MERRILYN GOOS

A SOCIOCULTURAL ANALYSIS OF THE DEVELOPMENT OF PRE-SERVICE AND BEGINNING TEACHERS' PEDAGOGICAL IDENTITIES AS USERS OF TECHNOLOGY

ABSTRACT. This paper reports on a study that investigated the pedagogical practices and beliefs of pre-service and beginning teachers in integrating technology into the teaching of secondary school mathematics. A case study documents how one teacher's modes of working with technology changed over time and across different school contexts, and identifies relationships between a range of personal and contextual factors that influenced the development of his identity as a teacher. This analysis views teachers' learning as increasing participation in sociocultural practices, and uses Valsiner's concepts of the Zone of Proximal Development, Zone of Free Movement, and Zone of Promoted Action to offer a dynamic way of theorising teacher learning as identity formation.

KEY WORDS: pre-service teachers, beginning teachers, technology, secondary mathematics teaching, identity, sociocultural theories

Much of the existing research on the role of technology in mathematics education has been concerned with effects on curriculum content or student learning (Penglase & Arnold, 1996). Limited attention has been given to the relationship between technology use and issues of pedagogy, and, in particular, to the impact on teachers' professional learning in the context of specific classroom and school environments. This paper reports on aspects of a study that is designed to address this gap in current knowledge. The study is situated at the interface between pre-service education and initial professional experience of secondary school mathematics teachers, and investigates the pedagogical practices and beliefs of beginning teachers who have graduated from a technology enriched teacher education program. (''Technology'' in this study refers to graphics calculators, computer software applications, and use of the Internet as a resource and communication medium.) This research builds on earlier work which applied sociocultural perspectives on learning to develop models of technology enriched mathematics learning (Goos, Galbraith, Renshaw & Geiger, 2000, 2003), and models of mentoring in pre-service teacher education (Goos, 1999).

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One of the major themes in current debates on ways of improving education identifies the need for teachers to become more effective, confident and creative users of technology in their teaching (e.g., Web-Based Education Commission, 2000). Similarly, there is growing recognition that pre-service teacher education programs should integrate technology into their own curricula to ensure beginning teachers are adequately prepared (McCoy, 1999). Within mathematics teacher education, research studies have yielded descriptions of pre-service courses that help student teachers design lessons and teaching resources, using general tools such as spreadsheets, multimedia and the Internet, as well as mathematics-specific educational software such as dynamic geometry programs (e.g., Connell & Abramovich, 1999; Da Ponte, Oliveira & Varandas, 2002; Halpin & Kossegi, 1996; Kim, Sharp & Thompson, 1998). Despite the increasing use of graphics calculators in secondary school mathematics classrooms, there has been negligible research on the impact of this technology on pre-service mathematics teacher education. Nor has previous research looked systematically at how beginning teachers of secondary school mathematics justify and enact decisions about using graphics calculators, computers and the Internet, and how these decisions contribute to the development of their identities as teachers.

The following questions guided the research study described in this paper: (a) what modes of working with technology are adopted by pre-service and beginning teachers? (b) how do personal factors and contextual factors come together to shape the pedagogical identities of novice teachers? A case study of a novice teacher is presented to illustrate changes over time and across school contexts in the ways he used technology, and changes in the relationships between his teaching actions, beliefs, and the constraints and affordances of the professional environments in which he worked.

SOCIOCULTURAL PERSPECTIVES ON TEACHER LEARNING AND DEVELOPMENT

Learning to Teach

Although research on mathematics teacher education has grown rapidly in the past 10–20 years, influential voices have argued that teacher education is an under-theorised field of inquiry, lacking coherent conceptual frameworks that address the complexity of individuals acting in social situations (e.g., Cooney, 1994; Lerman, 2001). Research on

teacher socialisation, which attempts to explain how teachers acquire the beliefs, values and attitudes of their professional culture, is particularly relevant to the present study. Studies of teacher socialisation from a functionalist perspective typically identify influences such as the beliefs that students bring to the pre-service course from their own schooling, and the classroom practices they observe and experience as novice teachers (Brown & Borko, 1992). Such approaches view teachers as being passively moulded by external forces to fit the existing culture of schools – thus producing the common explanation for why beginning teachers are unable to implement innovative approaches (e.g., those involving use of educational technologies) that they may have experienced during their pre-service courses (Loughran, Mitchell, Neale & Toussaint, 2001). However, Lerman (2001) claims that the study of teacher beliefs, and of apparent mismatches between espoused and enacted beliefs, is often too static and decontextualised to describe adequately these (dis)connections between theory and practice. As an alternative, he points to the work of Vygotsky (1978) and followers in proposing that teachers' learning is better understood as increasing participation in sociocultural practices that develop their identities as teachers.

While recent research in this theoretical tradition has investigated school students' learning in classroom communities (e.g., Forman & Ansell, 2001; Goos, Galbraith & Renshaw, 1999; Renshaw & Brown, 1997), few studies have applied sociocultural theories to teacher learning, particularly in pre-service teacher education. Some of these have adopted a neo-Vygotskian approach, extending the well known concept of the Zone of Proximal Development (ZPD) to incorporate additionally the social setting and the goals and actions of the participants (e.g., Blanton, Westbrook & Carter, 2001; Goos, Evans & Galbraith, 1994). Vygotsky defined the ZPD as the distance between a child's independent problem solving capability and the higher level of performance that can be achieved under adult guidance or in collaboration with more advanced peers. In a teacher education context, the ZPD can be thought of as a symbolic space where the novice teacher's emerging skills are developing under the guidance of more experienced people. However, this gap between present and potential ability is not the only factor influencing teacher development and socialisation. For this reason, the present study draws on the theoretical framework elaborated by Valsiner (1997) to explain children's development in the context of their relationships with their physical environment and other human beings. In addition to the ZPD, Valsiner described two further zones to conceptualise the developing child: the Zone of Free

Movement (ZFM) and Zone of Promoted Action (ZPA). These three zones constitute a system that can account for the dynamic relationships between the contextual constraints and affordances of the teaching environment, the teaching actions specifically promoted, and the development of the novice teacher's pedagogical identity.

According to Valsiner (1997), the ZFM represents environmental constraints that limit freedom of action and thought. For pre-service or beginning teachers, elements of the ZFM might include:

- their students, whose perceived abilities and behaviours may constrain teaching actions;
- curriculum and assessment requirements, which influence choice of topics, teaching methods, and the time available to teach required content;
- resources, in the form of teaching materials, computers or calculators, or specially equipped rooms, whose availability has a bearing on teachers' planning decisions.

Although these elements clearly have an external existence, teachers may also construct personal ZFMs within which constraints – or affordances – exist as a result of their interpretation of the external environment.

While the ZFM suggests which teaching actions are *possible*, the ZPA represents the efforts of a teacher educator, supervising teacher, or more experienced teaching colleague to *promote* particular teaching skills or approaches. It is important that the ZPA be within the novice teacher's ZFM, and is also consistent with their ZPD (as depicted schematically in Figure 1) – that is, the actions promoted must be within the novice's reach if development of their identity as a teacher is to occur. Additionally, pre-service teachers develop under the influence of two ZPAs – one provided by their university program, the other by their supervising teacher(s) during the practicum – which do not necessarily coincide. Unlike functionalist approaches, this sociocultural model facilitates an analysis of teacher learning and socialisation that considers the person-in-practice, and examines how identities develop as involvement in practice increases (Lerman, 2001).

Teaching with Technology

Research on mathematics teachers' use of technology has identified a range of factors influencing uptake and implementation, including: skill and previous experience in using technology; time and opportunities to learn (pre-service education, guidance during practicum and beginning teaching, professional development); access to hardware

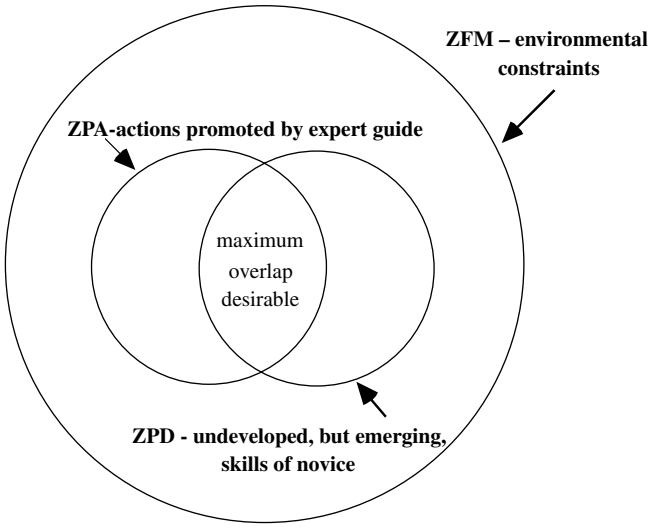

Figure 1. Relationships between the ZFM, ZPA and ZPD for student teachers.

(computers and calculators), software, and computer laboratories; availability of appropriate teaching materials; technical support; support from colleagues and school administration; curriculum and assessment requirements and how teachers interpret these for students perceived to have different mathematical abilities; knowledge of how to integrate technology into mathematics teaching; and beliefs about mathematics and how it is learned (Fine & Fleener, 1994; Forgasz & Prince, 2001; Manoucherhri, 1999; Norton & Cooper, 2001; Simmt, 1997; Simonsen & Dick, 1997). In terms of the concepts introduced in the previous section, these factors represent elements of a teacher's Zones of Proximal Development, Free Movement, and Promoted Action (as shown in Figure 2). However, previous research in this area has not necessarily considered possible relationships between the setting, actions and beliefs, and how these relationships might change over time or across different classroom or school contexts.

From a sociocultural perspective, technologies such as computers and graphics calculators can be viewed as cultural tools that not only re-organise cognitive processes but also transform classroom social practices. In an earlier study involving experienced mathematics teachers and their senior secondary school classes, my colleagues and I developed metaphors to describe how such technologies can provide a vehicle for incorporating new teaching roles (see Goos et al., 2000, 2003). Teachers can see technology as a *master* if their knowledge and competence are limited to a narrow range of operations, especially in

ZPD

- skill/experience in working with technology
- pedagogical knowledge (technology integration)
- general pedagogical beliefs

ZPA

- pre-service education
- practicum/beginning teaching experience
- professional development

ZFM

- access to hardware, software, and laboratories
- access to teaching materials
- support from colleagues (including technical support)
- curriculum & assessment requirements
- students (perceived abilities and behaviour)

Figure 2. Factors affecting technology usage.

situations where external pressures from education systems force implementation. Technology is a *servant* if it is used as a fast, reliable adjunct to pen and paper (e.g., as a tool for drawing graphs or performing numerical calculations), but does not change the nature of classroom activities. However, when teachers develop an affinity for technology as a *partner,* there is potential for students to achieve more power over their own learning by, for example, providing access to new kinds of tasks or new ways of approaching existing tasks. Technology becomes an *extension of self* when seamlessly incorporated into a teacher's pedagogical and mathematical repertoire, such as through the integration of a variety of technology resources into course planning and the everyday practices of the mathematics classroom. These four modes of working are not necessarily tied to the level of mathematics taught or to the kinds of technologies available, and teachers do not necessarily remain attached to a single mode of working with technology in the classroom (see Goos et al., 2003, for a classroom case study that illustrates multiple modes of working). Nevertheless, the categories elaborate increasingly sophisticated ways in which teachers may appropriate technology as a cultural tool, and also provide a means of tracing trajectories of professional growth as teachers construct new pedagogical identities.

THE STUDY

Context

The research discussed here is part of a four-year project that spans the transition from pre-service to beginning teaching of secondary school mathematics. In the research phase reported here, participants comprised a full cohort of Bachelor of Education (BEd) students ($n = 18$) enrolled in the mathematics curriculum studies class in the year 2000 at a university in the Australian State of Queensland.

The BEd is a pre-service program that prepares teachers for secondary schools. The program is available to undergraduates as a four-year dual degree or to graduates as a single degree taken in four semesters over eighteen months. Pre-service teachers in the dual degree program are typically school leavers who complete an initial three-year undergraduate degree with majors in two areas that provide the disciplinary knowledge for specialisation as teachers of these subjects in secondary school. (For example, in a Bachelor of Science degree, prospective secondary school teachers might major in mathematics and chemistry.) Students also begin their BEd studies while enrolled in this first degree by taking education courses that provide foundation knowledge of adolescent development, learning theories, sociological issues, and the nature of teachers' work in contemporary secondary schools. They finish the BEd in a fourth year, devoted solely to the study of practical and professional issues in education, and commonly referred to as the Professional Year. Twice during this year the pre-service teachers complete a seven week practicum in a secondary school.

Pre-service teachers in the graduate entry version of the BEd program are often mature age entrants who are changing careers, having already completed an undergraduate degree in areas such as Engineering, Computer Science, or Business Studies. The first year of the graduate entry BEd is identical to the fourth year (Professional Year) of the dual degree program. The remainder of the program comprises foundation education courses similar to those offered in the dual degree.

Pre-service mathematics teachers complete their curriculum studies as a single class group in a course that lasts for the duration of the Professional Year. The class meets twice weekly for three hour workshops during the 17 weeks of the year when the pre-service teachers are on campus (for the remaining 14 weeks of the year they are in schools completing the practicum). As the designer and teacher of this course, I aim to create a learning environment consistent with recent Australian and international curriculum reforms (e.g., Australian

Education Council, 1991; National Council of Teachers of Mathematics, 2000) in emphasising mathematical thinking, real world applications and collaborative inquiry. A significant feature of this learning environment is the regular and intensive use of graphics calculators, computer software (e.g., spreadsheet, graphing, and dynamic geometry applications) and Internet/multimedia applications, and exploration of the possibilities offered by these technologies for mathematics teaching.

Most pre-service mathematics teachers come to the course as quite competent users of the Internet and general purpose computer software (e.g., word processing, spreadsheets), having gained some experience with these technologies during previous university or school courses. Very few have been exposed in their own secondary schooling to graphics calculators and data logging peripherals, such as motion detectors and temperature probes. Graphics calculators became available to Australian mathematics teachers in the early to mid-1990s, and since that time Senior secondary school syllabuses (i.e., Grades 11 and 12) in each State and Territory have gradually moved towards making the use of these calculators compulsory in both teaching and assessment programs. In the State of Queensland, mathematics syllabuses have only since 2002 mandated graphics calculator and/or computer use.

One of the ways in which I emphasise integration of technology into mathematics education is through a low cost hiring scheme that provides each pre-service teacher with continuous personal access to a Texas Instruments TI-83 graphics calculator for the duration of the course (including the practicum). They bring their calculators to all classes so that we can use the technology spontaneously, as well as in workshops specifically planned for this purpose, thus modelling effective pedagogy while also circumventing some of the difficulties in gaining access to computer laboratories that need to be booked for classes some weeks in advance.

The course assessment program also incorporates technology. For example, one task requires pre-service teachers to work in pairs to design and present a computer or graphics calculator based activity that could be used in a secondary school mathematics classroom. Two full days are set aside for these Technology Seminar presentations so as to simulate a professional development conference and to develop the ethos of collaboration that this entails. I then encourage the pre-service teachers to contribute to the wider professional community by helping them to publish the resources they have produced and to present workshops at professional seminars and conferences. Thus, in

terms of the theoretical framework derived from Valsiner's zone concepts, this pre-service course offers a teaching repertoire, or ZPA, that emphasises technology as a pedagogical resource.

Research Design and Methodology

The research design for this phase of the study had two components: (a) a cohort study of practicum experiences in technology integration experienced by the group as a whole; and (b) individual case studies of selected pre-service teachers that allowed snapshots of experience to be captured at two developmental stages, during the second block of practice teaching (August 2000) and towards the end of the first year of full-time teaching (November 2001). For the cohort study, all participants completed a Technology Survey of their practicum schools to record information on the availability and accessibility of computers and graphics calculators, and the frequency and mode of technology use during lessons they observed or taught, and in assessment tasks. Survey findings were discussed and compared in an audio-taped whole class interview when the pre-service teachers returned from the first block of practice teaching.

Four pre-service teachers were also selected for individual case studies in a range of different practicum school settings including government and independent schools in capital city and regional locations. I was hopeful that some diversity in school settings would be maintained for these participants after they graduated from the pre-service program and entered their first year of teaching; however this was an aspect of the research design that was impossible to predict at the time they were selected for the case studies. Table I summarises some characteristics of the schools where the case study participants completed their practicum sessions and their first year of teaching.

Case study participants were chosen because of the interest and skills they demonstrated in using computer software, graphics calculators and Internet resources in mathematics teaching. Because these pre-service teachers were eager to use technology, it was anticipated that their experiences in schools could provide worthwhile insights into how they dealt with obstacles or took advantage of opportunities in incorporating technology into their pedagogical repertoire. Case study participants were visited in their schools during the second practicum session and again after graduation as described above (except for Allan, who deferred seeking employment until the start of the following year). The school visits involved lesson observations, collection of

TABLE I
Characteristics of Case Study Participants' Schools

School characteristics	Case study participants (BEd program structure)			
	Geoff (Dual degree)	Sandra (Dual degree)	Lewis[a] (Dual degree)	Allan[b] (Graduate entry)
School type				
Pre-service	Government	Catholic	Government	Government
First year	Independent	Catholic	Government	n/a
School size (n)				
Pre-service	Small (430)	Large (1160)	Large (1040)	Small (430)
First year	Large (1100)	Small (400)	Large (1040)	n/a
Location				
Pre-service	Capital city	Capital city	Regional city	Capital city
First year	Capital city	Rural	Regional city	n/a

[a]Lewis began his first year of teaching in the same school in which he completed his practicum sessions.
[b]Allan graduated in mid-2001 and did not seek employment until the start of the following year; thus no second school visit was possible within the time frame of this study.

teaching materials and audio-taped interviews. Observations focused on teachers' modes of working with technology, using the metaphors of technology as master, servant, partner and extension of self, as described in a previous section of this paper. These metaphors acted as analytical categories that were used to organise and select evidence from field notes and teaching materials.

Two types of interviews were used to gain insights into factors shaping the formation of beginning teachers' professional identities. A Post-lesson Interview was carried out immediately after the observed lesson to assist teachers to reflect on pedagogical beliefs that influenced lesson goals and methods (as in Goos, 1999). Key questions in this semi-structured interview included the following:

- How do you think the lesson went?
- What were you hoping for the students to gain during this lesson?
- How/why did you arrive at this lesson goal? Why was this goal important? Were there any constraints or restrictions that influenced your goal?
- What teaching strategies did you use in this lesson to achieve your goal? Why did you decide on this approach? Were there any constraints or restrictions that influenced your choice of teaching approach?
- What immediate learning goals do you have for these students? What are your own goals for your development as a teacher?

A more general Technology Interview was also conducted to discover what opportunities participants may have had to use technology in mathematics lessons, their perceptions of constraints and opportunities affecting their use of technology, and their views on the influence of technology on mathematics curricula, learning, teaching and assessment. They were then asked to reflect on how confident and competent they felt in using technology in their teaching, and to identify areas in which they felt the greatest need for their own development in educational uses of technology.

All interviews were fully transcribed to facilitate analysis. Participants' responses to the interview questions were categorised as representing elements of their Zones of Proximal Development, Free Movement, and Promoted Action. As the zones themselves are abstractions, this analytical process focused on the particular circumstances under which zones were "filled in" with specific people, actions, places, and meanings.

This paper draws on the Technology Surveys, lesson observations, teaching materials, and interviews from the three case study participants from whom a complete data set was collected. A detailed analysis of one of these cases (Geoff) is presented to compare modes of working with technology over time and in different school settings, and to examine how changing relationships between the Zones of Proximal Development, Free Movement, and Promoted Action generated an environment for development of his identity as a teacher. This is followed by a brief summary of issues arising from analysis of the other two case studies.

Geoff graduated from the dual degree program with Bachelor of Arts (majoring in English and Mathematics) and Bachelor of Education degrees. I have chosen to present his case in some detail because he was the only one of the case study participants whose practicum and first year teaching experiences took place in significantly contrasting school environments, in terms of not only school type (government versus independent) and size (small versus large), but also the type of students he taught (low academic motivation/low socioeconomic status versus high academic motivation/high socioeconomic status) and his access to human and material resources supporting technology usage (poor versus good). Thus Geoff's case has been selected for theoretical reasons as it illustrates a particular kind of transition from pre-service to beginning teaching that permits analysis of significant changes in relationships with his physical environment (ZFM) and with other people (ZPA).

CASE STUDY OF PRE-SERVICE TEACHING

School Context

Geoff's practicum placement was in a co-educational government school in a low socio-economic status suburb of Brisbane, the State capital in which the university is located. The student population of 430 was ethnically diverse, with many students having recently arrived in Australia on refugee visas. Geoff was assigned to teach a Grade 10 Mathematics class (students aged 14–15 years) and a Grade 11 Numeracy class (students aged 15–16 years), the latter being the focus for observation and interview for the purposes of this study. Geoff explained that Numeracy was a low status, school based subject – "a nothing subject" that was neither accredited for recording on students' school leaving certificate nor accepted as a pre-requisite for further study in technical or vocational education. He noted that most students at this school thought of the Numeracy class as "a repository for misbehaving students", or for "druggos and dropouts". Yet Geoff was determined to challenge this perception by designing interesting activities that demonstrated how mathematics is used in real life situations. He commented that students' negative attitudes towards mathematics often come from "ingrained mathematical practices from Grades 1 to Grades 10 and Grades 12 that maths is some kind of remote thing. It's some kind of island that you visit and then you go back to your other lessons. You go back to your English lessons, swim out to maths, swim back to English". Geoff's goals for these students were concerned as much with building their self-respect and encouraging their engagement with their futures beyond school as with teaching mathematical content.

Snapshot of Practice

In the Numeracy lesson I observed, towards the end of the second block practicum, Geoff adapted an activity he had seen presented by two of his fellow pre-service teachers for the Technology Seminar assessment task earlier in the BEd Professional Year. The aim of the activity was to compare the cost and quality of two brands of chocolate chip cookies and decide which offered the best value for money. The students did this by carefully eating the cookies and counting the number of chocolate chips they could see as they took each small bite. The data could be summarised by finding the mean and median number of chocolate chips per cookie for each brand. A comparison of

brand quality could also be facilitated by using graphics calculators to draw box and whisker plots; however, as neither the school nor the Numeracy students owned graphics calculators, Geoff limited his version of the activity to having the students collect the data and calculate the means. Although Geoff described these students as usually being restless, uninterested, and difficult to keep on task, in this lesson their interest was captured by the prospect of enjoying an edible treat and they willingly, if noisily, engaged with the task, even asking questions that demonstrated to Geoff that they had some understanding that mathematics could be used to make sense of their everyday experiences. It was largely because of these student questions that Geoff thought the lesson had gone well, as he commented afterwards that "I can't tell you how happy I was that those people actually asked mathematical questions in class". This was in contrast to other, less successful, Numeracy lessons where students were less responsive, an experience Geoff described as being "like you're talking to an empty classroom, it's like you're trying to do things with rocks".

Geoff was an experienced computer user and spoke enthusiastically of his desire to integrate technology into his teaching, mentioning in particular the potential for technology to speed up calculations and "make things easier to understand because ... it's dynamic and not static". Nevertheless, after almost fourteen weeks of practice teaching, he had only had one opportunity to use technology in a mathematics lesson. This involved creating an Internet research activity for the Numeracy class that required them to use the Australian Bureau of Statistics website to produce a fact sheet on a health issue of their choice, such as alcohol or drug use. The fact sheet was to include a graph (e.g., Excel chart) that compared how this health issue affected different age groups, genders, or countries.

Constraints and Affordances in Teaching with Technology

At the time of this study, mathematics syllabuses in Queensland only encouraged, rather than mandated, the use of technologies such as computers and graphics calculators. Geoff's school was poorly resourced in this area, with no graphics calculators and only two computer laboratories that were almost continually booked out to Information Technology or Business Studies classes. Geoff felt that teachers in this school did not regard mathematics as a subject worthy of computer use. In the Technology Survey of his school, Geoff noted that no technology was used in any of the mathematics classes he had observed. He commented that the mathematics staff seemed to be generally unin-

terested in learning about technology and unconvinced of its benefits for mathematics learning, especially for low status mathematics subjects such as Numeracy. Each of these elements of Geoff's ZFM could be interpreted as constraints that might limit his teaching actions.

Furthermore, while Geoff's supervising teacher allowed him to take the initiative in planning and delivering Numeracy lessons, the ZPA offered by this supervision excluded technology, and thus was not well matched with the ZPD that defined the direction in which Geoff hoped his teaching would develop. (This is represented in Figure 3 by the lack of overlap between Geoff's ZPD and the school ZPA.) In this respect, neither did the supervisory ZPA coincide with that offered by the pre-service course, which emphasised integrating technology into mathematics teaching and learning. (In Figure 3 we see that the university ZPA is distinct from the school ZPA and thus largely outside the school's ZFM. That is, the technology-related actions promoted by the university course do not appear to be feasible in Geoff's practice teaching environment, despite his desire to use technology as indicated by the overlap between his ZPD and the university ZPA.) The relationship between the three conceptual zones depicted in Figure 3 does not appear to predict a trajectory of development involving technology usage.

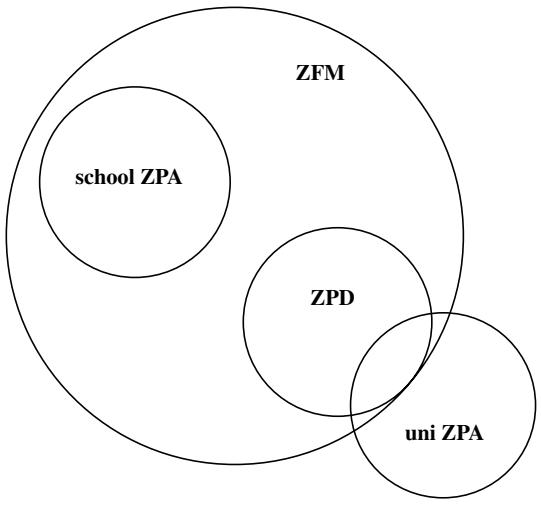

Figure 3. Apparent relationships between Geoff's ZFM, ZPD, and ZPAs as a pre-service teacher.

Yet, despite these many hindrances, Geoff did design and implement a technology-based activity with his Numeracy class. In theoretical terms, he achieved this by re-interpreting aspects of his teaching environment, or ZFM, so as to *afford* at least some use of technology in ways that were consistent with the actions promoted by the university course. (This can be represented as an expansion of the ZFM to include the university ZPA, as shown in Figure 4.) First, he found there was little direct opposition towards introducing technology activities into the Numeracy class "because basically it's a class that nobody cares about". Also, he was aware of the general expectation within the practicum environment that student teachers would be adventurous in trying out new ideas, including those involving technology. (These actions permitted by the school ZPA now overlap with his ZPD, as shown in Figure 4.) Thus he was able to construct his practice as a pre-service teacher of low status mathematics students to develop further his emerging identity as a teacher for whom technology was an important pedagogical resource. However, at this stage, his teaching experience had included technology only in the role of a *servant*, to facilitate his students' information searching or production of accurate graphs.

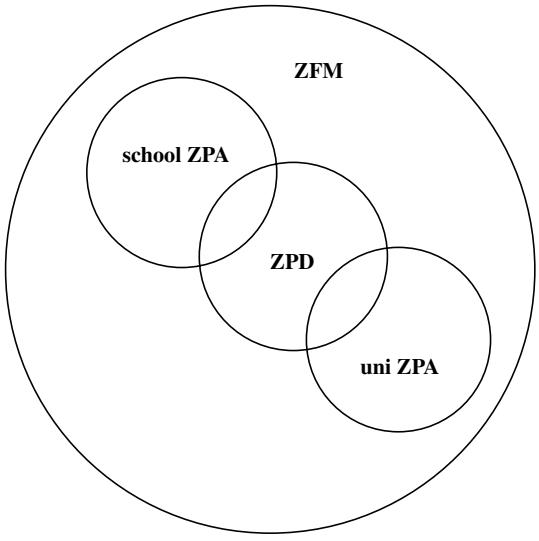

Figure 4. Actual relationships between Geoff's ZFM, ZPD, and ZPAs as a pre-service teacher.

CASE STUDY: BEGINNING TEACHING

School Context

After graduation Geoff found employment at an academically oriented, independent girls' school with an enrolment of over 1000 students. The school has been established for over 100 years, and is located in a prime inner-city position. Students come mainly from upper middle class professional families, although scholarships offering full or half remission of tuition fees allow the academically talented children of less wealthy parents to attend the school. Geoff taught two senior secondary Mathematics classes, and also a Grade 8 class which I observed during a visit to the school near the end of his first year of teaching. (Grade 8 is the first year of secondary school; students are aged 12–13 years.) Although he was now in a very different professional environment from that experienced during his practicum, he maintained a commitment to the general goals he had expressed during the previous year, which he now reiterated as "getting the students to mature socially as well as academically".

Snapshot of Practice

In the previous lesson with the Grade 8 Mathematics class, Geoff had presented a graphing task that introduced students to the use of a motion detector in conjunction with a graphics calculator and view screen. This was the first time he had used these technologies with the Grade 8 class. The aim of the activity was for individuals to walk towards, or away from, the motion detector so as to match a pre-selected distance-time graph displayed on the calculator screen. Students conducted "walking contests" within their working groups, followed by a hotly contested "walk off" to determine the most accurate walker in the class. In discussing his rationale for this task, Geoff referred to the motivational benefits of having students physically involved in creating a graph of their own movement, the capacity for the technology to provide instant feedback to walkers so they could adjust their movement to better match the target graph, and the thoughtful interaction this facilitated between walkers and observers. He also pointed out the mathematical skills required to make an accurate match, such as scale reading, estimation, and knowledge of the meaning of slope.

At the beginning of the following (observed) lesson, Geoff reinforced these skills through a simulated graph matching activity, where a student volunteer "walked" the graph he had drawn on the whiteboard

as he moved his pen along the *x*-axis to represent the passage of time. In these lessons, he worked with technology as a *partner* that entered into the mathematical practices and collective memory of the classroom.

Constraints and Affordances in Teaching with Technology

The teaching environment within this school contrasts significantly with that experienced by Geoff during his practicum. As a newly graduated teacher, Geoff came to an apparently well resourced school with an explicit policy of emphasising technology use across all subject areas. All students from Grade 9 upwards were required to buy their own graphics calculator, and peripherals such as data loggers and view screens were readily available, as was school based professional development on the use of this equipment. Thus Geoff's ZFM appeared to afford teaching actions consistent with his beliefs about mathematics learning and teaching, as expressed in his justification for the graph matching activity. Furthermore, the ZPA offered by his teaching colleagues seemed to be consistent with both his development as a teacher (i.e., his ZPD) and the ZPA offered by his pre-service course, in that new graduates teaching at the school were actively supported in integrating technology into their practice. For example, as part of a move to include at least one technology-based assessment task per semester in every mathematics subject, at each year level, Geoff had designed a Grade 8 assignment on tessellations that involved students in web-based research, and using Microsoft Paint to create their own tessellations. As Geoff commented, "I have basically been given a brief to go ahead and ... try whatever I like, and do anything I like with technology". It would appear, then, that development of Geoff's pedagogical identity was afforded by the apparent relationships between his ZPD, ZFM, and ZPAs, illustrated in Figure 5.

Nevertheless, other, less obvious, elements of the school context constrained Geoff's practice in more subtle ways. For example, some classrooms were designated as technology centres and specially fitted with equipment such as computers, Internet and intranet connections and data projectors. However, the timetabling of classes into these special rooms was neither transparent nor flexible, with the result that some teachers and classes regularly allocated these rooms rarely used the available technology while others who wished to use these resources were unable to gain access. Apart from these classrooms, the school had only three dedicated computer laboratories which, according to Geoff, were almost always fully booked to non-mathematics

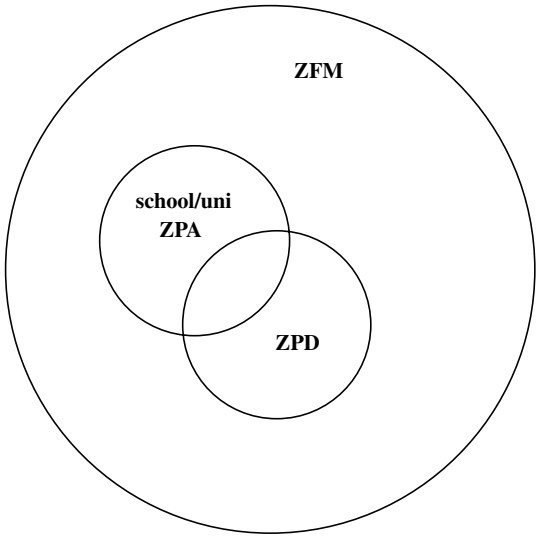

Figure 5. Apparent relationships between Geoff's ZFM, ZPD, and ZPAs as a beginning teacher.

classes. These components of Geoff's ZFM tended to undermine his goal of infusing technology as a *partner* in assessment tasks as well as learning activities. In particular, his original plan to include oral presentations and computer demonstrations of the tessellation assignment mentioned above had to be modified when it proved impossible to arrange access to the specially equipped technology centres for all Grade 8 classes. All of these factors led to a contraction of Geoff's ZFM in ways that tended to exclude some of the pedagogical practices promoted by his pre-service course (see Figure 6).

At the end of his first year of teaching, Geoff was looking for further challenges in exploring what technology could do:

> I know what things the graphics calculator can do, and I have a pretty good knowledge of Excel, but really now that teachers know how to include this in their pedagogy, I suppose the emphasis would be now on getting the most out of it. Instead of just knowing what to do, how to really take this technology and explore it to its fullest extent and use all of the resources that [it] has to offer instead of taking bits and pieces that might be good. I suppose unlocking the potential ... of what this technology has to offer. [...] I have been sort of nominated by the Maths faculty to go out and delve into the world of Microsoft PowerPoint because I believe there is a lot more to PowerPoint than what meets the eye in terms of the teaching tool ... how you can use animations to explain mathematical concepts, how you can integrate the whole thing into [your teaching] and have it available on line for every teacher. PowerPoint is not just something

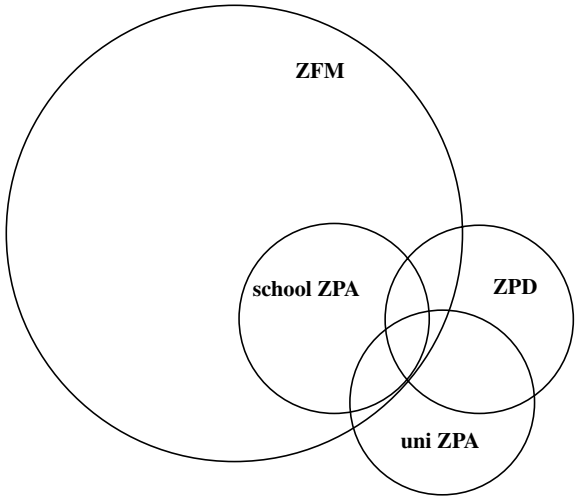

Figure 6. Actual relationships between Geoff's ZFM, ZPD, and ZPAs as a beginning teacher.

you can put bullet points up on the screen with ... There is [no in-service] for teaching with PowerPoint because everyone just takes it for granted as a display [tool]. I might get myself a book or two on it and maybe try to do an in-service of my own and try to get my head around how useful it can be.

Here he maps out the landscape of his ZPD in a way that suggests he is moving towards using technology as an *extension of self*, and anticipates seeking out – or perhaps even generating – a ZPA that will further develop his identity as a teacher.

ISSUES FROM OTHER CASE STUDIES

Analysis of the other two cases for which a complete set of data was available revealed different ZPD/ZPA/ZFM configurations, even though there were some similarities in the participants' pre-service experiences. For example, both Sandra and Lewis completed practice teaching in large schools where there was only one class set of graphics calculators (restricted ZFM) and minimal support for their use of technology from other teachers (school ZPA did not match university ZPA). Both attempted to enact their pedagogical beliefs (ZPD) by teaching graphics calculator lessons to students who had never used them before; yet Sandra encountered strong resistance from students while Lewis's class responded enthusiastically. The reason for this difference seemed to stem from the students' previous experiences of

mathematics lessons: Lewis's students were already accustomed to the investigative approach he adopted in using the calculators, while Sandra's students had only experienced a very transmissive approach with their other teachers where the focus was on covering the content that would be assessed via standard pen and paper tests. These cases illustrate contrasting ways in which ZFM elements (access to technology, assessment requirements, students' experiences and expectations) can come together to constitute problems of practice that help to shape teachers' identities.

Sandra and Lewis had quite different transitions into beginning teaching: Sandra moved from the city to a smaller rural school that was better resourced with respect to graphics calculators but lacking in experienced teachers who knew how to use them effectively, while Lewis accepted a teaching position in the same school where he completed the practicum. Thus neither was in a professional environment that provided models of teaching with technology (i.e. their ZPA was limited). However, both demonstrated the same kind of individual agency as Geoff in developing their pedagogical identities as users of technology: Sandra by drawing on knowledge gained during her university program to capitalize on the extensive technology resources available within her school, and Lewis by attending professional development workshops offered by the local mathematics teacher association.

DISCUSSION AND CONCLUSION

This study has examined how beginning teachers of secondary school mathematics integrate technologies such as computers, graphics calculators and the internet into their practice. Rather than analysing teacher beliefs about technology and its role in mathematics education, and possible connections (or conflicts) between beliefs, the teaching repertoire offered by the pre-service course and practicum experiences, the study applied sociocultural perspectives on learning to focus on beginning teachers' identities and the settings in which those can change (as proposed by Lerman, 2001). Case studies of teachers' early professional experiences demonstrated how they developed that part of their pedagogical identities concerned with technology use, by negotiating changing relationships between their teaching environments, actions, and beliefs.

The principal theoretical framework for the study used Valsiner's (1997) three zone concepts to depict case study participants' development as teachers. The analysis began by "filling in" the ZPD, ZFM,

and ZPA with specific factors that affected their use of technology in the pre-service and beginning teaching environments. This process is summarised for Geoff's case in Figure 7, which identifies potentially positive and negative influences on the direction of his development. Clearly, however, it is not possible to explain Geoff's appropriation of technology as being determined solely by the material and human resources available to him in technology-poor and technology-rich school settings – Figure 7's simple categorisation of factors that were present or absent is unable to predict what actually happened. Nor is it meaningful to describe his initial socialisation into teaching practice in functionalist terms that separate theory from practice. Instead, the sociocultural analysis presented here revealed how Geoff was an active agent in his own development as a teacher, not simply reproducing the practices he observed nor yielding to environmental constraints, but instead re-interpreting these social conditions in the light of his own professional goals and beliefs. Reading this as interactions between

Factors affecting technology usage	**PT**	**BT**
ZPD		
• skill/experience in working with technology	✓	✓
• pedagogical knowledge (technology integration)	✓	✓
• general pedagogical beliefs	✓	✓
ZPA		
• pre-service education	✓	✓
• practicum/beginning teaching experience	×	✓
• professional development	n/a	✓
ZFM		
• access to hardware, software, and laboratories	×	✓
• access to teaching materials	×	✓
• support from colleagues (including technical support)	×	✓
• curriculum & assessment requirements	×	✓
• students (perceived abilities and behaviour)	×	✓

Figure 7. Potentially positive and negative influences of Geoff's development as a pre-service teacher (PT) and beginning teacher (BT).

Zones of Proximal Development, Free Movement, and Promoted Action provides a dynamic way of theorising teacher learning as identity formation. The three zone framework can also be applied more broadly to analyse teaching actions as they are used to orchestrate the learning of students, thus providing a coherent theoretical approach for interpreting classroom learning episodes (see Galbraith & Goos, 2003).

In contrast with research that suggests beginning teachers are unlikely to implement innovative approaches promoted by their pre-service courses, this study documented different ways in which Geoff was able to work with technology in quite different school settings. In addition, it appears that this aspect of his teaching identity developed to the extent that his modes of working became more varied and sophisticated over time, as indicated by the metaphors of technology being used first as *servant*, then later as a *partner* and *extension of self*. Thus, these categories appear useful not only for describing different models of teaching and learning with technology, but also for anticipating a trajectory of development. In this regard, there is potential for technologically knowledgeable beginning teachers to act as catalysts for technology integration in schools, as Geoff's experience in his first year of teaching demonstrates. This observation raises interesting questions for further research on how novice teachers might develop their pedagogical identities by sharing their technology-related expertise with more experienced colleagues.

While only one case study has been elaborated in detail here, together they suggest issues that need to be addressed in applying the three zone framework to research in teacher education. First, longitudinal research involving more that the two snapshots captured in the present study is required for a more extensive investigation of identity formation over time and across contexts. This would also allow the theoretical framework proposed here to be tested in a variety of circumstances, representing many different configurations of Zones of Proximal Development, Free Movement, and Promoted Action and also different configurations of the elements that make up each zone. Second, as case study participants were selected because they were keen to use technology, further research should focus on pre-service teachers who are not convinced that technology benefits students' learning to determine whether the framework can account for teacher resistance in different types of professional environments (e.g., a well resourced versus poorly resourced school, with supportive versus unsupportive colleagues). Finally, although this study has presented evidence of the explanatory power of the zone concepts, more work is needed to determine

whether the framework can predict trajectories of development for beginning teachers as their circumstances change.

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