

Technology-Enriched Teaching of Secondary Mathematics: Factors Influencing Innovative Practice

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This paper reports on the initial phase of a research study that is investigating how and why secondary school mathematics teachers use digital technologies to help their students learn. Case studies of a beginning teacher and an experienced teacher, both of whom are regarded as effective users of technology, aim to identify critical factors that support or hinder innovative teaching and learning. The findings are analysed with the aid of Valsiner's (1997) zone theory to study interactions between teachers' knowledge and beliefs, their professional contexts, and their formal and informal professional development experiences.

For some time, education researchers have been interested in exploring the potential for digital technologies to transform mathematics learning and teaching. It is now widely accepted that effective use of technologies such as mathematical software, spreadsheets, graphics and CAS calculators, and data logging equipment offers students new opportunities for fast, accurate computation, collection, and analysis of real or simulated data, and investigation of links among numerical, symbolic, and graphical representations of mathematical concepts (see Forster, Flynn, Frid, & Sparrow, 2004; Goos & Cretchley, 2004). Support for technology use in secondary school mathematics is also found in most Australian state and territory curriculum documents.

A significant body of research has examined the effects of technology use on students' mathematical achievement and attitudes and their understanding of mathematical concepts, but less attention has been given to how teachers use technology in the classroom and how this use is related to their knowledge, beliefs, and professional contexts. Internationally there is research evidence that simply improving teachers' access to technology has not, in general, led to increased use or to movement towards more learner-centred teaching practices (Burrill, Allison, Breau, Kastberg, Leathem, & Sanchez, 2003; Cuban, Kirkpatrick, & Peck, 2001; Wallace, 2004). Windschitl and Sahl (2002) identified two factors that appear to be crucial to the ways in which teachers adopt (or resist) technology. First, teachers' use of technology is mediated by their beliefs about learners, about what counts as good teaching in their institutional culture, and about the role of technology in learning. Secondly, school structures – especially those related to the organisation of time and resources – often make it difficult for teachers to take up technology-related innovations. These are some of the issues that we are investigating in a 3-year study of technology-enriched teaching in secondary school mathematics. The overarching aim of the study is to generate models of successful innovation in integrating technology into secondary school mathematics teaching. This paper presents findings from the first year of the study, focusing on factors influencing teachers' use of technology.

Theorising Technology-Enriched Mathematics Teaching

The present study builds on a research program informed by sociocultural theories of learning involving teachers and students in secondary school mathematics classrooms (see 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 contextualised nature of learning in social situations, this perspective can offer rich insights into conditions affecting innovative use of technology in school mathematics. The theoretical framework for the study is based on an adaptation of Valsiner's (1997) zone theory to apply to interactions between teachers, students, technology, and the teaching-learning environment.

The zone framework extends Vygotsky's concept of the Zone of Proximal Development (ZPD) to incorporate the social setting and the goals and actions of participants. Valsiner (1997) describes two additional zones: the Zone of Free Movement (ZFM) and Zone of Promoted Action (ZPA). The ZFM represents constraints that structure the ways in which an individual accesses and interacts with elements of the environment. The ZPA comprises activities, objects, or areas in the environment in respect of which the individual's actions are promoted. For learning to be possible the ZPA must be consistent with the individual's possibilities for development (ZPD) and must promote actions that are feasible within a given ZFM. When we consider teachers' professional learning involving technology, the ZPD represents teachers' knowledge and beliefs about mathematics, mathematics teaching and learning, and the role of technology in mathematics education. 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, curriculum and assessment requirements, and organisational structures and cultures, whereas the ZPA represents formal and informal opportunities to learn, for example, from pre-service teacher education, professional development, and colleagues at school.

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; access to hardware and software; availability of appropriate teaching materials; technical support; organisational 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). 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 influence the extent to which teachers adopt innovative practices involving technology. In the present study, zone theory provides a framework for analysing these dynamic relationships.

Table 1
Factors Affecting Teachers' use of Technology

Valsiner's Zones	Elements of the Zones
Zone of Proximal Development	Mathematical knowledge Pedagogical content knowledge Skill/experience in working with technology General pedagogical beliefs
Zone of Free Movement	Students (perceived abilities, motivation, behaviour) Access to hardware, software, teaching materials Technical support Curriculum & assessment requirements Organisational structures & cultures
Zone of Promoted Action	Pre-service teacher education Professional development Informal interaction with teaching colleagues

Research Design and Methods

Participants in the first phase of the study are four secondary mathematics teachers who are acknowledged by their peers as effective and innovative users of technology. They include two beginning teachers who experienced a technology-rich pre-service program and two experienced teachers who have developed their technology-related expertise solely through professional development experiences or self-directed learning. The beginning teacher participants were recruited from a pool of recent Bachelor of Education (Secondary) graduates from The University of Queensland, whereas the experienced teacher participants were identified via professional networks, including mathematics teacher associations and contacts with schools participating in other university-based research projects. The teachers were selected to represent contrasting combinations of factors known to influence technology integration (as summarised in Table 1).

In the first year of the study the focus was on carrying out highly contextualised investigations of how and under what conditions the participating teachers integrate technology into their practice. There were three main sources of data. First, a semi-structured scoping interview invited the teachers to talk about their knowledge, beliefs, contexts, and professional learning experiences in relation to technology. A diagrammatic representation of the zone theory of teacher learning outlined in the previous section of the paper was used to structure the interviews. Each zone was represented by a circle, with its elements listed as shown in Table 1, and this information was printed on separate overhead transparencies for the three zones. As the zones themselves are abstractions, teachers “filled in” the details that were relevant to their own professional histories and contexts. They were also asked to superimpose the three transparencies to show the degree of overlap between the circles that matched their own circumstances and hence the relationships between their personal zones of influence. The abstract theoretical language for naming the Zones of Proximal Development, Free Movement, and Promoted Action was not used in these interviews. Instead the zones were labelled as Teacher Knowledge and Beliefs, Professional Contexts, and Sources of Assistance respectively.

Additional information about the teachers' general pedagogical beliefs was obtained via a Mathematical Beliefs Questionnaire (described in more detail in Goos & Bennison,

2002). The questionnaire consisted of 40 statements to which teachers responded using a Likert-type scale based on scores from 1 (Strongly Disagree) to 5 (Strongly Agree). The third source of data was lesson cycles comprising observation and video recording of at least three consecutive lessons in which technology was used to teach specific subject matter, together with teacher interviews at the beginning, middle, and end of each cycle. These interviews sought information about teachers' plans and rationales for the lessons and their reflections on the factors that influenced their teaching goals and methods.

The next section draws on the sources of data outlined above to present the contrasting profiles of two participating teachers, Susie (a beginning teacher) and Brian (an experienced teacher).

Teacher Profiles

Susie: A Beginning Teacher

Susie graduated from the university pre-service program at the end of 2003. She was in her third year of teaching at a co-educational independent school with an enrolment of around 600 students in Years 8 to 12. The student population is fairly homogeneous with respect to cultural and socio-economic background, with most students coming from white, Anglo-Australian, middle class families.

Sally's responses to the Mathematical Beliefs Questionnaire suggest that her beliefs were non-rule-based and student-centred (Tharp, Fitzsimons, & Ayers, 1997). For example, she expressed strong agreement with statements such as "In mathematics there are often several different ways to interpret something", and she disagreed that "Solving a mathematics problem usually involves finding a rule or formula that applies". Her beliefs about mathematics teaching and learning, as revealed through the questionnaire, were strongly supportive of cooperative group work, class discussions, and use of calculators, manipulatives and real life examples. Teachers who hold such inquiry-based views about mathematics are more likely to use calculators as a means of developing students' conceptual understanding than simply as tools for checking calculations or graphs done by hand (Simmt, 1997).

Susie's own experience of learning mathematics at school was very structured and content-based, but this is different from the approaches she tries to implement as a mathematics teacher. When interviewed she explained that in her classroom "we spend more time on discussing things as opposed to just teaching and practising it", and that for students "experiencing it is a whole lot more effective than being told it is so". Aged in her mid-20s, Susie feels she was born into the computer age and this contributes to her comfort with using technology in her teaching. Although her first real experience with graphics calculators was in her university pre-service course, she indicated that "the amount I learned about it [graphics calculators] during that year would be about 2% of what I know now".

Our observations of Susie's Year 10 mathematics class provide evidence of how she enacted her pedagogical beliefs. In one lesson cycle we observed, Susie introduced quadratic functions via a graphical approach involving real life situations and followed this with algebraic methods to assist in developing students' understanding. Lessons typically engaged students in one or two extended problems rather than a large number of practice exercises. For example, students worked on a task that asked them to investigate projectile

motion as a practical application of quadratic functions. They viewed a computer simulation in which the Sesame Street character Gonzo was shot from a cannon towards a bucket of water some distance away (<http://www.funny-games.biz/flying-gonzo.html>; see Figure 1). The simulation allowed students to vary the angle of projection and the cannon “voltage” (i.e., muzzle velocity) and observe the effects on the distance Gonzo travelled as they “aimed” him at the bucket of water. They were to use their graphics calculators to tabulate and plot data that would allow them to find a mathematical model for the relationship between this distance and the muzzle velocity. Algebraic methods were then to be used to determine the best cannon settings for Gonzo to hit a target at a given distance.

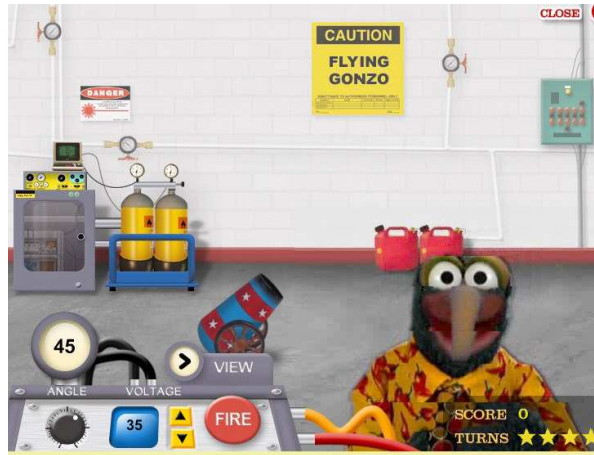


Figure 1. Flying Gonzo simulation.

The questionnaire, interview, and observation data “fill in” Susie’s Zone of Proximal Development with knowledge and beliefs about using technology to help students develop mathematical understanding by investigating real life situations and linking different representations of concepts. Elements of her Zone of Free Movement, or professional context, are also supportive of technology integration. Until recently the school’s mathematics department was led by a teacher well known for his expertise with technology, and his influence created a culture of technology innovation backed up by substantial resources. Students in Years 9-12 have their own graphics calculators (obtained through the school’s hire scheme), there are additional class sets of CAS calculators for senior classes, and data logging equipment compatible with the calculators is freely available. Computer software is also used for mathematics teaching; however, as is common in many secondary schools, computer laboratories have to be booked well in advance. Susie prefers to use graphics calculators so that students can access technology in class whenever they need it. The data projector installed in her classroom also makes it easy for her to display the calculator screen for viewing by the whole class.

Susie spoke enthusiastically of the support she had received from the school’s administration and her colleagues since joining the staff: “Anything I think of that I would really like to do [in using technology] is really strongly supported”. Nevertheless, as coordinator of the school’s junior secondary mathematics programs she has noticed that some of the recently appointed teaching staff are neutral and passive in their attitudes towards technology. Although they are willing to use technology in their teaching if shown how to, they rarely ask questions or engage in discussions about improving existing tasks

and technology-based teaching practices. These attitudes do not seem to be related to the number of years they have been teaching or to their previous experience in using technology.

The evidence outlined above suggests that there is a good fit between Susie's Zone of Proximal Development and her Zone of Free Movement, in that her professional environment affords teaching actions consistent with her pedagogical knowledge and beliefs about technology. Susie uses this ZPD/ZFM relationship as a filter for evaluating formal professional development experiences and deciding what to take from these experiences and use in her classroom. For example, she had first seen the Gonzo simulation at a mathematics teachers' conference and realised this was an application of quadratic functions she could exploit with her Year 10 class. Susie had attended many conferences and workshops in the 3 years since beginning her teaching career, but found that most of them were not helpful "for where I am". She explained: "because we use it [technology] so much already, to introduce something else we'd have to have a really strong basis for changing what's already here". Although Susie's exposure to technology in her mathematics pre-service course may have oriented her towards using technology in her teaching, the most useful professional learning experiences have involved working collaboratively with her mathematics teaching colleagues at school. The only real obstacle she faces is lack of time to develop more teaching resources and to become familiar with all of the technologies available to her. For Susie, the most helpful Zone of Promoted Action (sources of assistance) lies largely within her own school, and is thus almost indistinguishable from her Zone of Free Movement (professional context).

Brian: An Experienced Teacher

Brian has been teaching mathematics in government high schools for more than 20 years. For much of this time he was Head of the Mathematics Department in an outer suburban school serving a socio-economically disadvantaged community. In the late 1990s he recognised that the traditional classroom settings and teaching approaches the students were experiencing did not help them learn mathematics. He pioneered a change in philosophy that led to the adoption of a social constructivist pedagogy in all mathematics classes at the school. This new philosophy, expressed through problem solving situations and the use of technology, concrete materials and real life contexts, produced significant improvement in mathematics learning outcomes across all year levels. At the start of 2006 Brian moved to a new position as Head of Department in a different school, also situated in a low socio-economic area. Here he faces many challenges in introducing the mathematics staff to his teaching philosophy and obtaining sufficient technology resources to put his philosophy into practice.

Brian's espoused beliefs, as indicated in his responses to the Mathematics Beliefs Questionnaire, are consistent with the constructivist principles that guide his practice. For example, he expressed disagreement with statements such as "Doing lots of problems is the best way for students to learn mathematics", and he strongly agreed that "The role of the mathematics teacher is to provide students with activities that encourage them to wonder about and explore mathematics". When interviewed, he often emphasised that his reason for learning to use technology stemmed from his changed beliefs about how students learn mathematics.

When my philosophy changed, it became a question of – what can I put in front of my kids to allow them to access the concepts? So then it didn't really matter what it was, the outcome that I was after

was them accessing the concept. So it became obvious over time that technology was a way that many students do access concepts that they couldn't, wouldn't normally access.

Some of the lessons we observed dealt with solving trigonometric equations. Brian's method for teaching this topic exemplified his general philosophy in that he initially used a graphical approach to help students develop understanding of the central concepts so they might then see the need for analytical methods involving algebra. He justified this by saying:

The options are to give them heaps of algebra and watch them fail or try to get them to understand the concepts. If they're confident about what they're doing then I find the algebra's not such a task for them because there's a lot more meaning or reasoning behind it.

A vignette from a Year 11 lesson illustrates this approach. Brian used graphing technologies and probing questions to help students develop a general method for solving trigonometric equations, starting with a straightforward example, $2\sin x + \sqrt{3} = 0$ for $0 \leq x \leq 2\pi$. He emphasised the critical importance of attending to the domain, as this tells us how many solutions there are. Using his laptop computer and portable data projector, Brian launched the *Autograph* program and displayed the graph of $y = 2\sin x + \sqrt{3}$ shown in Figure 2.

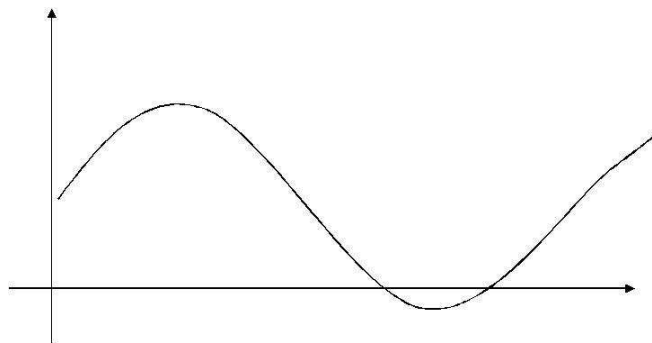


Figure 2. Graph of $y = 2\sin x + \sqrt{3}$.

The students also drew the graph using their graphics calculators, and observed that there are two roots. Brian then announced that they needed to “go into the algebra world”, and through careful questioning he led the class through the algebraic process of “unwrapping” the equation. Upon reaching the conclusion that $\sin x = -\frac{\sqrt{3}}{2}$, the students were reminded that they needed instantly to recognise the exact trigonometric ratios for certain angles, in this case 60° or $\frac{\pi}{3}$ radians. Brian explained that “the negative sign tells us a story too”, and he guided the students through sketching the unit circle and locating the relevant angles in the third and fourth quadrants as $\frac{4\pi}{3}$ and $\frac{5\pi}{3}$ respectively. The students then used the graphics calculator TRACE function to give meaning to the solutions by entering them as x -values and observing that the corresponding y -values were zero in both cases: in other words, they had found the points where the curve cut the x -axis.

Brian's knowledge and beliefs – his Zone of Proximal Development – were the driving force that led him to integrate technology into his inquiry-based approach to teaching

mathematics. When graphics calculators became available in the mid-1990s he attended several professional development workshops presented by teachers in other schools who had already developed some expertise in this area. More recently he won a state government scholarship to travel overseas and participate in conferences that introduced him to other types of technology resources. Apart from these instances Brian has rarely sought out formal professional development, preferring instead to “sit down and just work through it myself”. His Zone of Promoted Action, representing sources of assistance for his own learning about technology, is thus highly selective and focused on finding coherence with his personal knowledge and beliefs.

In the 17 years that Brian spent at his previous school he was able to fashion a Zone of Free Movement, or professional context, that gave him the human and physical resources he needed to teach innovatively with technology. However, when he arrived at his current school at the start of 2006 he found little in the way of mathematics teaching resources – “there was a lot of stuff here but it was just in cupboards and broken and not used, and not coherent, not in some coherent program”. Mathematics students in this school were not accustomed to technology, even though the use of computers or graphics calculators is mandated by the senior secondary mathematics syllabuses. At the start of the year there were no class sets of graphics calculators and only a few students could afford to buy their own. Because of timetabling and room allocation issues it was also difficult for mathematics classes to gain access to the school’s computer laboratories. Exacerbating the problems of limited access to technology resources was an organisational culture that Brian diplomatically described as “old fashioned”. Almost none of the mathematics teachers appeared interested in learning to use technology, and it appeared that an atmosphere of lethargy had pervaded the mathematics department for many years. Students demonstrated a similarly passive approach to learning mathematics, expecting that the teacher would “put the rule up and example up and set them up and away they go”. Brian responded to these challenges in several ways. First, he lobbied the newly appointed Principal for funds to buy software for the computer laboratories and a data projector for installation in his mathematics classroom. Secondly, he took advantage of the loan schemes operated by graphics calculator companies to borrow some class sets of calculators. He also used his influence as Head of Department to secure a limited number of timetable slots for senior mathematics classes to use the computer laboratories. Brian knows that the Principal is strongly supportive of his teaching philosophy and his plans for expanding the range of technology resources in the school.

Brian evaluates the adequacy of his present Zone of Free Movement, or professional context, by looking through the inquiry-based, technology-rich lens created by the relationship between his ZPD (knowledge and beliefs) and ZPA (previous professional learning). By the end of this first year at his new school, Brian identified his priorities for re-shaping the ZFM as continuing to advocate for the purchase of more technology resources and helping his staff become comfortable and confident in using these resources. He acknowledges that the main obstacles are lack of funds and a teaching culture that resists change.

Conclusion

The research reported in this paper is beginning to examine relationships between factors known to influence the ways in which teachers use technology to enrich secondary school mathematics learning. Our findings so far are consistent with results of other studies

of educational uses of technology in highlighting the significance of teachers' beliefs, their institutional cultures, and the organisation of time and resources in their schools (e.g., Windschitl & Sahl, 2002). Although access to technology is an important enabling factor, the profiles of Susie and Brian demonstrate that teachers in well resourced schools do not necessarily embrace technology (compared with Cuban, Kirkpatrick, & Peck, 2001), whereas teachers in poorly resourced schools can be very inventive in exploiting available resources to improve students' understanding of mathematical concepts.

The opportunities that teachers provide for technology-enriched student learning are affected by ways in which they interpret and analyse problems of practice. How do teachers justify and enact decisions about using technology in their classrooms? How do they negotiate potential contradictions between their own knowledge and beliefs about the role of technology in mathematics education and the knowledge and beliefs of their colleagues? How do they interpret aspects of their teaching environments that support or inhibit their use of technology? These questions, when framed within a sociocultural perspective, allow us to investigate systematically conditions affecting teachers' use of technology in mathematics classrooms through the application of Valsiner's (1997) zone theory – where the Zone of Proximal Development represents the possibilities for teacher learning shaped by their knowledge and beliefs, the Zone of Free Movement environmental constraints, and the Zone of Promoted Action the nature of specific activities that promote new pedagogical skills and understanding.

Both Susie and Brian held productive beliefs about mathematics and the role of technology in mathematics learning (ZPDs); however, they differed in the degree of fit between their respective ZPDs and ZFMs. For Susie, the Zone of Free Movement offered by her school was most important in allowing her to explore technology-enriched teaching approaches consistent with her knowledge and beliefs. It may be that the extent of overlap between the ZFM and the ZPD is critical in supporting beginning teachers in further developing the innovative practices they typically encounter in pre-service programs. On the other hand, Brian, as an experienced teacher and Head of Department, relied on his knowledge and beliefs about learning with technology to envision the kind of professional environment, or ZFM, he wanted to create in his new school. For him, the ZPD/ZFM mismatch was a powerful incentive to pursue his goal of technology-enriched mathematics teaching and learning. These tentative proposals will be tested as we continue to work with Susie and Brian, and the other participating teachers, throughout the remainder of the research study.

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