Professional development that supports the development of teacher knowledge: From design experiments to full-scale evaluation studies

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Educational reform movements worldwide are setting ambitious goals for student achievement. Many factors can potentially contribute to meeting these goals. The positive association between teachers' knowledge and student achievement is one contributing factor (Darling-Hammond, 1996; Spillane & Zeuli, 1999). This association is particularly strong in the field of mathematics (NRC, 2000; Wayne & Youngs, 2003) and may be even stronger when teachers' mathematical knowledge for teaching is considered (Hill, Rowan, & Ball, 2005). Professional development that focuses on fostering teacher knowledge and improving instructional practice as a means of promoting student achievement is increasingly in demand. To meet this demand, the educational community must create PD models that are sustainable and scalable—models that can ultimately be carried out by schools and districts on a long-term basis, using their own resources (Loucks-Horsley et al., 2003).

Researchers are beginning to unpack exactly what and how teachers learn from professional development, and the impact of teacher change on student outcomes (Garet, Porter, Desimone, Birman & Yoon, 2001; Fishman, Marx, Best & Tal, 2003). However, most findings regarding teacher knowledge and professional development are from small qualitative studies that are not generalizable. As the educational community creates promising models of PD, the research community must conduct evaluation studies to provide evidence regarding the feasibility of implementing these models on a large scale, and their impact on student achievement.

Borko (2004) suggested a three-phase research agenda for designing, implementing, and investigating scalable models of professional development. Phase 1 research projects take place at a single site and provide initial evidence that a PD program is feasible and can have positive impact on teacher learning. Typically these "proof-of-concept" studies are relatively small; both qualitative and quantitative research methodologies often are employed to document the design process and to study the impact on teachers' knowledge and practice. Phase 2 research projects build on and extend Phase 1 projects by closely examining particular features of the PD to determine whether it is a scalable model. These research projects might examine the PD at multiple sites, use multiple facilitators, examine student achievement, or use non-volunteer teachers. With successful results from a Phase 2 study, researchers will have evidence that a full scale-up of the PD program would be useful to the field. Phase 3 research projects involve a comparison of multiple, well-defined PD programs, each enacted at multiple sites. Central research issues include the necessary resources requirements for the PD programs and their impact on teacher and student learning.

This article discusses and expands on these three phases of research, and provides examples from our own research agenda involving a model of mathematics professional development we call the Problem-Solving Cycle (PSC). The PSC consists of a series of three interconnected workshops, in which teachers share a common mathematical and pedagogical experience, organized around a rich mathematical task. This common experience provides a structure within which the teachers can build a supportive community that encourages reflection on mathematical concepts, students' mathematical reasoning, and instructional practices (Koellner, et al., 2007).

Initial Research: Development and Examination of the PSC PD Program

Early phases of development and research on PD models often use a design experiment approach (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Design-Based Research Collective, 2003) to document the processes of the PD and the impacts on teacher learning. In general these projects have focused on implementation of a PD program by the designer at a single site, typically with "motivated volunteers" (Fishman, Marx, Best, & Tal, 2003). Their goal is to provide evidence that, under ideal conditions, the program is feasible and can have a positive impact on teacher learning (Borko, 2004). Our initial program of research, designing the PSC model and implementing it with a single group of mathematics teachers, provides an example of Phase 1 activities.

The development of the Problem-Solving Cycle. Our project started in 2003 as part of the grant "Supporting the Transition from Arithmetic to Algebraic Reasoning[1]" (STAAR). In the STAAR project we worked with a small group of middle school mathematics teachers to support their learning and teaching of algebraic concepts. We began the STAAR PD program in summer 2003 with a two-week algebra institute, and then conducted six, full-day PD workshops per year for two years. The central goal of workshops held in fall 2003 was to develop norms for viewing and analyzing classroom video. We conducted the first iteration of the PSC in spring 2004 and two more iterations during the 2004–2005 academic year. The three iterations used different algebra problems and focused on different aspects of the teachers' instructional practices and students' mathematical reasoning.

During the three iterations of the PSC, we utilized a design experiment approach to develop, implement, and refine the PD model. We collected and analyzed a large amount of data on the processes involved in developing and enacting the model, and on the impact of the PD experience on the teachers' knowledge of mathematics for teaching and instructional practices. The entire program was videotaped with multiple cameras to capture small-group and whole-group conversations. We collected all written materials from each workshop and interviewed the facilitators after each workshop to document their goals, intentions, and reactions. We collected data on teachers' experiences and learning outcomes using various approaches, including a content assessment and frequent oral and written reflections. We also regularly videotaped mathematics lessons taught by the teachers throughout each school year and interviewed the teachers after each classroom observation (and several other times during the program). In the next sections we summarize our research questions and findings.

*PSC processes: developing community and fostering productive discussions***.** With respect to the processes involved in the PSC model, our central research questions were: (1) What strategies in professional development support a strong discourse community? and (2) How did the use of video in the PSC foster productive conversations and a community of learners?

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To address the first question, our analyses revealed that four strategies were fundamental to creating a supportive mathematical discourse community: posing rich tasks that promote discussion, establishing and maintaining a safe environment for communication, asking the teachers to explain and justify their thinking, and encouraging teachers to actively process one another's ideas. The two facilitators of the summer algebra institute systematically incorporated these strategies throughout the workshops. They explicitly pointed out their use of the strategies and provided opportunities for the teachers to reflect on their own learning. Thus, in addition to learning algebra content, many teachers became inspired to implement similar strategies in their own classrooms. Several commented in interviews and written reflections on the ways in which the facilitators' modeling of communication strategies contributed to their learning of instructional practices as well as algebra content (Borko et al., 2005; Clark, Jacobs, Pittman, & Borko, 2005).

To address the second question we drew upon multiple data sources and used quantitative coding and qualitative vignette analyses to examine the nature of full-group discussions around video during the PSC and changes in the discussions over time. The teachers talked in an increasingly focused and analytical manner about issues related to teaching and learning the selected mathematical problem (Borko, Jacobs, Eiteljorg, & Pittman, in press). Many teachers reported that viewing and discussing video was the most valuable aspect of participation in the PD program—that it helped them to learn new pedagogical strategies, better appreciate their students' capacity for mathematical reasoning, and realize that they all struggle with similar issues (Jacobs et al, in press).

PSC impact: supporting professional knowledge and instructional change. With respect to the impact of the PSC, our central research questions were: (1) To what degree did participation impact teachers' knowledge of mathematics for teaching? and (2) To what degree did participation impact teachers' instructional practice?

To address the first question, we examined changes in teachers' content knowledge using an instrument designed to assess several foundational topics in algebra—including variable, equality, pattern recognition, representational fluency and systems of equations. The assessment was administered prior to the summer algebra institute, immediately after the institute, and at the end of the second year of PD workshops. We analyzed time-1 to time-3 differences in the number of correct answers and the number of solution strategies used by each teacher. Significant increases on both measures—represented by effect sizes of 0.93 for number of correct answers and 1.96 for number of solution strategies—indicate the teachers gained algebra content knowledge and retained these gains over several years (Borko et al., 2005).

We also analyzed conversations during the PSC workshops for changes in the teachers' knowledge of mathematics for teaching (KMT) (Ball & Bass, 2000). The workshops supported the development of both content knowledge and pedagogical content knowledge through structured discussion of the mathematics problems and video from the teachers' lessons. For example, the teachers gained new understandings of the algebraic content embedded in the selected tasks and pedagogical strategies that would better support student thinking (Koellner et al., 2007). Teachers' self-report data also indicate a strong impact on specific, targeted areas of KMT: mathematics content (e.g., generating multiple solution strategies), methods for improving classroom discourse (e.g., how to conduct group work and foster conversations about mathematics), and ways of encouraging student thinking (e.g., building on students' thinking, using tasks that promote student thinking) (Jacobs et al., in press).

With respect to impact on classroom teaching, question 2, we conducted cases studies of three teachers, based on videotapes of their mathematics lessons and interviews throughout the study. All three teachers made substantial and intentional changes in their practice, which they explicitly attributed to the STAAR project (Clark, Jacobs, Pittman, & Borko, 2005; Eiteljorg & Borko, 2006). Their changes reflected several of the pedagogical topics emphasized in the workshops, such as improving group dynamics and using more effective questioning strategies. For example, analysis of one teacher's mathematics lessons revealed a dramatic shift in classroom discourse patterns. In fall 2003, discourse in his class followed an initiation-reply-evaluation pattern focused on identifying the correct answer. In spring 2004, he moved beyond requests for correct answers to include probes for procedural explanations of students' solution strategies. During the 2004–05 school year, we increasingly observed this teacher asking questions to probe students' mathematical reasoning (Borko, 2004; Eiteljorg & Borko, 2006). Another set of analyses showed a relationship between the mathematical communication strategies modeled in the PD program and one teacher's application of those strategies in her classroom (Clark, Jacobs, Pittman, & Borko, 2005).

These small-scale studies provide initial evidence that the PSC is an effective model for enhancing teachers' knowledge of mathematics for teaching—including their subject matter knowledge and pedagogical content knowledge—and improving their mathematics instruction. Next we discuss our conceptualization of the upcoming steps in our program of research on the PSC; these steps can be considered Phase 2 studies.

Examination of Well-Specified PD Programs

After initial design research on a PD program many more questions must be answered about that intervention before it is reasonable allocate resources for a Phase 3 evaluation. Such questions include: (1) the impact on student achievement, (2) feasibility on a larger scale (e.g., an entire school district) and with non-volunteer teachers, and (3) whether the PD materials and resources are sufficient to ensure that multiple facilitators can implement the model maintaining integrity with the designers' intentions (Borko, 2004). There is not one correct next step in this phase of research; rather, there are multiple paths that can be explored in the on-going study of a PD program. Based on the outcomes of the process and impact studies conducted as Phase 1 of our research on the PSC, our research team has conceptualized two different Phase 2 research studies.

One Phase 2 study we have conceptualized is to implement the PSC program with all grade eight teachers in a large urban school district that has expressed a need for mathematics professional development. Schools would be randomly assigned to either the treatment condition (in which teachers participate in the PSC program) or the control condition (in which teachers participate in the professional development activities typically available in the district). This random assignment of schools would provide the basis for comparing the effects of participation versus nonparticipation in the PSC program on the knowledge and instructional practices of teachers, as well as the achievement of their students. The overarching research question addressed by this study is: Does participation in the Problem-Solving Cycle (PSC) mathematics professional development program over two years have a significant impact on middle school mathematics teachers and their students? This broad question can be broken into three sub-questions: (1) Do teachers in schools assigned to the PSC professional development program demonstrate larger gains in knowledge of algebra for teaching than do teachers in control schools? (2) Do teachers in schools assigned to the PSC program change their instructional practices in ways that differ from teachers in control schools? (3) Do students in schools assigned to the PSC program demonstrate larger gains in mathematics achievement than do students in control (nonparticipating) schools? Our initial research on the PSC model provides a solid foundation to hypothesize that participation in the PD will positively impact teachers' knowledge and instructional practices. We also expect students to benefit from receiving instruction in schools staffed by teachers with a stronger knowledge base and better preparation for teaching algebra.

Another Phase 2 research design, addressing different questions about the PSC, is to work with middle school instructional leaders (ILs) at a large school district and support their implementation of the PSC model. The primary goal of this project would be to investigate the scalability of the Problem-Solving Cycle (PSC) model and accompanying facilitation materials—that is, whether the ILs can adapt and implement the PSC to meet the needs and conditions of a local site while maintaining the integrity of the model's underlying goals and principles. We would provide ongoing support to a group of middle school mathematics ILs to help them develop the skills to successfully implement the PSC with the mathematics teachers in their schools. The specific nature of this support would be expected to change over the duration of the project, and to gradually decrease as the ILs develop the ability to implement the PSC on their own.

This study addresses the following questions: (1) What support is provided to ILs prior to and during their implementation of the PSC? How does this support change with successive iterations of the PSC? (2) How do ILs implement the PSC? How does implementation vary across ILs and over time? What factors account for the variation? (3) What is the impact of preparation for, and implementation of, the PSC on ILs? (4) What is the impact of participation in the PSC on middle school mathematics teachers? and (5) What is the impact on the mathematics achievement of students whose teachers participate in the PSC?

The results of the two Phase 2 studies conceptualized here, taken together, would provide our research team with enough data on the PSC model to determine whether or not we should conduct a Phase 3. If the PSC program is *pragmatically successful* (i.e., has a net positive impact on student outcomes in relation to the practices to which it is being compared), our next step will be to compare the PSC to other well-defined professional development programs with respect to their impact on teacher and student learning and resource requirements for successful enactment, in multiple school districts.

Full Scale Evaluation Projects of PD Programs

To the best of our knowledge, there are no full-scale comparative studies of PD models in the literature to date. With the urgency and commitment to raise achievement levels in mathematics for all students, and the call for effective professional development for mathematics teachers, such studies are essential. However, it is not realistic to implement a full-scale comparative study before the critical research questions at Phase 1 and Phase 2 have been answered. The time and commitment put towards planning, developing, and researching teacher knowledge and professional development at all phases are critical to add to the knowledge in the field.

References

Ball, D. L., & Bass, H. (2000). Interweaving content and pedagogy in teaching and learning to teach: Knowing and using mathematics. In J. Boaler (Ed.), Multiple perspectives on the teaching and learning of mathematics pp. 83-104). Westport, CT: Ablex.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3-15.

Borko, H., Frykholm, J. A., Pittman, M. E., Eiteljorg, E., Nelson, M., Jacobs, J. K., Clark, K. K., & Schneider, C. (2005). Preparing teachers to foster algebraic thinking. *Zentralblatt für didaktik der mathematik: International reviews on mathematical education, 37*(1), 43-52.

Borko, H., Jacobs, J. K., Eiteljorg, E., & Pittman, M. E. (in press). Video as a tool for fostering productive discussions in mathematics professional development. *Teaching and Teacher Education*.

Clark, K. K., Jacobs, J., Pittman, M. E., & Borko, H. (2005). Strategies for building mathematical communication in the middle school classroom: Modeled in professional development, implemented in the classroom. *Current Issues in Middle Level Education, 11*(2), 1-12.

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

Darling-Hammond, L. (1996). The quiet revolution: Rethinking teacher development. *Educational Leadership, 53*(6), 4-10.

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5-8.

Eiteljorg, E., & Borko, H. (2006, April). Uncovering student reasoning: The transformation of Ken’s questioning. In *The Problem-Solving Cycle: An approach to mathematics professional development*. Symposium conducted at the annual meeting of the American Educational Research Association, San Francisco.

Fishman, B. J., Marx, R. W., Best, S., & Tal, R. T. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education*, *19*, 643-658.

Garet, M.S., Porter, A.C., Desimone, L., Birman, B.F., Y Youn, K.S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38,* 915-945.

Hill, H. C., Rowan, B., & Ball, D. L. (2005). Effects of teachers' mathematical knowledge for teaching on student achievement. *American Educational Research Journal*, *42*(2), 371-406.

Koellner, K., Jacobs, J. K., Borko, H., Schneider, C., Pittman, M. E., Eiteljorg, E., Bunning, K., & Frykholm, J. A. (2007). The Problem-Solving Cycle: A model to support the development of teachers' professional knowledge. *Mathematical Thinking and Learning, 9*(3), 271-300.

Loucks-Horsley, S., Love, N., Stiles, K. E., Mundry, S., & Hewson, P. W. (2003). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin.

National Research Council [NRC]. (2000). *Educating teachers of science, mathematics and technology: New practices for the new millennium*. Washington, DC: National Academy Press.

Spillane, J. P., & Zeuli, J. S. (1999). Reform and teaching: Exploring patterns of practice in the context of national and state mathematics reforms. *Educational Evaluation and Policy Analysis, 21*(1), 1-27.

Wayne, A. J., & Youngs, P. (2003). Teacher characteristics and student achievement gains: A review. *Review of Educational Research, 73*, 89-122.