachers in Australia (Goos & Bennison, 2004) found that while most were convinced of the advantages of technology in performing calculations more quickly and easily, many were unsure whether technology really helped students to understand mathematical concepts or explore unfamiliar problems. This uncertainty was reflected in their desire for professional development that would show how to plan activities that combine technology with mathematical concepts in order to meaningfully incorporate technology into lessons. One respondent commented that professional development should involve "more of why and less of how" to use technology in mathematics teaching. These findings highlight the need for frameworks to describe, interpret and explain the ways that teachers and students engage in technology-enriched learning activities.

Early research in this area examined the effects of technology use on *students'* mathematical achievements and attitudes and their understanding of mathematical concepts (Penglase & Arnold, 1996). However these studies did not distinguish between the use of technology and the context of that use, and little attention was given to issues of pedagogy and the nature of *teachers'* professional learning within and beyond the school environment (Windschitl & Sahl, 2002). To address some of these issues my colleagues and I have carried out studies informed by sociocultural theories of learning involving teachers and students in Australian secondary school mathematics classrooms (e.g., Galbraith & Goos, 2003; Goos, 2005). Sociocultural theories view learning as the product of interactions with other people and with material and representational tools offered by the learning environment. Because it acknowledges the complex, dynamic and contextualized nature of learning in social situations, this perspective can offer rich insights into conditions affecting innovative use of technology in school mathematics.

In this research program Valsiner's (1997) zone theory of human development was adapted to apply to interactions between teachers, students, technology, and the teaching-learning environment. This framework extends Vygotsky's concept of the Zone of Proximal Development (ZPD) – often defined as the gap between a learner's present capabilities and the higher level of performance that could be achieved with appropriate assistance – to incorporate the social setting and the goals and actions of participants. Valsiner describes two additional zones: the Zone of Free Movement (ZFM) and Zone of Promoted Action (ZPA). The ZFM structures an individual's access to different areas of the environment, the availability of different objects within an accessible area, and the ways the individual is permitted or enabled to act with accessible objects in accessible areas. The ZPA represents the efforts of a more experienced or knowledgeable person to promote the development of new skills. For learning to be possible the ZPA must be consistent with the individual's potential (ZPD) and must promote actions that are feasible within a given ZFM. When we consider teachers' professional learning, the ZFM can be interpreted as constraints within the school environment, such as students (their behaviour, motivation, perceived abilities), access to resources and teaching materials, and curriculum and assessment requirements, while the ZPA represents opportunities to learn from pre-service teacher education, colleagues in the school setting, and professional development.

Previous research on technology use by mathematics teachers has identified a range of factors influencing uptake and implementation. These include: skill and previous experience in using technology; time and opportunities to learn (pre-service education, professional development); access to hardware and software; availability of appropriate teaching materials; technical support; institutional culture; knowledge of how to integrate technology into mathematics teaching; and beliefs about mathematics and how it is learned (Fine & Fleener, 1994; Manoucherhri, 1999; Simonsen & Dick, 1997; Walen, Williams & Garner, 2003). In terms of the theoretical framework outlined above, these different types of knowledge and experience represent elements of a teacher's ZPD, ZFM and ZPA, as shown in Table 1. However, in simply listing these factors, previous research has not necessarily considered possible relationships between the teacher's setting, actions, and beliefs, and how these might change over time or across school contexts. Zone theory provides a framework for analysing these dynamic relationships.

Table 1. Factors affecting technology usage

Valsiner's Zones	*Elements of the Zones*
Zone of Proximal Development	Skill/experience in working with technology Pedagogical knowledge (technology integration) General pedagogical beliefs
Zone of Free Movement	Access to hardware, software, teaching materials Support from colleagues (including technical support) Curriculum & assessment requirements Students (perceived abilities, motivation, behaviour)
Zone of Promoted Action	Pre-service education (university program) Practicum and beginning teaching experience Professional development

Background to the Research Program

The research program referred to above has used Valsiner's (1997) zone theory to investigate relationships between factors influencing how novice and experienced teachers use technology in the mathematics classroom. Examples from two separate studies are analysed later in the paper. A brief outline of the research design and methods for each study is provided below.

The first study, conducted in 2001, aimed to analyse processes through which mathematics teachers learned to use technology as an educational resource (Galbraith & Goos, 2003). Participants were a group of ten experienced teachers who volunteered for a training program, conducted intensively over a single week-end, that prepared them to deliver professional development workshops on the use of graphics calculators. These sessions engaged participants as learners in technology-rich activities that could be used in secondary school classrooms, and in discussion of associated teaching and learning issues. We followed the progress of three teachers who subsequently delivered professional development workshops at conferences or in their own schools, and interviewed them on how their views about technology had been affected by the training program.

The second study followed successive cohorts of pre-service teachers into their first years of teaching from 2000-2004. Its main aims were to identify factors that influence how beginning teachers graduating from a technology rich pre-service course integrate computers and graphics calculators into their mathematics teaching practice (Goos, 2005). One element of the research design involved individual case studies that captured developmental snapshots of experience during the final practice teaching session and towards the end of the first year of full-time teaching. Participants were visited in their schools for lesson observations, collection of teaching materials and audio taped interviews.

Case Study of a Novice Teacher Learning to Integrate Technology

Sandra was one of the pre-service participants in the second study described above. Her practicum placement was in a large school in the State capital city. At this time the mathematics syllabuses merely encouraged teachers to use computers and graphics calculators, although new syllabuses to be introduced the following year would make technology use mandatory. The school was well equipped with computer laboratories and had recently purchased its first class set of graphics calculators. However, none of the teachers had yet found time to learn how to use the calculators. Sandra was very familiar with computer applications such as Excel and regularly searched the internet for teaching ideas and resources. She used both these technology resources in her mathematics teaching during her practice teaching sessions, although she had not observed other teachers in the school use any kind of technology with their classes. Before starting the pre-service course Sandra had no experience with graphics calculators but she was now keen to explore the possibilities this technology might offer for developing students' understanding of mathematical concepts.

Sandra was teaching linear programming, a topic that deals with the kind of optimisation problems commonly encountered in engineering and economics. A typical example would be maximising the profit in a factory that manufactures a number of different products from the same raw materials using the same resources. As graphical methods are usually used to solve linear programming problems in secondary school treatments of this topic, Sandra decided this presented an ideal opportunity for students to use the graphics calculators instead of drawing graphs by hand. She adapted an activity from the internet that asked students to work out the optimal quantities to be produced of two different kinds of pasta, using three different varieties of cheeses, so as to ensure maximum profit for the manufacturer. Part of the graphical solution is shown in Figure 1. (The enclosed region contains values for the number of batches of each type of pasta that can be made from the amount of cheeses in stock. The profit function, represented by equation Y4, has its maximum value at a vertex of this region.) Because the students had never used graphics calculators before, she also devised a worksheet with keystroke instructions and encouraged students to work and help each other in groups.

Unexpectedly, Sandra encountered strong resistance from the students, which seemed to stem from their previous experiences of mathematics lessons. Other mathematics teachers in the school tended to take a very transmissive approach and focused on covering the content in preparation for pen and paper tests, so the students were not interested in learning how to use technology if this would be disallowed in assessment situations. According to Sandra, the students' attitudes could be summed up as: "Just give me enough to pass … I don't want to know how to do group work, I don't want to know how to use technology".

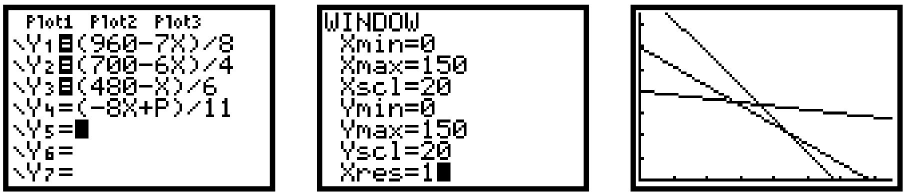

Figure 4. Calculator screens for graphical solution of a linear programming problem

In theoretical terms, the Zone of Promoted Action offered by the teachers in the school was not a good match with the ZPD defined by Sandra's pedagogical beliefs and her knowledge and skills in using technology to teach mathematics. Neither did her supervising teacher's ZPA provide a model of teaching that was consistent with the technology emphasis of the pre-service course. Some elements of Sandra's Zone of Free Movement, such as her easy access to calculators that no other teacher knew how to use, presented favourable opportunities to use technology. However, most other aspects of her ZFM – students' attitudes and lack of motivation, curriculum and assessment requirements that excluded technology – represented constraints. Yet Sandra was not discouraged by this experience and remained committed to enacting her pedagogical beliefs about using technology.

After graduation Sandra moved from the city to a smaller rural school that was much better resourced with respect to graphics calculators but lacking in experienced teachers who knew how to use them effectively. All Grade 11 and 12 mathematics students had continuous personal access to graphics calculators via a hiring scheme operated by the school, and there were two additional class sets available for teachers to use with other classes – although Sandra was the only teacher to use these with younger students. She was also beginning to use temperature probes and motion detectors that could be used in conjunction with graphics calculators to collect and analyse data from experiments.

Compared with her practicum experience, Sandra's first year of teaching offered a more expansive Zone of Free Movement: motivated and cooperative students, good access to technology resources, and new syllabuses that mandated use of computers and graphics calculators in Grades 11 and 12. Yet there was no Zone of Promoted Action within her school environment, and geographical isolation, compounded by a very slow internet connection, made it difficult for her to access professional development and teaching materials (an external ZPA). While she was still able to draw on the knowledge gained during her university program (the pre-service ZPA), Sandra recognised her need to gain new ideas via collaboration with other more experienced teachers beyond the school in order to further develop her identity as a teacher for whom technology was an important pedagogical resource.

Case Study of an Experienced Teacher Learning to Integrate Technology

Teachers who completed their pre-service education before computers and graphics calculators were introduced into school classrooms rely on formal or informal professional development to learn how to use technology. By comparison with Sandra, Lisa was a very experienced teacher but a relative novice in the use of technology when she participated in the research study associated with the graphics calculator training program described earlier. When reflecting on her initial professional development experiences in this field, she commented that she "got lost in the first ten seconds, and was really turned off so didn't touch them again for a while". After several more workshops she felt confident enough to use graphics calculators in her teaching, "but not confidently and not proficiently. Not really realising how much they improved the thinking, more just as a tool to do graphs and things".

The training program proved to be a turning point for Lisa as it emphasised the impact of technology in developing students' understanding of mathematical concepts and in facilitating classroom discussion, rather than focusing on "pushing buttons". In the interview excerpt below she refers to an activity that investigated the periodic, oscillating motion of an object suspended from a spring. A data logging instrument was used to record the motion of the object. This information was downloaded to graphics calculators and a plot produced of the object's vertical distance from the ground against time (as in Figure 2). Participants then had to fit a mathematical function to the data and present their work to the group using the overhead projection unit.

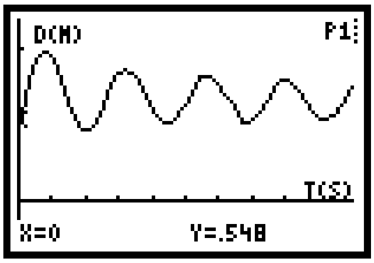

Figure 5. Graphics calculator graph of object suspended from a spring (vertical distance from ground vs time)

> It was out of that week-end that I really understood the impact that [graphics calculators] had on the pedagogy. Up to then I saw it as a tool to draw graphs and analyse statistics. But at that workshop, just one little thing from that workshop, how we were working in groups, and they explained to us how kids start trying to help. So when we were doing that we were grabbing somebody else's calculator and sharing our data, so it made the group work thing a whole lot better. And I really valued the part where we, as groups, we went out and used the overhead projector and we presented our information back to the group. So I just, I really started to see different ways of using it that I hadn't thought of before. So it really enhanced group work, it really showed me that you could do a lot more hands on stuff, the practical activity with the motion detectors. That graphics calculators are good for inspiring all those other good things in teaching, like the hands on, the group work, and really starting to think when we were fitting functions to the data. Really having to think and understand what the intercept and the gradient mean. We weren't just *doing*, we were really *understanding* at a higher level. I found that really powerful. Because I had thought that all they do is save you that boring part of maths.

Environmental constraints and affordances (ZFM) seemed to play little part in Lisa's learning, possibly because as Head of her school's Mathematics Department she had plenty of autonomy in obtaining the resources she wanted and in managing curriculum and assessment programs. Instead, Lisa's learning can be understood in terms of the changing relationship between her goals and interests (ZPD) and the ZPAs offered by the professional development and training she experienced. She described previous workshops she had attended as "off-putting", because the emphasis was on procedural aspects of operating the calculators and the mathematics presented was too difficult for participants to engage meaningfully with the technology. She contrasted this with the approach taken in the week-end workshops offered as part of this research project:

> I didn't really feel super confident until I went to the workshop. And I think it was then, understanding the bigger concepts, rather than just pushing buttons. Because at the pushing buttons level you never really understand how they operate. And after that I was just so inspired. It was just that whole valuing and that sharing and learning from each other, and just to realise that other people are out there. So that was really the turning point for me to say that this is really exciting stuff.

Lisa seemed to find a professional development ZPA that matched her need to focus on pedagogical, rather than procedural, aspects of using technology, and acknowledged the potential for experienced teachers to learn from each other.

Discussion

This paper has analysed relationships between mathematics teachers' access to technology resources and the ways in which they incorporate these resources into their pedagogical practices. Evidence from research studies carried out in Australian classrooms suggests that simple notions of "access" and "use" are inadequate for understanding the roles that technology plays in mathematics teaching and learning. The case studies of Sandra and Lisa showed that teachers interpret access to technology in relation to what they believe is beneficial for students and feasible in the light of their own expertise and institutional context.

Teachers' learning can be understood in terms of relationships between Valsiner's (1997) Zones of Proximal Development, Free Movement and Promoted Action, and this provides a useful way of analysing the extent to which teachers adopt innovative practices involving technology. The ZFM can be interpreted as teachers' institutional context, the ZPA represents their experiences in learning about teaching with technology, and the ZPD is influenced by their knowledge of how to integrate technology into their teaching and their pedagogical beliefs. The case study of Lisa illuminated issues facing experienced teachers who are unfamiliar with new technologies such as graphics calculators. While her ZFM presented few constraints, she had to search for professional development (ZPA) that would extend, rather than only accommodate, her existing ideas about teaching with technology (her ZPD). On the other hand, novice teachers like Sandra who are knowledgeable and enthusiastic about using technology may encounter obstacles in their professional environment (ZFM) that hinder implementation of preferred teaching approaches. Thus the theoretical approach outlined in this paper provides a way of interpreting teachers' actions in mathematics classrooms and may generate informed discussion about conditions that support or inhibit teachers' learning and adoption of new technologies.

References

Arnold, S. (2004). Mathematics education for the third millennium: Visions of a future for handheld classroom technology. In I. Putt, R. Faragher & M. McLean (Eds.), *Mathematics education for the third millennium: Towards 2010* (Proceedings of the 27th annual conference of the Mathematics Education Research Group of Australasia, pp. 16-28). Sydney: MERGA.

Commonwealth of Australia (2001). *Backing Australia's ability: An innovation action plan for the* future. Retrieved 26 November 2004 from http://www.innovation.gov.au/iap/.

Commonwealth of Australian (2003). *Australia's teachers: Australia's future. Advancing innovation, science, technology and mathematics. Agenda for action.* Retrieved 26 November 2004 from www.dest.gov.au/schools/teachingreview.

Cuban, L., Kirkpatrick, H. & Peck, C. (2001). High access and low use of technologies in high school classrooms: Explaining an apparent paradox. *American Educational Research Journal*, *38*, 813-834.

Fine, A. E. & Fleener, M. J. (1994). Calculators as instructional tools: Perceptions of three preservice teachers. *Journal of Computers in Mathematics and Science Teaching*, *13*(1), 83-100.

Forster, P., Flynn, P., Frid, S. & Sparrow, L. (2004). Calculators and computer algebra systems. In B. Perry, G. Anthony & C. Diezmann (Eds.), *Research in mathematics education in Australasia 2000-2003* (pp. 313-336). Flaxton, Qld: Post Pressed.

Galbraith, P. & Goos, M. (2003). From description to analysis in technology aided teaching and learning: A contribution from zone theory. In L. Bragg, C. Campbell, G. Herbert & J. Mousley (Eds.), *Mathematics education research: Innovation, networking, opportunity* (Proceedings of the 26th annual conference of the Mathematics Education Research Group of Australasia, Geelong, Vic, pp. 364-371). Sydney: MERGA.

Goos, M. & Bennison, A. (2004). *Teachers' use of technology in secondary school mathematics classrooms.* Paper presented at the annual conference of the Australian Association for Research in Education, Melbourne, 28 November-2 December. Retrieved 12 October 2006 from www.aare.edu.au/04pap/goo04319.pdf

Goos, M. (2005). A sociocultural analysis of the development of pre-service and beginning teachers' pedagogical identities as users of technology. *Journal of Mathematics Teacher Education*, *8*(1), 35-59.

Goos, M. & Cretchley, P. (2004). Teaching and learning mathematics with computers, the internet, and multimedia. In B. Perry, G. Anthony & C. Diezmann (Eds.), *Research in mathematics education in Australasia 2000-2003* (pp. 151-174). Flaxton, Qld: Post Pressed.

Hennessy, S., Fung, P. & Scanlon, E. (2001). The role of the graphic calculator in mediating graphing activity. *International Journal of Mathematical Education in Science and Technology*, *32*(2), 267-290.

Manoucherhri, A. (1999). Computers and school mathematics reform: Implications for mathematics teacher education. *Journal of Computers in Mathematics and Science Teaching*, *18*(1), 31-48.

Morony, W. & Stephens, M. (Eds.) (2000). *Students, mathematics and graphics calculators into the new millennium*. Adelaide: Australian Association of Mathematics Teachers.

National Council of Teachers of Mathematics (2000). *Principles and standards for school mathematics*. Reston, VA: NCTM.

Penglase, M. & Arnold, S. (1996). The graphics calculator in mathematics education: A critical review of recent research. *Mathematics Education Research Journal*, *8*, 58-90.

Queensland Studies Authority (2000). *Mathematics B senior syllabus.* Brisbane: QSA.

Simonsen, L. M. & Dick, T. P. (1997). Teachers' perceptions of the impact of graphing calculators in the mathematics classroom. *Journal of Computers in Mathematics and Science Teaching*, *16*(2/3), 239-268.

Valsiner, J. (1997). Culture and the development of children's action: A theory of human development. (2nd ed.) New York: John Wiley & Sons.

Walen, S., Williams, S. & Garner, B. (2003). Pre-service teachers learning mathematics using calculators: A failure to connect current and future practice. *Teaching and Teacher Education*, *19*(4), 445-462.

Wallace, R. (2004). A framework for understanding teaching with the Internet. *American Educational Research Journal*, *41*, 447-488.

Windschitl, M. & Sahl, K. (2002). Tracing teachers' use of technology in a laptop computer school: The interplay of teacher beliefs, social dynamics, and institutional culture. *American Educational Research Journal*, *39*, 165-205.