Glimpses of Generative Practice: Constructing Pre-service Teachers' Learning in Partnership

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In this paper we describe a program to enhance pre-service teachers' mathematical and pedagogical knowledge through a partnership with middle years teachers and learners in a primary school. We wanted to investigate how pre-service teachers' experience of teaching mathematics could enhance both their knowledge of mathematics and the development of generative practices. The findings have inspired us to develop similar partnerships with other primary schools.

Southwell, White and Klein (2004), in their review of Australasian research titled "Learning to teach mathematics", challenge mathematics educators and researchers to investigate "ways of being a learner, pre-service teacher and teacher of mathematics," that may illuminate "something more to the innovative and generative teacher" (2004, p. 210). In this paper we report on a collaborative project with teachers at a primary school and a cohort of our pre-service education students who trialled an innovative way of constructing pre-service teachers' learning of mathematics and mathematics pedagogy. Over a number of years the Victoria University has been developing partnerships with schools that enabled pre-service teachers to inquire into teaching practice through their experience of teaching and curriculum projects in schools (Cherednichenko, Davies, Kruger & O'Rourke, 2001). As a result, our assessment tasks in the mathematics curriculum and pedagogy subjects have become much more focussed on pre-service teachers' experiences in schools but this had not yet happened in the mathematics content subject. What we sought to do in this project was to construct a partnership experience for pre-service teachers that would facilitate their inquiry into both their mathematical and pedagogical knowledge. Teachers at a local primary school were seeking new ways to engage their grade 5 and 6 students with mathematics that would enhance their appreciation and knowledge of mathematics. A conversation between the teachers at the school and the university staff resulted in the idea of working together to connect the learning of school children and pre-service teachers.

Background to the Study

Mathematical knowledge is axiomatic to teaching mathematics well (AAMT, 2002), yet we know that pre-service teachers have weaknesses in skills and conceptual understandings that are central to the primary curriculum (Mewborn, 2001; Perry, Southwell & Howard, 2000; Southwell, White & Klein, 2004). While these weaknesses embrace all fields of knowledge in mathematics, recent studies of pre-service teachers' knowledge in Australasia have focussed on number sense, geometry, statistics and probability (Southwell, et al, 2000). Our experience of teaching mathematics to pre-service teachers is that many have difficulty with fractions, decimals, ratio, area and volume. These weaknesses are similar to those identified in the Middle Years Numeracy Research project (Siemon, Virgona & Cornielle, 2001) which included: explaining and justifying mathematical thinking; reading, manipulating and using common fractions, decimals, ratio, proportion and formulae; thinking multiplicatively; generalising simple patterns and interpreting results in context. However, when pre-service teachers know the facts and

algorithms of primary level mathematics they are not necessarily able to provide conceptual explanations or make connections and generalization (Mewborn, 2001). Moreover, knowing the mathematics does not mean that you will be able to teach mathematics in ways that give agency to the learners as constructors of their mathematical understanding (Kaminski, 2003; Klein, 2004; Mewborn, 2001, Prestage & Perks, 2000; Lins, 2004).

Prestage and Perks (2000) developed a model to distinguish between 'learner-knowledge' (or procedural knowledge) and 'teacher-knowledge', which they argued involved multiple, fluid and complex understandings of mathematics. They identified three phases of teacher-knowledge: professional traditions, practical wisdom and deliberate reflection. They found that only one teacher in their study of pre-service and practicing teachers (N=8) was at the stage of deliberate reflection, that is, "a deliberate standing back in order to rethink and plan for teaching." Rather their participants' responses showed the powerful influence of their experience as learners with the discourse of mathematics and of mathematics curricula. Practical wisdom was evident when, for example, teachers described the way that they adjusted their explanations or the time spent on particular content. They argued that deliberate reflection enables teachers "to challenge 'learner-knowledge', by identifying redundancy, adapting to new contexts such as technology and integrating new topics."

The notion of practical wisdom used by Prestage and Perks may be too simplistic since Mousely and Herbert (2002) showed that pre-service teachers in their second year of education study had already developed similar views about quality mathematics teaching to those of experienced teachers. Still it is difficult for a pre-service teacher to be a generative teacher of mathematics, that is, one who takes responsibility for the creation and generation of his or her own knowledge (Carpenter, et al, 2004). This is not only because they don't have experience of this in their own schooling, but also because teacher education practices, even those that use a social-constructivist approach, may unwittingly support transmission of knowledge, especially through assessment procedures (Klein, 2004). Klein (2004) argued that the agency needed to transform mathematical pedagogy

> requires that pre-service teachers recognize the productive (constitutive) power of the process of pedagogic interactions, that they act on this recognition to structure learning opportunities … to authorize and celebrate the voices and sense-making of those they teach (p. 38).

The work of Kaminski (2003) and Lins (2004) illustrate the way that the discourse of the mathematics classroom may operate to facilitate inquiry. Klein (2004) concluded that there were many obstacles to overcome. These included the pre-service teachers' lack of mathematical knowledge, the unwillingness of school based teacher educators to facilitate innovative practices and the assessment processes in teacher education.

In this study a partnership with a primary school enabled us to work collaboratively to address these concerns and work towards the development of the innovative and generative mathematics teacher. We were interested in developing the pre-service teachers' mathematical and pedagogical knowledge in a school based setting and using the university setting for reflection on practice and mathematical knowledge. In the following sections we describe and evaluate the partnership.

The Partnership

The partnership that is the focus of this paper was negotiated with a local primary school for a group of third year students in a P-12 pre-service education program. There

were 14 university students who took part in this partnership project during one semester in 2004. These students were in their first year of education studies, but were enrolled in an accelerated program, since they all gained entry to the course on the basis of completion (or near completion) of an under-graduate degree.

The principles of Victoria University partnerships with schools involve a commitment to improving school students' learning, engagement with school issues and needs through collaborative projects, and the generation of theory from reflection on practice by pre-service teachers. The teacher education program for the group of third-year students involved the study of four university subjects along with pre-service teaching in schools. As part of their program they worked as pre-service teachers on Mondays for six weeks at Hilltop Primary School. The four subjects were Mathematics and Numeracy; Numeracy and Mathematics Curriculum; Science, Technology and Numeracy Curriculum; and Inclusive Curriculum. Contact time at university was reduced from three to two hours per subject per week. In this paper we focus in particular on their work as pre-service teachers at Hilltop Primary School and the Mathematics and Numeracy subject, though evidence of pre-service teachers' learning is corroborated through other aspects of program and tasks that the pre-service teachers completed.

At Hilltop Primary School university staff met with the curriculum coordinator and teachers. We agreed upon the aims and together planned the program. There were two parts to the program: a series of mathematics lessons and seven integrated curriculum projects for the Grade 5/6 students. In the series of mathematics lessons the teachers wanted to address the middle years numeracy 'hot spots' (Siemon et al, 2001) and together we selected five tasks that would focus on fractions, decimals, multiplicative thinking, word problems and algebra. A brief outline of these tasks is included in Table 1.

Over six weeks the pre-service teachers worked five per class in three Grade 5/6 classrooms. Within the class each pre-service teacher worked with five or six students following a task rotation model. Each lesson began with a 'tuning in' activity and concluded with the sharing activity in the whole class setting. Classroom teachers facilitated the tuning in activity in the first week and the share time each week. Over the period most of the pre-service teachers also planned a tuning in activity for their group that was relevant to the particular topic and task for the week. Both the students and the pre-service teachers had to record an explanation of the task and what had been learnt in a learning journal. During these activities we incorporated the thinking tools being used in the school. The classroom teachers normally took a passive role during the small group tasks, responding to occasional questions from pre-service teachers or students, though on a few occasions the classroom teacher took a group of students for an absent pre-service teacher. One of us worked with one group of Grade 5/6 students; the other roamed the three classrooms and observed pre-service teachers for four of these weeks.

Seeking to explore science, technology and numeracy through an integrated curriculum inquiry, seven projects were selected by the pre-service teachers on the basis a survey of Grade 5/6 students' interests. These included projects that contained a lot of mathematical applications and investigations such as the Orrery group who designed and built a model of the solar system and the Mini-golf group who designed and built a mini-golf hole to others with a stronger focus on technology or science. The pre-service teachers conducted these projects over six weeks with the aim of ending with a final product that could be presented to all students in the final week.

Table 1
Grade 5/6 numeracy tasks for each 'hot spot'

Numeracy 'hot spot'	Task
Fractions	Fraction strips: An open-ended task. Students made fraction strips, found equivalent fractions and then found fractions that were less than two-thirds.
Decimals	Five cards (Beesey et al., 2001): An open-ended task in which students compared and ordered decimals using digits depicted on playing cards.
Multiplicative thinking	Arrays: An open-ended task in which students made arrays with concrete materials for given numbers, for example, 56, and generated number sentences for the array.
Worded problems	Tree Diagrams[1]: Three combinations problems and one permutation problem that required students to interpret the context and develop a strategy for finding all the possible combinations.
Algebra – problem solving	Eric the Sheep (Maths300, Curriculum Corporation): A problem solving task involving generalising simple number patterns and the development of pre-algebra skills.

The university program included a debriefing session held at the end of each school day. These were used to reflect on experiences and explore issues. Some time was also devoted to sharing and planning the mathematics lessons during the Numeracy and Mathematics Curriculum class. The Mathematics and Numeracy class focussed more explicitly on mathematics content and skills. It included the third-year students and a group of 16 first-year students. These sessions were designed to model social-constructivist practices. They ran as workshops involving a variety of open-ended and problem solving tasks related to the key areas of primary mathematics curriculum (number, space, measurement, chance and data, and reasoning). Working in small groups, the third-year pre-service teachers introduced the Grade 5/6 'hot spot' tasks to their peers. Pre-service teachers also revised routine procedures and shared alternate methods and procedures for routine and non-routine problems. Concept maps were used to summarise the concepts and skills explored in the sessions. For this subject, the pre-service teachers were required to keep a journal of their learning and to construct a concept map of the mathematics for one of the tasks. Some students also drew on their Hilltop Primary School experience for a second assignment based on a problem-solving task or online learning object (Maths300 and The Learning Federation resources). Two other assessment tasks were involved: one being the satisfactory completion of a mathematics and numeracy skills test, the other a quantitative analysis of the pre-service teachers' use of numeracy in their daily life.

Data Collection

Multiple sources of data were collected during this partnership: the university staff and students kept descriptive and reflective journals; the pre-service teachers, the primary

[1] The teachers used this title for the task and they thought that tree diagrams were an efficient method for solving these problems, though this was not the strategy adopted by primary students and pre-service teachers.

teachers, the university staff and primary school children, completed an evaluation questionnaire; primary students wrote letters to pre-service teachers; and a video-tape of the final presentation day at which primary teachers and students gave speeches was made. University staff and pre-service teachers compiled these data into a partnership project report for the school. In addition, samples of pre-service teachers' work were gathered including selected extracts from pre-service teachers' journals, selections of concept maps, copies of the mathematics resource assignments and records of descriptive feedback for assessment tasks. After the completion of the program and the assessment of tertiary students a commentary was written for each sample of pre-service teacher work (Western Melbourne Roundtable, 1997). The following questions guided the writing of these commentaries: What evidence is there of 'teacher-knowledge' in these samples? What kind of mathematical knowledge is evident: procedural, connected or multiple, fluid and complex? What evidence is there of professional traditions, practical wisdom and deliberate reflection? What evidence is there of a social-constructivist approach to learning and teaching of mathematics?

Findings and Discussion

The partnership provided the tertiary students with the opportunity to revisit and relearn some mathematics concepts during the program as well as to learn about teaching mathematics. It was clear from the speeches and letters of the Grade 5/6 students at the end of the project, that they appreciated the opportunity to work in small groups, the support with their mathematics learning, and also enjoyed the new learning relationships.

Initially the pre-service teachers were apprehensive about their mathematics knowledge and skills, and some were very anxious about being 'thrown in the deep end' in the first week. This was clearly a weakness in our planning; they felt ill prepared and we should have devoted at least one week to preparing for the numeracy 'hot spot' task. This experience revealed our confusion over an agreed goal of tertiary students' learning along with the grade 5/6 students. The pre-service teachers were immediately positioned as teachers in the small group and so felt a responsibility of needing to know everything. Moreover the primary teachers took a more passive role in this first lesson than expected by the university lecturers. However the opportunity to debrief at the end of the day, discuss the tasks and prepare for their next lesson in their subjects at university each week enabled them to become more comfortable with their role and the mathematics of the tasks.

The pre-service teachers' learning about mathematics was demonstrated during the debriefing sessions at Hilltop Primary School, in the university classes, in their journals and in their planning for the integrated learning activities each week. Analysis of the concept maps constructed by the pre-service teachers at the end of the project showed that they more often used this device to brainstorm concepts and skills related to the task, than make deliberate grouping and connection of concepts and skills. There was a strong indication of procedural knowledge only in some concept maps. One pre-service teacher represented a series of pathways or learning trajectories in their concept map that may indicate the development of some practical wisdom, however the map does not document a connected network of knowledge about fractions.

The interactions with children and the children's explanations of concepts and thinking were illuminating for a number of pre-service teachers. Not only did they learn what some students are capable of doing, the pre-service teachers reported new mathematical ideas introduced by the children. For example Linda recorded the explanation of place value provided by one student to the group when working on the decimal task. The relationship

made between decimal place value and division of whole numbers by multiples of ten as explained by the primary student was a new insight for her. She valued this insight for her own understanding and for the other students in the group.

The structure of the program enabled the third year pre-service teachers to get to know the Grade 5/6 children very well and for them to be able to take this into account when planning and preparing for the next session and task. As the program progressed this enabled some insightful discussion about teaching strategies and catering for individual student needs, indicative of the development of practical wisdom and even glimpses of generative practice. Owen commented on the personal connections that the students made with the scenarios in the word problems and he explained that this personal connection "drove" the whole activity. Making a personal connection between the problem context and the students was a consistent theme in his reflective writing. When evaluating the use of the Heads and Legs problem (Maths300) with a group of reluctant learners in year 7, he emphasised the need to know more about the students so that the problem could be reworded to make connections with the students' cultural background. The pre-service teachers would have been able to test out their theories of teaching and learning mathematics if we had included a week in the program for the pre-service teachers to prepare and teach a mathematics task for the children that they had come to know over the five weeks.

Two cases are presented here to show pre-service teachers at different phases of teachers' subject knowledge (Prestage & Perks, 2000). Mathematically, David is one of the most confident and competent pre-service teachers in the group. He recorded the highest score on the skills test and was comfortable explaining an algebraic representation of the solution of the Eric the Sheep problem. In his diary entry about the fractions strips task he reported on the effectiveness of using concrete materials to visualise fraction concepts. He also learned that misconceptions could occur when the size of one whole is not the same for the fraction strips made by the students. He draws distinctions between students as "better" or "slower" and is embarrassed when one student reminds him about the meaning of an improper fraction. This extract illustrated that the task enabled the pre-service teacher to begin to develop some practical wisdom, however, his reflections on student interactions indicated a valuing of procedural knowledge and the professional tradition of the transmission of knowledge. In his report on Eric the Sheep he did not fully appreciate the power of productive interactions between students. He clearly explained the procedures using concrete materials that the students used as a group to solve the problem and was surprised that one girl was able to compute a solution very quickly mentally and explain the idea of a multiple to the rest of the group. He argued that the students in his group had developed a "deeper knowledge of the meaning of multiples and especially multiples of three." With this assessment of the students it was surprising then that he recommended that the groups needed to be re-organised by skill level. He thought that the students were intimidated by the skills of one particular student in the group and that there would be more value in the students helping each other through the task rather than having one bright student explain the short-cut to the rest of the group. So here we see that he has rejected the idea that telling in mathematics is sufficient for learning. What is not clear though, is how he imagined that the students would develop knowledge of multiples without the social interaction with the "lead girl".

Six students in the group reflected on the productive power of the interactions between students. Nerida was one such pre-service teacher. She was one of the least confident about her mathematical knowledge and skills. She recorded a low score for the skills test at the

end of the semester and completed a supplementary test in order to pass the subject. In her account of the problem-solving lesson, Eric the Sheep, the pre-service teacher valued the discussion among the students in the small group and recorded examples of the questions that they posed each other to show how they sought explanation and justification and posed further problems:

> How do you think we should set up the counters? Should we use the same colour counter? Why are we making Eric a different colour? Let's read the task again and work through it together. What do we do next? Why did you do that? Why? What's next? How should we correct our work to check if we got the answer correct? Are we doing this right Miss? What else can we do? What happens if we try to add more counters and more Erics? Let's work this out together.

She also recorded the mental computation method that she asked one student to explain to the rest of the group. Elsewhere in the course, when giving a class presentation on good questions, she showed that she valued the use of non-routine problems for engaging children in mathematical thinking. The authority that this pre-service teacher, and others like her, gave to the sense-making of students' questions and explanations illustrates an openness in regard to her own learning and support for a constructive approach to student learning.

A number of factors appeared to contribute to such beginnings of generative practice for these pre-service teachers. The primary teachers wanted to develop innovative curriculum with the university and they gave legitimacy to the use of problem solving and open-ended tasks and negotiated integrated curriculum projects. Two different learning contexts were provided during the school experience: open-ended and problem solving tasks in mathematics lessons and the purposeful mathematical inquiries imbedded in the planning and teaching of the integrated curriculum projects. The use of the 'hot spot' tasks in the university classroom setting provided some ownership of the tertiary mathematics program by the pre-service teachers. The pre-service teachers' assessment tasks provided opportunities for pre-service teachers to demonstrate learner knowledge, practical wisdom and deliberate reflection. And finally, the common teaching and learning inquiry as constructed in the partnership with the school enabled the pre-service teachers to compare and contrast their experiences with familiar tasks and with children whom they all had come to know. This aspect of the partnership contributed to a community of inquiry with common objectives and joint responsibility for the learning of the primary children.

We observed that pre-service teachers' mathematical and pedagogical knowledge does not necessarily flow from complex knowledge of mathematics to deliberate reflection, rather pre-service teachers may develop their knowledge of mathematics in conjunction with their practical experience of teaching and use of deliberate reflection (Lins, 2004). The openness that these pre-service teachers showed toward primary students' explanation of their thinking and the use of some deliberate reflective practices suggests that some may adopt generative practices. We have learned that it is important for mathematical learning, practical knowledge and deliberate reflection to be connected in our university and school based course program and assessment of pre-service teachers. This partnership has given us some indication of what is possible when school based teacher educators are willing to develop innovative practices. We are building on the positive outcomes of this project at Hilltop Primary School by developing further connections between the content, learning and assessment processes of the university subjects and the school based work. We are also negotiating similar partnerships with other schools. We think that "teacher knowledge" (Prestage & Perks, 2000) can be enhanced through collaboration among university staff and students and school based teacher educators.

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