CGI Down Under

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Mathematics education reforms in numeracy focus on children's thinking and problem solving strategies. Cognitively Guided Instruction (CGI), developed by researchers at the University of Wisconsin, provides a model for both mathematics pedagogy and the professional development of teachers. In the same way that children's learning of mathematics in the classroom builds on their previous understanding, the activities of CGI workshops are deigned to build on the previous understanding of the participant teachers. This paper discusses the challenges and changes to participants, both teachers and teacher educators, of a CGI-based professional development numeracy programme.

Currently there is a worldwide focus on numeracy and associated intervention and professional development programmes. The reforms required to successfully improve numeracy are ambitious and it is widely accepted that changes in pedagogical practice will require a great deal of learning on the part of teachers, the vast majority of whom were taught, and learned to teach, within a traditional transmission paradigm (Ball & Bass, 2000a; Bobis, 2000; Stipek, Givvin, Salmon, & MacGyvers, 2001). The necessity to provide effective professional development to practising teachers is recognised as crucial (Department of Education, Training and Youth Affairs, 2000; Ministry of Education, 2001).

The kind of learning that is identified in mathematics reform professional development programmes has been described as "transformative, that is, as requiring wholesale changes in deeply held beliefs, knowledge, and habits of practice" (Stein, Smith, & Silver, 1999, p.238). However, how best to challenge teachers' existing practice and beliefs remains problematic: Is it more effective to influence teachers' beliefs and knowledge (with a resultant change in practice), or is it best to influence practice (with a resultant change in beliefs), or is a more integrated approach needed to ensure self-sustaining, generative changes in the teaching of mathematics?

> Self-sustaining, generative change does not involve acquiring a set of procedures to implement with fidelity; rather it frequently entails teachers making changes in their basic epistemological perspective, their knowledge of what it means to learn, as well as their conceptions of classroom practice. (Franke, Carpenter, Fennema, Ansell & Behrend, 1998, p. 67)

A concern for self-sustaining, generative change shifts the focus of professional development from the factors that initiate change to principles that make it possible for teachers to continue to learn and grow.

Cognitively Guided Instruction (CGI), a professional development programme developed by researchers at the University of Wisconsin, is designed to challenge teachers' beliefs about children's learning and classroom practices. CGI is a philosophy of teaching and learning school mathematics that focuses on children's thinking within a problem-solving context. The teacher guides children to use more effective strategies and more complex mathematical representations through a process of problem solving and reflective classroom discourse about mathematical thinking.

Unlike some other professional development programmes, CGI is not an instructional programme in the sense that teachers are provided with a ready-made script or set of resources. The CGI professional development programme aims to provide teachers with knowledge, derived from research, about the development of children's mathematical thinking and to let the teachers decide how best to make use of that knowledge in the context of their own teaching practice (Carpenter, Fennema, Franke, Levi & Empson, 1999). However, these unique classrooms develop common components: Children's problem solving strategies are the focus of instruction; children communicate to their teachers and peers how they solved the problems, reconciling the multiplicities of solutions; and teachers use their understandings of children's problem-solving strategies to plan their instruction, thus students' ideas contribute substantially to the enacted curriculum.

This paper reports on the implementation of a CGI-based professional development numeracy programme[1] (following our attendance at a University of Wisconsin CGI summer school) involving teachers from three low-decile[2] schools. Additionally, we describe some of the challenges to professional development from our perspective as teacher educators.

CGI Professional Development Implementation

Thirteen teachers of junior classes (Years 1-4) from three low-decile schools were involved in a CGI-based professional development programme with a specific focus on numeracy. The programme was initiated at the request of the Principals rather than out of particular interests of the teachers. Despite the teachers' limited input at the initial design stage the majority appeared enthusiastic and freely acknowledged that professional development in mathematics was a priority area.

The professional development programme used workshops and classroom-based teacher inquiry to help teachers understand children's mathematical thinking in the domain of number. The workshops focused teachers' attention on the research-based knowledge related to the development of children's mathematical thinking in addition/subtraction, multiplication/division, multidigit computation and place value. Additional sessions briefly discussed fractions, beginning algebra and geometry.

The initial focus was on organised, principled knowledge about basic numerical word problems, including what might make one problem more or less difficult than another. This leads to a connection between the problems and the strategies that children use to solve them. The strategies build within problems, in terms of mathematical sophistication, and classes of strategies exist across problems (e.g., direct modelling and counting strategies can be used with increasing sophistication for joining or separating problems). Strategies can be discussed in terms of what the strategy would look like for a specific problem, or in terms of how it can be applied to a range of problems involving all four operations, place value, or fractions. The theme that ties together the analysis of students' mathematical thinking is that young children intuitively solve word problems by modelling the action and relationship described in them. The development of this theme was used to examine how children developed basic concepts of addition, subtraction, multiplication and division, and

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[2] Schools in New Zealand are classified by decile ratings (1-10) representing the socio-economic status of the school community.

how they can construct concepts of place value and multidigit computational procedures based on their intuitive mathematical knowledge.

In working with the teachers, we attempted to build on their existing knowledge about children's mathematical thinking that they have acquired through their classroom experiences. Teachers viewed videos of children solving problems as a stimulus to discussion of children's strategies and shared their own students' solutions to assigned problems like the ones seen in the videos. We consistently engaged the teachers in tasks that (a) helped them think about how their students would solve particular problems, (b) encouraged them to discuss their thoughts so we could understand their thinking, and (c) helped them organise their own thinking about the development of children's thinking.

The workshops provided one avenue of teacher learning. However, another major source of learning for teachers was through interactions with their students. It was hoped that as teachers listened to their students' thinking, they would learn more about possible problems to pose, strategies to expect, and relationships that exist between problems and strategies (Chambers & Hankes, 1994). Their knowledge of the problem types and range of strategies for each problem helped teachers understand why some problems were more or less difficult for children and assisted teachers to interpret the mathematical understanding of their students.

As their new knowledge was connected with their existing knowledge through inquiry practice, the teachers continued to elaborate and develop problem/strategy frameworks of children's mathematical thinking in subsequent workshops. The arrangement whereby all teachers from the junior school of each of the three schools participated in the programme created opportunities for teachers to work with colleagues within their school and across their year level among schools. As facilitators, we provided on-going support with visits to the schools between each workshop session. Because support was matched to participants' requests, it varied among schools and for individual teachers within each school. Support included observing in the teachers' classrooms, discussing the children's thinking, planning activities together, assessing children, and providing demonstration lessons. Overall, it was envisaged that this inquiry framework would create an environment supportive of self-sustaining and generative change for teachers.

Challenging Beliefs and Practices

Overseas research studies of teacher change from CGI professional development suggests that focusing on frameworks of children's mathematical thinking provides opportunities for teachers to change either in beliefs or classroom practices or both (Fennema, Carpenter, Franke, Levi, Jacobs, & Empson, 1996; Franke, Fennema, & Carpenter, 1998). Our informal evaluations, based on teacher self-evaluations, classroom observations and teacher interviews, also found teachers changed to varying degrees in both beliefs and practices.

Teachers' beliefs about the types of problems that children could solve and the range of strategies children use to solve them were challenged. The examination of students' thinking through video exemplars, before formal instruction occurred, allowed teachers to reformulate their beliefs about children's learning and the role of intuitive, informal knowledge. Their expectations of what and when students can 'cope' with basic arithmetic, previously determined by the prescribed curriculum level, were frequently challenged. Moreover, when the teachers listened to their students' strategies they expressed surprise; not only by what strategies students could already use, but also, that the children's actions/strategies matched what they had learnt about in the workshops. For example, several of the teachers reported examples of Year 1 children clearly being able to work with numbers greater than 20 and successfully solving multiplication problems and division problems. Teachers also reported surprise and delight when they were able to clearly discern children who could solve Join/Separate Result Unknown problems but could not solve Change Unknown problems (problem types) and distinguish those children who needed to directly model from those who could used more advanced counting strategies.

Examples of the unexpected appeared to stimulate many of the teachers to continue to listen to their students and to create opportunities for students to share their strategies with the teacher and their peers. There was an increased awareness that students could invent strategies, and that there were multiple ways of solving what had been initially regarded as closed type problems.

As the teachers listened to students' strategies they were challenged to think about the relationship between their own emerging knowledge of children's strategies and their classroom practices. Teachers were observed to change their *role* during mathematics teaching: they made a conscious effort to encourage students to articulate their strategies and explain their thinking to their peers, rather than demonstrate ready-made procedures. Increasingly, teachers experimented with posing more challenging problems and encouraged students to freely select from a range of manipulative material to explore and explain their solution strategies. The teachers became increasingly aware of the importance of wait time (or think time), often sharing with other teachers in the group examples of how children were able to solve problems, previously thought to be 'too hard' when given encouragement to persist or freedom to think at their own pace.

Just as children's learning of mathematics in the classroom builds on their previous understanding, we also tried to build on teachers' knowledge and experiences. Within the broad aim of encouraging teachers to think about children's mathematical thinking, teachers also needed to reflect on which pedagogical practices would enable them to effectively engage their students in problem solving¾how could they encourage children to discuss their strategies and create a classroom climate in which students strategies were valued and openly shared? When a teacher asked about classroom management, we often asked the teacher what he or she thought, encouraging the teacher to relate his or her question to the students' mathematical thinking. Specifically, we resisted directing the ways in which teachers 'should' implement their teaching practice stressing that there is not one 'right' way of implementing CGI. The intent of CGI is not to cajole teachers to adopt a particular set of teaching behaviours; rather, CGI aims to provide a framework so teachers can think about their students' understandings of mathematics and then make instructional decisions based on the underlying principles (Carpenter, Fennema, & Franke, 1996; Carpenter, 1997).

This approach was not initially appreciated by all teachers¾it appeared that some teachers had entered the professional development experience with an expectation that they would be told how to implement an already developed and successful approach to mathematics instruction. They later appreciated that we valued their experience and grew more confident to tackle the issues themselves using inputs from colleagues, classroom experimentation and facilitators. As the programme progressed several teachers openly admitted that to have us, as facilitators, supply ready-made ‘recipes’ would provide as much, or as little, ownership of the solution as would the presentation of standard algorithms to their students. Within the workshops and classroom visits teachers were encouraged to share concerns; these issues relating to classroom management and instructional strategies were constantly revisited and revised by the teachers themselves throughout the programme. This process of co-reflection encouraged a strong sense of professional ownership, increased teacher confidence, avoided problems of authority from facilitators by valuing teacher knowledge, and enabled us as facilitators to assess progress and plan further activities. This strategy was a deliberate attempt to model behaviour in much the same way as teachers’ encourage children’s sharing of mathematical strategies; the intention was that it would serve as a pedagogical model.

Within the group of teachers, a few teachers were only partly successful in adapting classroom practices. For example, one teacher using word problems based on the frameworks (with some expectation of the strategies the children might use), was observed to encourage children to solve and explain problem solutions in a variety of ways¾ a practice modelled in several of the CGI video excerpts. However, her reflective feedback with the facilitator related to her success with the teaching strategies, children’s use of equipment and sharing of solutions, rather than the substance of the children’s thinking. The purpose of sharing was unclear and was not used to create an opportunity to understand the children’s thinking. It appears that although she realised that children could solve problems in a variety of ways she had only a tentative understanding of the children’s knowledge. It is possible that the teacher’s pedagogical content knowledge was insufficiently developed to listen to the “multiple voices” of the classroom (D’Ambrosio, 2000); specifically the effective teacher needs to integrate the voice of the discipline¾ this includes the ways of thinking, the strategies, the understanding of the content¾ with the voice of the learner, the ways in which the learn makes sense of an idea. In not searching for the specifics of the children’s thinking the teacher had limited the opportunities to develop her understanding about the role of children’s thinking, and about how mathematical ideas are connected to each other in conceptual ways. While this teacher continued to experiment with new teaching strategies trials were restricted to specific days and small groups¾ for the majority of the time her mathematics classroom practice remained unchanged.

Franke, Fennema and Carpenter’s (1997) case-study research suggests that while changing practice might help teachers initially engage in transforming their teaching, teachers also need to experience *changes in beliefs* in order to make changes in classroom practice at the higher levels: “continuing to change practice, without changes in beliefs, may not engage the teachers in self-generated, self-sustaining changes that enable teachers to create opportunities in the classroom that reflect the needs and understanding of their students” (p. 277). Other researchers have also noticed that teachers can “talk the change” while implementing it marginally, especially those teachers whose focus remains on teaching rather than children’s learning (Bliss, Askew, & Macrae, 1996).

Challenges for Teacher Educators

In thinking about the professional development of teachers, we, the teacher educators, need to reach the level of practical inquiry that we expect effective teachers to engage in. Stein, Smith and Silver (1999) note that although much has been written about the magnitude of the shift that teachers will have to make, little is known about the changes that are required of professional developers as they make their practice more responsive to the demands of the current reform era. Franke and colleagues (1998) argue that, "we need to understand what teachers are capable of and refocus our goals for teacher development in light of this understanding" (p. 79).

If we are concerned with self-sustaining, generative change, our professional development programmes must include more effective ways to foster the kind of stance that we see illustrated in those teachers that made changes in both beliefs and practices based on their personal inquiry with their students. In order for change to become self-sustaining, programmes must engage teachers in practices that have built-in support for the changes; otherwise, the changes are likely to erode over time. For example, when the teachers began to encourage students to discuss alternative solution approaches, observations of students generating a variety of productive, interesting and unexpected solutions reinforced the practice of allowing students to generate and discuss solutions to problems. Within the timeframe of our professional development programme, specific problems occurred with those teachers who exhibited difficulties with understanding and interpreting students' strategies or who were unable to establish communicative norms to support the "centrality of the reasoning of justification" (Ball & Bass, 2000b, p.219). The discursive act of students reasoning about mathematics and sharing their ideas appeared to shape the ways that both the teachers and students did mathematics (Blanton, Berenson, & Norwood, 2001)

For change to become generative, teachers must engage in practices that serve as a basis for their continued learning. In this regard we hypothesise that the CGI conceptual framework for the development of children's mathematical thinking would be a powerful tool to help teachers understand the development of children's mathematical thinking. However, teachers need to do more than simply assimilate the research-based knowledge about children's mathematical thinking (Rhine, 1998); they need to engage in practical classroom-based inquiry focused on the details of their children's thinking in order to inform and further develop their conceptual frameworks and beliefs. Bobis's (2000) contention that the development of skills designed to monitor and analyse students' thinking strategies could profitably be integrated with skills needed to access 'good' research-based resources to further facilitate effective instruction is another example of generative change.

As a result of this project we are more aware that understanding the developmental patterns of teachers' knowledge, beliefs, and practice is critical for learning how to plan effective professional development. Just as teachers need to be more receptive to the development of children's mathematical thinking to derive their instructional practice, the patterns of development in teachers' thinking and classroom practice may provide a basis for the analysis of teacher development programmes. We contend that the ways teachers engage in practical inquiry with students in their classroom is a critical factor in the resulting impact on teachers' beliefs, knowledge and practice. Some teachers incorporated aspects of the programme as a model of teaching¾problem solving is something we do on Fridays¾others incorporated aspects into specific group tasks, and others successfully integrated the principles into all their mathematics teaching, and still others reported changes in their teaching approaches and beliefs across several curricula areas.

Broadly speaking, it appeared that the teachers who consistently engaged in practical inquiry focused on children's mathematical thinking, as evidenced in their teaching and the focus of their discussions in the workshops, reported more positive changes in beliefs and classroom practice. Examples of teachers' reports of change include:

- Greater focus on building from where each student is at.
- I am more aware of where my students are at with their number concepts.
- My expectations of the children have developed.
- Reinforces my beliefs that all children can do maths.
- They are far more capable at problem solving than I thought.

These teachers appeared to change their beliefs before, or in conjunction with, changing their practice¾they were enthusiastic from the start and reported such statements as: "This is what I always felt learning should be like, deep down" or "This is like putting into words what I couldn't really explain". Thus, for them, engaging in classroom inquiry entailed changing classroom practices in ways that related to a set of corresponding and emerging beliefs. Their conscious attention to their students' mathematical thinking will strengthen their pedagogical content knowledge and ensure that ongoing instructional decisions are based on content, pedagogy, and children's thinking in a generative manner.

Thus, on reflection we have learned that we need to place more explicit emphasis on teachers using their emerging knowledge to investigate and re-create their understanding of the development of children's thinking¾it is important for facilitators to attend closely to *how* teachers are engaging in this practical inquiry. Near the end of the professional development programme we asked teachers to videotape a group of students working on a problem or a classroom episode. The constraints of equipment and time proved to be extremely trying for some. However, the activity proved to be most useful in engaging teachers in analysing their students' thinking and reviewing related classroom practices associated with teacher feedback, prompting, and task analysis.

This episode also highlighted the importance of the positive and negative factors within the school environment¾consideration of these factors needs to be more carefully monitored and incorporated into professional development programmes. Teachers should rightly expect to situate their ongoing development within the expectations and structures of their schools. A possible way to more fully appreciate these factors is suggested by Stein, Smith, and Silver (1999). They recommend that professional developers

> become immersed in the actual settings in which their clients do their work, to be willing to examine firsthand the impact of their efforts on teachers' practice and student learning, and to hold themselves responsible for the successful implementation of an instructional program by a cohesive group of teachers, not simply the development of teachers as individuals. (p. 243)

Similarly, Bobis (2000) notes the need for continued professional partnerships between teacher education institutions and schools in the bid to enhance numeracy.

Conclusions

The CGI-based professional development programme's focus on children's mathematical thinking provided a sound basis for teachers to engage in ongoing practical inquiry directed at understanding students' thinking and implications for their teaching practice. The changes in practice were not merely in response to the external influences of the professional development programme but were deeply connected to the situated context. However, the teachers varied in their response to opportunities for their own classrooms to become environments for continued learning. A few teachers experienced some difficulty in changing the focus of their inquiry from teacher behaviour to student behaviour¾ rather than focusing on learning about children's mathematical thinking, they focused on implementing their interpretation of the programme. However, for the majority of the teachers, the opportunities for collaborative reflection in the professional development sessions and reflection within their classroom helped them to better understand their children's mathematical thinking and simultaneously challenged their beliefs about teaching and learning mathematics. Specifically, changes in classroom discourse appeared to mediate changes in classroom practice.

A critical challenge for professional developers is how can we best foster inquiry learning in the classroom and how do different teachers involved in professional development accomplish self-sustaining, generative change? Creating professional development experiences that confront the "constructive dilemma" (Stocks & Schofield, 1997) of teaching content knowledge while respecting teacher constructions, and acknowledging the importance of building a community of practice requires a greater understanding of the nature and process of professional development. Such understanding should be informed by further research collaboration between teachers and professional developers.

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