# Inquiry-Based Learning in Mathematics: Designing Collaborative Research with Schools

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A series of research projects were implemented over seven years to understand and facilitate teachers' experiences in adopting inquiry. An overview of the project, methodology and key outcomes are outlined as a basis for the partnership described in this symposium. We end the paper with a list of recommendations for designing collaborative research with schools.

Research suggests that mathematical knowledge developed in a structured environment alone is unlikely to transfer to less structured problems (Mestre, 2005). In mathematical inquiry, students address ill-structured problems: where the problem statement and/or method of solution contain ambiguities to be negotiated (Reitman, 1965). While inquiry is an accepted pedagogy in science, it lags behind in mathematics.

Inquiry-based learning is challenging for students, and more so for teachers, as it incorporates skills often at odds with traditional instruction in mathematics: tolerance for ambiguity, ability to manage uncertainty, negotiation and debate of ideas, greater student independence and control, collaboration and integration of knowledge—all critical skills for citizenship. In particular, it takes time for teachers to learn to envision inquiry in mathematics, develop a classroom culture and scaffolding techniques that support inquiry-based learning, and gain confidence in applying their own understandings of mathematics to open-ended problems. Whilst many teachers are sympathetic to the ideals of inquiry teaching, few take an inquiry approach in teaching mathematics.

A study aimed to understand teachers' evolving experiences as they gain expertise teaching inquiry. Funding extended into a three-phase project over seven years (2006-2012), with each phase having a different focus and sample size (Table 1). Key outcomes have included a model of teachers' evolution in learning to teach mathematical inquiry, quantitative evidence of aspects of change in pedagogy over time and case studies illustrating particular aspects of teaching and learning. This paper provides an overview of the research component of a project consisting of a partnership between researchers, schools and a state education department.

Table 1
*Phases of the Research 2006-2012*

| Phase | Funding | Sample | Research team | Aim |
|---|---|---|---|---|
| I | UQ grant 2006-07 | 4 | Makar | To understand teachers' evolving experiences in teaching inquiry |
| II | ARC Linkage 2007-09 | 20 | Makar, Wells, Allmond | To elaborate teachers' evolution in learning to teach mathematics through inquiry (and improve evidence of change) |
| III | ARC Linkage 2009-12 | 40 | Makar, Dole, Gillies, Wells, Allmond, Fry | To facilitate teachers' transition in adopting inquiry pedagogies in mathematics |

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## Background of the Research over Three Phases

Design Research (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003) formed the framework to accommodate the changing nature of the research and classroom contexts, interventionist focus, cycles based on feedback from classrooms to test and revise theories, and humility of context-specific outcomes. Research data relied heavily on recorded lessons and professional development, artefacts and interviews. Over 1200 lessons were observed or videotaped, 150 interviews conducted and hundreds of artefacts collected.

*Phase I.* The first phase focused on understanding teachers' changing experiences. Teachers were recruited from a large suburban primary school in Queensland where the researcher was a parent and volunteered professional development, facilitating access. Teachers were selected by administration as those who would be committed to project ideals. The school saw benefit in the professional development being offered as a way to address new curricular demands that included greater emphasis on mathematical practices.

Close contact between the researcher and teachers created a strong rapport that built a critical foundation for later phases. In this phase, teachers were not "told" whether they were teaching inquiry "correctly" (although they asked) because the researcher wanted to be open to the generative practices that teachers developed. The researcher's knowledge of inquiry came from literature, but theirs emerged from their practice. Therefore, they were in a better position to teach the researcher about inquiry than the reverse. The extended time in classrooms gave the researcher insights and appreciation of the diversity of teachers' practice. Their extensive feedback contributed significantly to the knowledge that emerged (Makar & O'Brien, 2013). For example, the project was designed to focus on statistical inquiry, but teachers extended it to other strands, enabling the project to expand.

*Phase II.* The second phase extended the design, inviting more teachers (nominated by Phase I teachers) and an entire teaching staff from a small, rural school. The second school had a transient population with poor outcomes on state assessments. Access was initiated by their curriculum coordinator (known to the researcher) and made mathematical inquiry a school-wide initiative. Phase II sought to test and expand a model developed in Phase I (Figure 1), quantify pedagogical change (Makar, 2011) and design exemplar inquiry unites for teachers (Allmond, Wells, & Makar, 2010). The challenging nature of the second school context provided new insights into the robustness of the model and respect for diversities in teachers' practices. A research assistant and PhD student (both teachers in Phase I) were engaged to assist with data collection, coach teachers and provide advice.

*Phase III*. Feedback from teachers in Phases I & II suggested three key "pivots of practice" were particularly challenging in adopting mathematical inquiry: (1) acquiring a vision of an inquiry classroom; (2) learning to "see mathematics" beyond the classroom; and (3) creating a classroom culture of inquiry (Makar, 2012). Researchers with expertise in these three pivotal areas lead the expanded research team as well as a second PhD student (also a Phase I teacher) studying formative assessment within inquiry. Professional development and feedback targeted the "pivots of practice" to facilitate teachers' adoption of inquiry. Schools were recruited from the networks of the Phase II schools. The benefits of the larger sample size were in collecting substantial quantitative evidence of changing practices. This phase was challenging, however, in that the larger numbers of teachers made it impossible to spend as much time in classrooms as was previously possible. This meant that while the project was potentially more scalable, it may have made it more difficult for teachers to engage in adopting inquiry practices.

*Relationships with schools*. The project continually sought ways to ensure that schools received benefits in ways that *they* valued, rather than assuming the knowledge gained in

the project would suffice to maintain schools' interests. Professional development was offered to non-project teachers, classroom resources were provided and support was funded for teachers to attend conferences. Teachers with particular leadership were invited to present their inquiry units at state and national conferences. This capacity-building added to schools' profile among local schools and with the state and district offices.

## Key Preliminary Findings

The research has so far published findings in three main categories: a model of teachers' experiences as they develop expertise in teaching mathematical inquiry; initial quantitative analysis of aspects of pedagogy that tends to change as teachers adopt inquiry; and classroom case studies to provide illustrations of particular outcomes.

A preliminary model (Makar, 2008) was later elaborated (Makar & Fielding-Wells, 2011) to offer insights into teachers' experiences. The model (Figure 1) is useful for teachers, school leaders and policymakers to anticipate challenges and needs that teachers encounter, and acknowledges (with the pedagogical evidence, discussed below) that changes in pedagogy take several years and require local support (Makar, 2007).

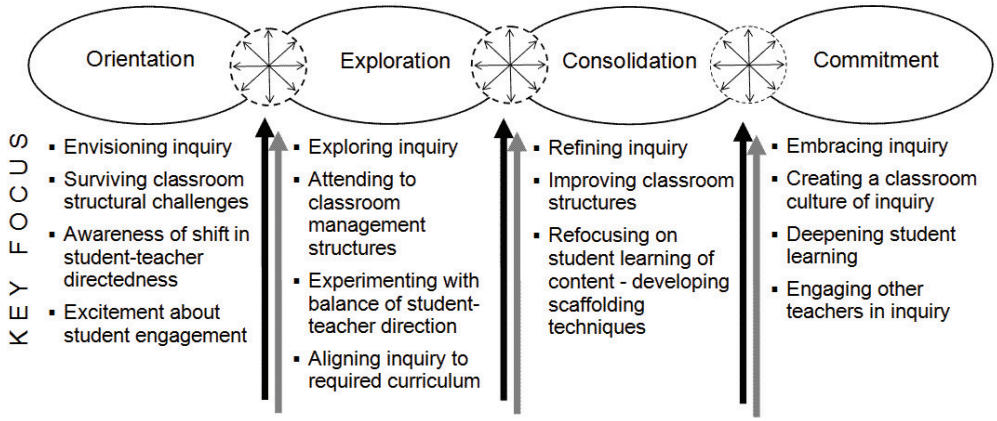


*Figure 1.* Model of teachers' evolving experiences as they gain expertise teaching mathematical inquiry.

The Productive Pedagogies Classroom Observation Scheme (QSRLS, 2001) was used to quantify changes in teachers' practices as they gained expertise over a number of years. Phases I and II data suggest that overall pedagogical practices (as measured by Productive Pedagogies) improved as teachers gained experience over three years and that changes in *Connectedness* were significant from the first inquiry, acknowledging that the nature of inquiry requires connection with other mathematics, subject areas and beyond school (Makar, 2011). An "implementation dip" was often observed in the second year, aligning with research on operationalising innovation (Fullan, 2007). Analysis from the combined phases is in progress to test or expand initial findings.

Cases studies provide rich insights into local issues and teachers often co-authored these papers. They included cases of student learning (Makar & McPhee, 2009), challenges and contexts of teachers' practices (Dole, Makar, & Gillies, 2012; Makar, 2012), teachers' contributions to knowledge-building (Makar & O'Brien, 2013), and illustrations of theory (Makar & Rubin, 2009).

## Recommendations

- *Win-win*. Designing research where all parties gain significant benefits for their own context can improve respect, trust, enthusiasm and extended commitment.
- *Start small, stay manageable*. School-level research is time-consuming and if resources are over-extended, short-cuts can leave both parties dissatisfied.
- *Have a research trajectory in view*. Consider the potential long-term trajectory of the research to remain mindful of impact, scaling issues and opportunities.
- *Be passionate*. Commitment, focus and engagement with the long-term vision can produce insights and new research directions that may not have been anticipated.
- *Nurture your team, appreciate the teachers and develop champions*. Acknowledge the work and commitment of all those who contribute; mentor future leaders to help continue the initiatives after the funding ends.
- *Write!* Classroom-based research requires new mindsets about research methodology. Ensure that findings are published for broader impact and access.

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## References

Allmond, S., Wells, J., & Makar, K. (2010). *Thinking through mathematics: Engaging students in mathematical inquiry*. Melbourne: Curriculum Press.

Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32*(1), 9-13.

Dole, S., Makar, K., & Gillies, R. (2012, July). *Enacting the intended curriculum through inquiry pedagogy*. Paper presented at the Twelfth International Congress of Mathematics Education, Seoul Korea.

Fullan, M (2007). *Leading in a culture of change* (Rev. edition). San Franciso: Jossey-Bass.

Makar, K. (2007). 'Connection levers': Supports for building teachers' confidence and commitment to teach mathematics & statistics through inquiry. *Mathematics Teacher Education & Development, 8*(1), 48-73.

Makar, K. (2011, July). *Learning over time: Pedagogical change in teaching mathematical inquiry*. Presented at the Mathematics Education Research Group of Australasia conference, Alice Springs.

Makar, K (2012). The pedagogy of mathematical inquiry. In R. Gillies (Ed.), *Pedagogy: New developments in the learning sciences* (pp. 371-397). Hauppauge NY: Nova Science.

Makar, K., & Fielding-Wells, J. (2011). Teaching teachers to teach statistical investigations. In C. Batanero, et al (Eds.), *Teaching statistics in school mathematics* (pp. 347-358). New York: Springer.

Makar, K., & McPhee, D. (2009, July). *Young children's explorations of average in a classroom of inquiry*. Presented at the Mathematics Education Research Group of Australasia conference. Massey University.

Makar, K., & O'Brien, M. (2013). Blurring the boundaries: The transformative nature of research participation. In M. Baguley, G. Curro, P. A. Danaher & W. Midgley (Eds.), *The role of participants in education research: Epistemologies, ethics, and methods* (pp. 110-124). New York: Routledge.

Makar, K., & Rubin, A. (2009). A framework for thinking about informal statistical inference. *Statistics Education Research Journal 8*(1), 82-105.

Mestre, J (Ed.) (2005). *Transfer of learning: Research and perspectives*. Charlotte NC: Information Age.

Queensland School Reform Longitudinal Study (QSRLS) (2001). *Productive pedagogies classroom observation scoring manual*. St Lucia: University of Queensland.

Reitman, W. R. (1965). *Cognition and thought: An information processing approach*. Oxford UK: Wiley.