A Sociocultural Framework for Understanding Technology Integration in Secondary School Mathematics

Merrilyn Goos

This paper proposes a theoretical framework for analyzing relationships between factors influencing teachers' use of digital technologies in secondary mathematics classrooms. The framework adapts Valsiner's zone theory of child development to study teacher learning in terms of the interaction between teacher knowledge and beliefs, professional contexts and professional learning experiences. Use of the framework is illustrated by case studies of an early career teacher and an experienced teacher.

Keywords: Mathematics teacher development; Sociocultural theories; Technology

Un Marco Sociocultural para Comprender la Integración de la Tecnología en las Matemáticas Escolares de Secundaria

Este artículo propone un marco conceptual para analizar las relaciones entre los factores que afectan al uso que el profesor hace de las tecnologías digitales en el aula de matemáticas de secundaria. Este marco adapta la teoría de Valsiner sobre el desarrollo del niño para estudiar el aprendizaje del profesor en términos de la interacción entre el conocimiento y las creencias del profesor, los contextos y las experiencias profesionales de aprendizaje. La puesta en práctica de este marco conceptual se ilustra con estudios de caso de un profesor novel y un profesor experimentado.

Términos clave: Desarrollo profesional del profesor de matemáticas; Tecnología; Teorías socioculturales

The potential for digital technologies to transform mathematics learning and teaching has been widely recognized for some time. Research has demonstrated

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that effective use of mathematical software, spreadsheets, graphics and CAS calculators and data logging equipment enables fast, accurate computation, collection and analysis of real or simulated data, and investigation of links between numerical, symbolic, and graphical representations of mathematical concepts (see Hoyles, Lagrange, Son, & Sinclair, 2006, for a recent review of the field). However, integration of digital technologies into mathematics teaching and learning has proceeded more slowly than initially predicted (Cuban, Kirkpatrick, & Peck, 2001; Ruthven & Hennessy, 2002). Many studies have shown that access to technology resources, institutional support, and educational policies are insufficient conditions for ensuring effective integration of technology into teachers' everyday practice (Burrill, Allison, Breaux, Kastberg, Leatham, & Sánchez, 2003; Wallace, 2004; Windschitl & Sahl, 2002). These findings suggest that more sophisticated theoretical frameworks are needed to understand the teacher's role in technology-integrated learning environments and relationships between factors influencing teachers' use of digital technologies. The purpose of this paper is to propose such a framework and illustrate its use via analysis of sample data from secondary school mathematics classrooms. The data were collected in a three year study that aimed to understand how and why technology-related innovation works, or not, within different educational settings.

Theoretical Framework

The theoretical framework for the study is the product of an extended research program informed by sociocultural theories of learning involving teachers and students in secondary school mathematics classrooms (summarized in Goos, 2008). Sociocultural theories view learning as the product of interactions between 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.

The framework used in the present study adapts Valsiner's (1997) zone theory of child development in order to theorize teachers' learning (Goos, 2005a, 2005b). Valsiner extended Vygotsky's (1978) concept of the *zone of proximal development* (ZDP) to incorporate the social setting and the goals and actions of participants. He described two additional zones: the *zone of free movement* (ZFM) and the *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 engage with the individual's possibilities for development (ZPD) and promote actions that are believed to be feasible within a given ZFM. When we define these zones from the perspective of the teacher as learner, the ZPD represents a set of possibilities for teacher development influenced by their knowledge and beliefs about mathematics and mathematics teaching and learning. The ZFM suggests which teaching actions are allowed by constraints within the school environment, such as teachers' perceptions of students —abilities, motivation, behavior—, access to resources and teaching materials, curriculum and assessment requirements, and organizational structures and cultures. The ZPA represents teaching approaches that might be promoted by pre-service teacher education programs, professional development activities and informal interaction with colleagues at school. Table 1 presents the elements of Valsiner's zones for the case of teachers' use of technology.

Table 1
Factors Affecting Teachers' Use of Technology

Valsiner's zones	Elements of the zones
ZDP	Mathematical knowledge
	Pedagogical content knowledge
	Skill/experience in working with technology
	General pedagogical beliefs
ZFM	Students' perceived abilities, motivation, behavior
	Access to hardware, software, teaching materials
	Technical support
	Curriculum and assessment requirements
	Organizational structures and cultures
ZPA	Pre-service teacher education
	Professional development
	Informal interaction with teaching colleagues

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, organizational 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 analyzing these dynamic relationships.

RESEARCH DESIGN AND METHODS

Four secondary mathematics teachers participated in the study. They were selected to represent contrasting combinations of the factors known to influence technology integration, summarized in Table 1. They included two early career teachers who experienced a technology-rich pre-service program and two experienced teachers who developed their technology-related expertise solely through professional development experiences or self-directed learning. The early career teacher participants were recruited from a pool of recent teacher education graduates from The University of Queensland (Australia), while the experienced teacher participants were identified via professional networks, including mathematics teacher associations and contacts with schools participating in other university-based research projects.

There were three main sources of data. First, a semi-structured scoping interview invited the teachers to talk about their knowledge and beliefs, professional contexts and professional learning experiences in relation to technology. Additional information about the teachers' general pedagogical beliefs was obtained via a Mathematical Beliefs Questionnaire (Goos & Bennison, 2002) consisting 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 a series of lesson cycles —typically 4 cycles per year— comprising observation and video recording of at least 3 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. Data from these sources were categorized as representing elements of participants' ZPDs, ZFMs, and ZPAs, an analytical process that enabled exploration of how personal, contextual and instructional factors came together to shape the teachers' pedagogical practice in relation to use of technology.

The next section draws on the sources of data outlined above to illustrate use of the zone framework in comparing the cases of two teachers, Susie —early career teacher— and Brian —experienced teacher—.

SUSIE: AN EARLY CAREER TEACHER

Susie graduated from the university pre-service program at the end of 2003 and found a position teaching in an independent secondary school located in a large city. Most students in this school come from white, Anglo-Australian middle class families.

Susie's responses to the Mathematical Beliefs Questionnaire suggested that her beliefs were non-rule-based and student-centered (Tharp, Fitzsimmons, & 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". The beliefs about mathematics teaching and learning revealed through questionnaire responses were supportive of cooperative group work, class discussions, and use of calculators, manipulatives and real life examples.

Susie's own experience of learning mathematics at school was structured and content-based, but this was different from the approaches she tried 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 felt she was born into the computer age and this contributed 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". She 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".

Observations of Susie's Grade 10 mathematics class provided evidence of how she enacted her pedagogical beliefs. For example, in one lesson cycle 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.

The questionnaire, interview and observation data "fill in" Susie's ZDP with knowledge and beliefs about using technology to help students develop mathematical understanding by investigating real life situations and linking different representations of concepts. Likewise, the ZPA within the school explicitly promoted technology-enriched teaching and learning. Elements of her ZFM were also supportive of technology integration. The school's mathematics department had for many years cultivated a culture of technology innovation backed up by substantial resources. Students in Grade 9-12 had their own graphics calculators, there were additional class sets of CAS calculators for senior classes, and data logging equipment was freely available. Computer software was also used for mathematics teaching; however, computer laboratories had to be booked well in advance.

The evidence outlined above suggests that there was a good fit between Susie's ZPD and her ZFM, in that her professional environment afforded teaching actions consistent with her pedagogical knowledge and beliefs about technology. Susie used 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. She had attended many conferences and workshops 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 had involved working collaboratively with her mathematics teaching colleagues at school. The only real obstacle she faced was 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 ZPA lay largely within her own school, and was thus almost indistinguishable from her ZFM.

Brian: an Experienced Teacher

Brian had been teaching mathematics in government high schools for more than twenty 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 recognized 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 grade 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 faced 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, were consistent with the constructivist principles that guided 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 emphasized that his reason for learning to use technology stemmed from his changed beliefs about how students learn mathematics. For him, technology was a vehicle that allowed students to engage with concepts that they would not otherwise be able to access.

Observations and interviews from several lesson cycles revealed that Brian's preferred teaching approach exemplified his general philosophy in that he initially used graphical representations to help students develop understanding of concepts so they might then see the need for analytical methods involving algebra. He justified this by saying that developing an understanding of the concepts gives meaning to the algebra and students would then became more likely to persevere with algebraic methods.

Brian's knowledge and beliefs (ZPD) 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 professional development workshops presented by teachers who had already developed some expertise in this area. He later won a government scholarship to travel overseas and participate in conferences that introduced him to other types of technology resources. Apart from these instances Brian had rarely sought out formal professional development, preferring instead to "sit down and just work through it myself". His ZPA was thus highly selective and focused on finding coherence with his personal knowledge and beliefs.

In the seventeen years that Brian spent at his previous school he was able to fashion a ZFM 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". There were no class sets of graphics calculators and it was difficult for mathematics classes to gain access to the school's computer laboratories. Exacerbating this situation was an organizational culture that Brian diplomatically described as "old fashioned". Almost none of the mathematics teachers were 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, who was strongly supportive of his teaching philosophy and plans for expanding the range of technology resources in the school, for funds to buy software for the computer laboratories and a data projector for installation in his mathematics classroom. Secondly, he took advantage of loan schemes operated by graphics calculator companies to borrow class sets of calculators. He also used his influence as head of department to secure timetable slots for senior mathematics classes to use the computer laboratories.

Brian evaluated the adequacy of his present ZFM, 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—. He identified his priorities for re-shaping the ZFM in his new school as continuing to advocate for the purchase of more technology resources and helping his staff become comfortable and confident in using these resources. His main obstacles were lack of funds and a teaching culture that resisted change.

DISCUSSION

The research reported in this paper examined relationships between factors that influence ways in which teachers use digital technologies to enrich secondary school mathematics learning. While the findings are consistent with results of other studies of educational uses of technology in highlighting the significance of teachers' beliefs, their institutional cultures, and the organization of time and resources in their schools, the socioculturally oriented zone theory framework offers new insights into technology-related innovation. For example, although access to technology is an important enabling factor, the cases of Susie and Brian show that teachers in well resourced schools do not necessarily embrace technology while teachers in poorly resourced schools can be very inventive in exploiting available resources to improve students' understanding of mathematical concepts.

The knowledge and beliefs that Susie and Brian hold about the role of technology in mathematics learning are central in shaping their pedagogical practice, but more important are the relationships between their knowledge and beliefs (ZPDs), professional contexts (ZFMs) and professional learning experiences (ZPAs). It was significant that Susie and Brian differed in the degree of alignment between their respective ZPDs and ZFMs. For Susie, the ZFM offered by her school was important in allowing her to explore technology-enriched teaching approaches consistent with her knowledge and beliefs. It may be that this kind of alignment is critical in helping beginning teachers seek out professional learning opportunities consistent with the innovative practices they may have encountered 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 to envision the kind of professional environment he wanted to create in his school. For him, the ZPD/ZFM misalignment was a powerful incentive to pursue his goal of technology-enriched teaching and learning. These initial findings need to be tested with different teachers in a wider range of settings in order to further explicate the application of zone theory to teachers' technology related professional learning.

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Merrilyn Goos
The University of Queensland
m.goos@uq.edu.au