Designing Research on Teachers' Knowledge Development

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Progress in improving the practices of teaching and learning requires a shared knowledge base for teaching that is grounded in professional practice. In this paper, we argue for an approach to the design of research on teachers' knowledge development that can contribute to a knowledge base by being open enough to accommodate variability in perspectives and structured enough to allow for the sharing of knowledge. We illustrate this methodology with examples of investigations on the development of secondary teachers' knowledge.

The past two decades of research and development in mathematics education in the United States has led to the emergence of curriculum and professional standards (National Council of Teachers of Mathematics, 1989, 1991, 2000) and a wealth of curriculum materials (c.f., www.showmecenter.missouri.edu) that purport to meet these standards at all grade levels. Yet the progress towards changes in teaching practices remains slow and large (though closing) gaps continue to exist between the highest achieving schools and the lowest achieving schools. Translating research results into forms that are useful for teachers and school administrators continues to be a stubborn problem, resistive to change. Some researchers (Hiebert, Gallimore & Stigler, 2002) have argued that to improve classroom teaching, the professional knowledge base for teaching needs to be built from practitioner knowledge in a way that can continue to be grown and improved. In this paper, we will outline some of the practical problems that have impeded the development of that knowledge base and suggest some theoretical underpinnings for the nature of the development of teachers' knowledge that provide a foundation for addressing those problems. We will then present a research design that we have used in multiple contexts that appears to hold some promise for investigating and supporting the growth and development of teachers' knowledge. We will illuminate that research design with some results from a recent project that investigated the development of secondary teachers' knowledge about functions. Finally, we will conclude with some discussion of the current limitations and challenges that we face in using the research design.

Some Practical Problems in Research on Teacher Development

It has become increasingly clear that students, teachers, classrooms, and schools, along with the curricula, technology, and learning tools that support them, need to be viewed as complex systems. This ecological view of teaching and learning is true whether we consider any one of these elements as a single complex system (such as the curriculum) or as a combination of interacting systems (such as the student, the teacher and the curriculum). This makes research on teaching particularly problematic, since there are no easy or straightforward ways to disentangle teachers' knowledge from the complexity of the systems in which it takes place. Indeed, investigating teaching as dis-embedded from this complexity is likely to lead to research that would have little (if any) relevance to practice. The challenge facing us as researchers is to design research that can enable us to make sense of the multiplicity of interacting factors that influence teachers' practice in ways that will lead to an improved knowledge base for teaching.

Current research on teaching mathematics (and on teaching more generally, for that matter) is plagued with a plethora of research designs and methodologies that tend to impede rather than promote the development of a shared knowledge base for teaching. The complexity that characterizes teaching and learning seems to have yielded a multiplicity of research designs and methodologies with an insufficient coherence across those designs to support the development of a shared knowledge base. We would argue that research designs need to be sufficiently open to allow for a multiplicity of perspectives and variability within areas of inquiry and at the same time sufficiently structured to allow for the sharing of models, metaphors, tools and principles. Achieving some balance between openness and structure across research projects and professional development programs could provide the coherence that is needed for multiple contributions to the development of a shared knowledge base.

We wish to argue that the current knowledge base on the growth and development of teachers' knowledge is still in its infancy when compared to the knowledge base on the conceptual development of children. Over the past 20 years, substantial progress has been made in children's learning in those areas where we have had extensive, sustained, and successful research on children's knowledge in such areas as number sense, rational numbers, algebra and functions. Numerous researchers in many countries have investigated both what it is that children know in each of these domains and how it is that their ideas develop. In contrast, the corresponding research base on what teachers know about teaching in each of these domains and how the teachers' knowledge develops is sparse and plagued by several problems of scale and scope.

One of the problems of scale can be seen in the relatively large number of studies of teaching for which the number of subjects is N=1 or which involve the self-study of teaching, sometimes using a member of the research team. While such studies do provide us with important insights into teaching, it remains difficult to scale the methodologies or the results of such studies to larger numbers of teachers. Another problem of scale can be seen in the dimension of time. It would appear from current research that studies on the development of teachers' knowledge need to be of the order of several years, rather than the several months (or even weeks) that can be sufficient to investigate the conceptual growth of children. And, finally, the scope of the data collection and analysis present particular problems for research on teacher development. Since teaching is itself a complex activity embedded in a complex system, the potential data sources for understanding teaching are vast, including volumes of student work, reams of observational notes, and boxes of video and audio tape of teaching episodes. Much of this data is not of the form of artefacts or tools that could be used by teachers in the improvement of practice.

Another problematic area is with the design of interventions. While some research studies on teachers' knowledge do take the form of naturalistic studies, intended to gain insight into practices as they are, most research on teachers' knowledge development tends to be interventionist. That is, there is some intervention (such as a professional development program designed to promote inquiry in the classroom), grounded in current research, which is the basis for the study. We wish to argue that the design of interventions for teachers should be such that the interventions themselves become artefacts or tools that can be re-used and shared across research projects and professional development programs. In this way, the design of effective interventions can become increasingly useful to researchers across a range of settings and at multiple levels within those settings, thus lending a needed coherence across research and professional development projects.

Theoretical Perspective on the Development of Teachers' Knowledge

In earlier work, we have argued that the focus of research on teacher knowledge needs to shift from examining what it is that good teachers *do* in particular situations to investigating how it is that good teachers *think* about particular situations (Doerr & Lesh, in press). In other words, teaching is much more about seeing and interpreting the tasks of teaching than it is about doing them. A distinguishing characteristic of excellent teaching is reflected in the richness of the ways in which the teacher sees and interprets her practice not just in the actions that she takes. It is precisely a teacher's interpretations of a situation that influence when and why as well as what it is that the teacher does. The nature of teacher knowledge is much more about how teachers interpret the complexity and the situated variability of the practical problems of the classroom, how those interpretations evolve over time and across settings, and how and when those interpretations influence decisions and actions in the classroom. It is not enough to see what a teacher *does*, we need to understand *how* and *why* the teacher was thinking in a given situation, that is, interpreting the salient features of the event, integrating them with past experiences, and anticipating actions, consequences, and subsequent interpretations.

Increasingly, researchers on the development of teachers' knowledge have come to recognize two important perspectives on that knowledge: (1) that the knowledge needed for teaching is an ill-structured content domain (Feltovich, Spiro, & Coulson, 1997; Lampert, 2001) and (2) that to a large extent such knowledge is situated and grounded in the particularities of the contexts and constraints of practice (Borko, Mayfield, Marion, Flexer, & Cumbo, 1997; Lave & Wenger, 1991; Leinhardt, 1990). These two perspectives on teachers' knowledge suggest that expertise in teaching is not a single, uniform image of a "good" teacher. Rather, expertise in teaching is highly variable, both across and within individuals and across multiple settings. This suggests that teaching needs to be viewed as evolving expertise that grows and develops along multiple dimensions in varying contexts for particular purposes. The central problem, then, from the perspective of research design on teacher professional development is precisely the design of interventions and tasks that are likely to promote this growth and development in ways that are continually better.

The Design of Multi-Tiered Teaching Experiments

The multi-tiered experiment (Lesh & Kelly, 1999) falls within the broader category of research design experiments (Lesh, 2002). There are two important characteristics of such design experiments for investigating the development of teachers' knowledge. The first characteristic is the deliberate intention of designing (as in the sense of engineering) an improved process or product for some purpose within a system that necessitates trade-offs and constraints. In the case of teacher development, the processes and products that we seek to improve are the interpretations (or models) that teachers use to make sense of teaching and the artefacts and tools that help teachers in their work. We seek to understand the trade-offs and constraints that teachers encounter in practice so that the kinds of outcomes that will be generated by research will be more like guidelines for understanding the variation in the particulars of practice than universal rules that govern all situations. Such guidelines need to include not only rich descriptions of the variations in practice, but also a sense of how teachers might effectively respond to those variations.

The second important characteristic of design experiments is that they require multiple cycles of analysis and interpretation at multiple levels. In other words, the collection of data and its interpretation does not happen at the end of the experiment, but rather it is the on-going collection and interpretation of data at all levels that is intended to generate and refine theories, processes and products that are increasingly useful to researchers, teachers, and other practitioners. One of the challenges in implementing multi-tiered teaching experiments is in articulating the interpretations at each level in ways that allow those interpretations to be tested and revised as well as become increasingly sharable and generalized across participants and settings. These multiple levels of interaction, interpretation, and analysis are summarized in Figure 1.

Tier #3 Researchers	With teachers' and students' help, researchers develop models to make sense of teachers' and students' learning and to re-interpret and extend their own theories.
Tier # 2 Teachers	Teachers work with teachers and researchers to describe, explain, and make sense of student learning.
Tier #1 Students	Teams of students work, with teachers' support, on model-eliciting tasks in which they construct, revise and refine their interpretations of the problem situation.

Figure 1. The design of multi-tiered teaching experiments.

We have found that the greatest challenge in designing multi-tiered teaching experiments centres on the difficulties in designing the tasks (which are the interventions) for teachers. The essential characteristic of the tasks for teachers (and this is completely analogous to the design of model-eliciting tasks for children) is that the task must elicit (or reveal) teachers' current ways of thinking (or interpreting) in such a way that those interpretations can be tested, revised and refined. As can be seen in Figure 1, the tasks for teachers are intended to directly engage teachers in working with each other as they develop ways of interpreting classroom events that support student learning. We have found the following tasks particularly useful:

- Develop a library of exemplary and illuminating results of students' responses to modelling activities. Such a library captures the range of quality work that can be done by students and reveals what aspects of that work are most important to the teachers.
- Create a "quick notes" sheet for other teachers to use with students' modelling activities. When writing "quick notes," teachers create the annotations that reveal

the critical features of the lesson, such as discussion points and questions that might be useful.

- Refine strategies for making useful observations about students' works-in-progress. Generating "ways of thinking sheets" or "consensus ways of thinking sheets" engages teachers in the task of anticipating and evaluating how their students' ideas might develop.
- Design methods for engaging students in sharing and revising their work. Devising guidelines for eliciting student explanations reveals how teachers balance their role in explaining mathematical ideas with the need to engage students in explaining their mathematical thinking.

In creating, sharing, and examining these kinds of artefacts and tools of practice, we have found that as researchers we are able to gain insight into how and why a teacher was thinking about a particular lesson or set of lessons. For example, on the "quick notes" sheets, the teachers included quick reminders about how students might think about the task mathematically, annotations about particular difficulties students might have, and a list of points that might be raised in discussion.

Some Results From Research

These results are from a two-year research project using modelling tasks to investigate the teaching and learning of the mathematics of relative motion. Using the methodology of the multi-tiered teaching experiment (Lesh & Kelly, 1999), the development of students' reasoning was examined by teachers and the development of teachers' reasoning was examined by researchers. All three sets of participants were engaged in a cyclic process of interpreting tasks, and revising, refining and sharing their developing ideas about the tasks. In the particular lesson discussed here, the students were engaged in making sense of how they can determine the change in position of a character in a simulation world by examining the character's velocity graph (Kaput & Roschelle, 1997). This model eliciting activity began with a velocity graph and elicited a variety of student constructions for its related position graph. We note that this is a reversal of the usual curricular strategy of teaching position graphs first and then their related derivatives, namely their velocity graphs.

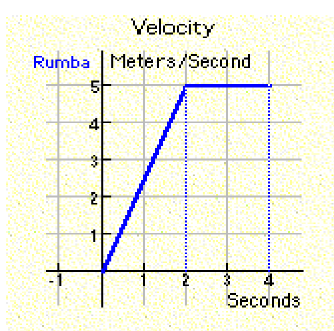
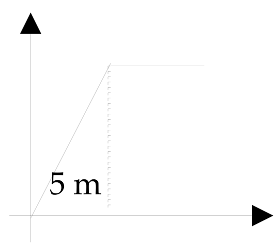


Figure 2. The students' velocity graph.

The students had created a velocity graph (see Figure 2) that corresponded to this description of a character's motion: "Rumba sets off and accelerates with constant

acceleration to his fastest walking velocity of 5 meters per second in two seconds. From there, he walks at his fastest walking velocity for two more seconds." The students then engaged with the following question: *"Exactly* when will Rumba have walked 12.4 meters? Give a mathematical justification for your answer!"
The teachers in this study had investigated this problem themselves and had discussed various strategies that students might devise for solving this problem. Their work had attuned them to observing differences among students' ways of thinking about the problem, including those that might be different from any that the teachers themselves had thought about. At a subsequent meeting, after the teachers had taught the lesson, one of the teachers shared three solutions that had emerged in her classroom, as part of the shared library of illuminating student work. The first of these solutions (see Figure 3) involved partitioning the area under the velocity graph into two regions, computing the area under the triangle as 5, and computing the time needed to travel the remaining distance of 7.4 meters using the area of the rectangle.



$$A = \frac{1}{2} \cdot b \cdot h \qquad A = bh$$
$$7.4 = b \cdot 5$$
$$A = \frac{1}{2}(2)(5) \qquad 7.4 = 5b$$
$$A = 5m \qquad 1.48 = b$$

$$2s + 1.48s = 3.48s$$

Figure 3. An area strategy.

The correct solution is then the sum of the two times. The second solution consisted of an incorrect proportional reasoning argument that reflected a persistent student difficulty in understanding the role of changing velocity when determining position (see Figure 4).

$$\frac{5m}{2s} = \frac{12.4m}{x}$$
$$x = 4.96s$$

Figure 4. An incorrect proportional reasoning strategy.

The first solution had been anticipated by the teachers, since it was the same solution that many of them had used. But the proportional reasoning error was not as easy for some teachers to anticipate and respond to. However, the most interesting solution was the third solution that the teacher shared. This solution involved finding two points on the position graph (namely (3,10) and (4,15)), then finding the equation of the line through those two points and using that equation to find the time (x) when the position was at y=12.4 (see Figure 5). Not only did the teachers regard this solution as elegant, they also felt that it reflected an integrated and abstract understanding of both the velocity graph and its related position graph. But the most impressive aspect of this solution for the teachers was the fact that none of the teachers themselves had used or anticipated this way of thinking about the problem. This revealed to them that their students might reason about problems in ways that they themselves had not. Further discussion on this issue revealed that they, as teachers, needed to be increasingly aware of alternative ways of thinking that students might have. This was a particularly convincing notion since the solution had emerged in the practice of one of their colleague's classrooms. In this sense, it was a research finding embedded in practice. The ways of thinking that were reported by this one teacher later became incorporated into the "quick notes" that the teachers collectively devised to capture their ideas about students' ways of thinking when re-teaching the lesson in the future.

By examining students' solutions, the teachers became increasingly aware of the range of quality work that was done by students. As they assembled illuminating examples of their students' work, they revealed what aspects of that work was most important to them and they developed strategies for observing and responding to variations in students' thinking.

(3,10) (4,15)

$$\frac{\Delta y}{\Delta x} = \frac{15-10}{4-3} = 5$$

y=5x+b
10=5(3)+b
-5=b

y=5x-5
12.4=5x-5
17.4=5x
3.48=x

Figure 5. Reasoning from the equation of the unseen position graph.

Concluding Remarks and Continuing Challenges

As we indicated in the opening paragraphs of this paper, one of the central difficulties in current research on teachers’ knowledge is the lack of both openness and structure across research designs so as to promote the sharing of results in ways that will lead to the development of a knowledge base for teaching. The design of the multi-tiered teaching experiment allows us to be open in the multiplicity of perspectives and the variability of areas of inquiry by deliberately including multiple levels of tasks with multiple levels of analysis. At the same time, we have attempted to achieve some structure in our teaching experiments by focusing explicitly on the principles of design for effective tasks for promoting the development of teachers’ knowledge (Doerr & Lesh, in press). Our next steps in this effort are to revise and refine our principles for the design of such tasks for teachers across a range of research settings, participants and questions. As illustrated by the results reported in this paper, we have made some progress in designing tasks that reveal teachers' thinking. However, we have encountered some challenges in engaging teachers in testing, revising and refining their thinking. For example, at the secondary level, some teachers have relatively low expectations of their students. Even when faced with the success of the students of other teachers (who have similar or lower ability students) and (in some cases) their own students, teachers’ levels of expectation for student thinking appear particularly resistive to change.

Since teachers work in teams in multi-tiered teaching experiments, we've made some progress on the issue of having more than one subject in a study or using a self-study of teaching. Important work that still remains to be done is address how changes are generated and sustained. In the United States, teaching is not a culture of shared critique; as difficulties in revising and sharing interpretations are encountered and resolved, we hope to make further progress on understanding these cultural constraints. The time scale for change is still at issue; while we have seen that development of teachers' thinking can occur over time frames of several months, change is only likely to be sustained for teachers over time frames of a year or more.

Finally, we need to become increasingly sophisticated in creating and collecting the artefacts and tools of practice. We would like to have artefacts and tools that are revealing, revisable, and shareable across teachers and across contexts. The examples we have described above are deeply embedded in the teachers' practices. We want these artefacts and tools to continue to be useful to teachers as their practices continue to evolve. We continue to need to understand how the artefacts and tools are modified, extended and re-applied in practice. To do this, we still are relying on observational and video/audio data. We anticipate that continued work will enable us to better understand how to collect and analyse with teachers the tools and artefacts that enable them to continue to learn and grow as professionals.

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