Developing an Effective Professional Development Model to Enhance Teachers' Conceptual Understanding and Pedagogical Strategies in Mathematics

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ABSTRACT: The professional development program model presented in this paper aimed at deepening teachers' conceptual understanding of mathematics content knowledge and exposing them to innovative and creative instructional approaches. The paper shares the program goals, design of the program, evaluation means for measuring effectiveness of the program, and outcomes of the program. The four components of the program were active in concert: systemic support, knowledge building workshops, classroom implementation and application, and building a professional community. The outcomes of the program were based on the reports of the project instructors, participants, and the project evaluator: changes in participants' beliefs about teaching mathematics and instructional approaches; and participants' efforts to adapt new/alternative pedagogical strategies in their teaching and create a student-centered classroom.

RÉSUMÉ: Le modèle du programme de formation professionnelle qui est présenté dans cet article a eu pour but d'approfondir le discernement conceptuel des enseignants face à la connaissance du contenu des mathématiques et aussi de leurs exposer les approches innovatrices et créatives de l'enseignement. Vous pourrez y découvrir les buts et la conception du programme, les moyens d'évaluation pour quantifier son efficacité et ses résultats. Les quatre composants du programme ont fonctionné ensemble: appui systémique, compréhension de la création d'ateliers, mise en place et mise en pratique d'une salle de cours et constitution d'une communauté professionnelle. Les résultats du programme reposaient sur les rapports du projet des instructeurs, des participants et de celui qui évalue. Ces projets ont révélé des changements dans les opinions des participants sur la façon d'enseigner les mathématiques et sur leurs approches pédagogiques, sur leurs efforts à adapter de nouvelles stratégies

Journal of Educational Thought
Vol. 41, No. 2, 2007, 125-144.

> pédagogiques, et/ou alternatives, dans leur enseignement et à créer une salle de cours orienté vers l'étudiant.

The importance of continuing professional development of a mathematics teacher is addressed in numerous documents (NCTM, 1991, 2000; NRC, 2001). Research on mathematics teacher education has grown over the last several decades in various areas: classroom processes or structures, teachers' personal traits, or the influence of the teacher on children's learning of mathematics (Lerman, 2001; Richardson, 1999). Most professional development programs share a common goal, "to increase teachers' use of classroom practices that are believed to improve students' achievement" (McCaffrey et al. , 2001, p. 1). Also, teacher educators agree that, in order to be successful, teachers should have mathematical competence in: conceptual understanding, procedural fluency, strategic competence, adaptive reasoning, and disposition (NRC, 2001). The professional development program in this paper was designed in response to these recommendations.

Foundation of the Study

Effective teachers should know and understand mathematics, students as learners, and pedagogical strategies. Effective teaching also requires a challenging and supportive classroom learning environment, as well as continually seeking improvement (Graham & Fennell, 2001; NCTM, 2000). In order to be effective, teachers "need sustained, ongoing professional development ... must continue to learn new or additional mathematics content, study how students learn mathematics, analyze issues in teaching mathematics, and use new materials and technology" (NCTM, 2000, p. 370). These recommendations suggest that opportunities be provided for teachers to deepen their content and pedagogical knowledge and to reflect while they are involved in the practice of teaching. The professional development model in this paper shared this view of the effective teacher in teaching mathematics and aimed at deepening teachers' conceptual understanding of mathematics content and exposing them to innovative and creative instructional approaches.

According to research on teacher education, "change in teaching would occur if teachers experienced consistent, high-quality professional development" (Desimone, Porter, Garet, Yoon, & Birman, 2002, p. 105). Powerful teacher education programs have to be based on knowledge about students and teachers. For example, a professional development

program must address issues on how students learn, what students need to know and to be able to do, how teachers learn, and what teachers need to know and be able to do to educate their students.

Also, our program was designed based on the belief that "successful reform requires acceptance and adoption by teachers" (McCaffrey et al., 2001, p. 493). In order for teachers to implement their learning into teaching, a professional development program should motivate teachers, individualize professional growth plans, and respond to teachers' personal and intrinsic needs (Belcastro & Isaacson, 1992; Bolin & McConnell-Falk, 1986; Bradley, 1996; Olivero, 1976). It is also strongly suggested that university personnel must consider the unique context of teacher education in planning the professional development program for classroom teachers. In other words, teacher educators must understand students and classroom teachers' needs/expectations, their learning processes, and educational contexts. Also, a professional development program developed collaboratively by classroom teachers, teacher educators, administrators, and community/parents is reported to be more effective (Lee, 2005).

The Professional Development Model in This Study

The professional development model presented here is based on three externally funded projects. These three projects shared common foundational and organizational features such as longer project duration, emphasis on teacher community, and an on-going evaluation process. Figure 1 depicts the professional development model. This model consists of four components: systemic support, knowledge building workshops, classroom implementation and application, and building a professional community. The knowledge building workshops and classroom implementation and application, which were the main activities of the program, occurred simultaneously. Intra and inter professional communities were built as a result of the program structure and activities. Systemic support from administrators, community, and colleagues was sustained throughout the project period.

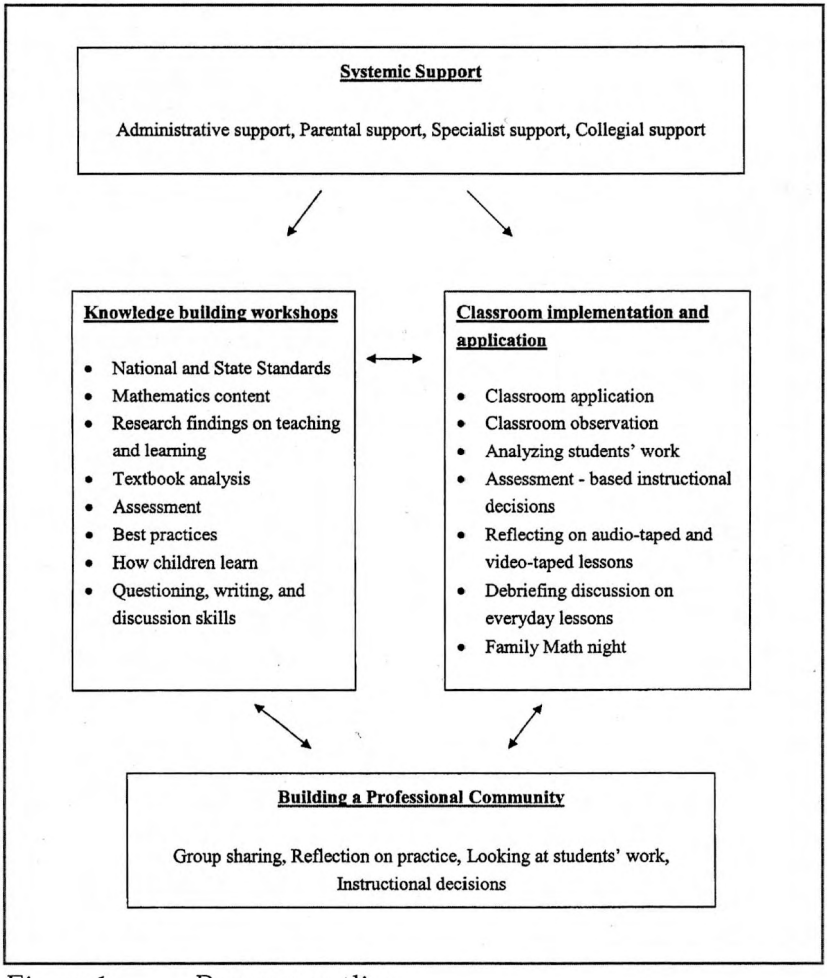

Figure 1. Program outline.

Systemic Support

Local educational administrators, the community, non-project participant teachers, and the higher education community supported the projects from the planning stage through the follow-up evaluation phase. The Ohio State University at Lima (OSU-Lima) served as the lead institution and fiscal agent. The West Central Regional Professional Development Center (WC-RPDC) and Education Service Centers (ESCs)

provided details about perceived needs of teachers in eight counties in the region. The ESCs and WC-RPDC aided in the recruitment of teachers through the use of fliers and demonstrations held at individual schools in the area. This support also occurred financially. Local education agencies shared the costs for conducting the projects, such as recruiting substitutes, advertising the project, and partially covering the cost of guest speakers and teacher stipends. The fiscal agent, OSU-Lima, paid the salaries of the project director, guest speakers, project instructors, graduate assistants, and the total cost of meals. OSU-Lima also shared the cost for equipment, communications and other services. The collaborative structure enhanced the project, with these many agencies and schools working toward the common goal of increasing teachers' content knowledge and pedagogical strategies in mathematics.

Knowledge Building Workshops

The professional development model focused on knowledge of mathematics content, as well as understanding how children learn specific content (Desimone et al., 2002; Garet, Porter, Desimone, Birman, & Yoon, 2001; Hiebert et al., 1996). In order to build teacher knowledge, we provided the opportunity to engage in the kinds of learning that teachers are expected to practice with their students (Loucks-Horsley, Love, Stiles, Mundry, &Hewson, 2003). For example, the main activities during the regular workshops were: discussions, collaborative group work, hands-on activities, readings in textbooks, developing lesson plans by using children's literature, solving mathematics problems with invented ways, developing a sample alternative assessment tool with rubric, and keeping reflective journals on each workshop session.

Classroom Implementations and Application

Curriculum implementation and replacing curriculum units were also used as fundamental activities for practicing teaching. Participants videotaped their lessons and reflected on these taped lessons. Creating new instructional materials and strategies helped teachers translate theory into practice (Loucks-Horsley et al., 2003). Moreover, analyzing their own lessons promoted reflection and helped to examine student work and thinking (Lee, 2005). As an application of instructional strategies, participants organized their own five-hour professional development programs or provided parental involvement programs (such

as a Family Math Night) within their respective school districts. This parental involvement activity focused on learning mathematics and increasing parents' awareness of the National and State Standards, which assisted parents in helping their children become mathematically literate.

Building a Professional Community

To build a teacher community the program recruited at least two or three teachers from the same school district. Collective participation, teachers from the same building have the opportunity to discuss concepts, skills, and problems encountered during the professional development (Garet et al., 2001; Weidemann & Humphrey, 2002). They can also integrate what they learn with other aspects of their instructional contexts such as common curriculum materials, course offerings, and assessment requirements. The teachers can discuss students' needs across classes and grade levels, as well as sustain changes in practice over time (Garet et al., 2001). These groups of teachers involved in the project were subsequently expected to act as leaders of professional development groups in their own schools and districts, by sharing their experiences at regional conferences/seminars and running workshops. Recruiting teachers from the same buildings was thus dually beneficial, increasing the project participants' leadership abilities and introducing effective teaching strategies to other teachers who did not participate in the project. In this last respect, the program also provided staff-embedded professional development.

Project Goals

The purpose of the program was to increase teachers' knowledge in the areas of (a) state and national standards for mathematics, (b) how students construct mathematical ideas, (c) higher order teaching strategies that promote active learning, (d) standardized and alternative means of assessment, and (e) effective use of technology (Desimone et al., 2002; NCTM, 2000). These five goals guided the design and activities of the project. The projects were aligned to the recommendations of the National Council of Teachers of Mathematics, Principles and Standards for School Mathematics (NCTM, 2000), as well as Ohio Academic Content Standards K-12 Mathematics (ODE, 2001). These NCTM and ODE standards state that "conceptual understanding provides a firm grasp of the ideas, definitions, and relationships in mathematics" (ODE,

2001, p. 193) and that teachers "must know and understand deeply the mathematics they are teaching and be skillful in choosing from and using a variety of pedagogical and assessment strategies" (NCTM, 2000, p. 17). The documents listed above suggest that learners construct meaning by being actively involved in the learning process, and that the effective teacher is one with expertise in both content and pedagogy.

Design of the Project

The major activities may be grouped into four phases: Part I was the recruitment of teachers. Part II provided workshops at The Ohio State University at Lima and included the follow-up activities of applying instructional strategies in participants' classrooms, reflecting on workshop and classroom activities, and monitoring observable and/or measurable changes in teachers' mathematics competency. In Part III, participants organized a professional development and/or parental involvement program for learning mathematics in their school districts. Part IV was a summative evaluation of the project.

Part I: Recruitment of teachers. The Regional Professional Development Center (RPDC) staff and curriculum supervisors from the Education Service Centers (ESCs) in the region prepared an initial flier announcing the projects. Public, private, and parochial school teachers from the region were invited to participate. The school districts rated at Continuous Improvement, Academic Watch, and Academic Emergency were the primary targets. Application materials were available at the institute/RPDC/ESC offices and their websites. The ESC and RPDC administrators aided in the recruitment and selection of the project participants.

Part II: Workshops and implementation. The topics covered were drawn from NCTM Standards (2000), Ohio Academic Content Standards (ODE 2001), standardized test results, as well as the needs expressed by teachers in the needs survey study and planning meetings. The workshops were conducted through discussions, collaborative group work, hands-on activities, problem-solving opportunities, and presentations by participants. On-site assignments included readings in textbooks, audio and videotaping of participant lessons, peer observation and self-reflection on these recorded lessons, reflecting on activities introduced during the workshop, developing lesson plans, solving mathematics problems with invented ways, developing a sample alternative assessment tool including rubrics, using various forms of

technology to solve problems and perform tasks, keeping a reflective journal on each workshop session, and mentoring and on-going communication with colleagues through WebCT (Web based course tool).

Part III: Application of instructional strategies. Teachers who participated in the project subsequently acted as the nuclei of professional development groups in their own schools and districts, by sharing their experiences at regional conferences/seminars and running workshops. In Part III, the application of instructional strategies, the participants developed and provided an inservice professional development program and/or parental involvement program (such as a Family Math Night) within their respective school districts that focused on learning mathematics. The activities were either self-made or a modification of a commercially available unit. In collaboration with the project director, the participants chose activities to present to their peers and/or parents.

Part IV: Evaluation of the project. Evaluating the effectiveness of the professional development program was on-going throughout the project period. The program was evaluated through analysis of the goals, design, instructional materials, classroom activities, and the responses of participants to the interview questions. The components of the evaluation implemented throughout the project included: a one-minute paper after each workshop, entering and exit survey questionnaires, observation of randomly chosen lessons by participants in their classroom, interviews with participants, reviews of participants' assignments, and a family math night of a professional development program conducted by the participants. In addition, the project evaluator visited a workshop session during Part II in order to observe activities and interview participants.

On the first day of instruction, a pre-study questionnaire developed by the Ohio Board of Regents, concept maps of effective mathematics teaching and an open-ended survey were used to evaluate participants' initial knowledge and dispositions toward teaching and learning mathematics. The same methods were administered on the last day of the workshop to measure participants' exit knowledge, beliefs, and attitudes toward teaching and learning mathematics. The project assignments included developing several curriculum mappings and lesson plans that respond to the national and state standards. Participants were expected to incorporate technology into their lesson plan. They also collected information about standardized tests including the purpose of the test, performance standards and achievement test

outcomes, and rubric. They developed classroom assessments based on the academic content standards. The project team developed an Activity Reflection Form, and, to digest each activity, participants used the form for every activity during or after the instruction. Participants' classroom practices were observed during Parts II and III. These visitations helped the project team better understand each teacher's needs and outcomes of the professional development program. Project instructors also observed a family math night or a professional development program conducted by participants.

Table 1. Project Evaluation.

Evaluation Means.	Project Goal				
	1	2	3	4	5
Pre- and post questionnaires developed by the state	x	x	x	x	x
Concept maps of effective mathematics teaching	x	x	x	x	x
Open-ended survey	x	x	x	x	x
Reflective journal and/or one minute paper	x	x	x	x	x
Curriculum map developed by the participants	x				
Lesson plans developed by the participants	x				x
Standardized tests analysis done by the participants		x		x	
Classroom assessment developed by the participants	x			x	
Activity reflection form completed by the participants	x	x	x	x	x
Observation: participants' classroom practice		x	x	x	x
Observation: a family night or a professional development program conducted by the participants	x	x	x	x	x

Methodology of Program Evaluation

In order to determine the effectiveness of the professional development programs, the project used a combined research design of qualitative and quantitative methods.

Data Collection

Data were collected from four different sources: survey (pre- and post-), classroom observation, teacher documents, and interviews, which fulfill data triangulation (Denzin, 1970). By using multiple measurements, "the uncertainty of its interpretation is greatly reduced. The most persuasive evidence comes through triangulation of measurement process" (Webb et al., 1966, p. 3). In the beginning and end of each program, we administrated a survey study, which was developed by the state. Summaries of pre- and post- survey data were submitted to the state as evidence of the effectiveness of the program. A total of 89 participant teachers from three programs completed open-ended survey questions inquiring their expectations, experiences, and assessment of the program. Teacher participants were also required to write weekly journal entries, which evaluated workshop sessions and required them to reflect on their teaching and learning. Teachers also submitted their lesson plans and assessment tools, which demonstrated their knowledge and instructional skills for teaching mathematics. Observation field notes were collected from project instructors and the evaluator during and after the project. Interview data were collected by project instructors and the evaluator during and after the project. The interview data provided information about changes in teachers' growth during the project.

Data Analysis

Descriptive analysis was done for the quantitative data by using a spreadsheet. For the qualitative data, a constant comparative data analysis was used in this study. Analysis for qualitative data progressed through various stages, including open and selective coding, integrating for similarities, assigning category names, examining recurring patterns and emerging themes, and delimiting the theory. The initial coding system for the written data sources was developed by the author and graduate associates collectively; the preliminary data analysis was carried out individually. The interpretation of the data was then compared as the coding system was developed.

Since this paper sought to answer questions related to the experiences of teachers participating in professional development programs and attempted to understand what experiences helped them improve their conceptual and pedagogical skills in mathematics, it was appropriate to center this inquiry in qualitative research methodology. The outcomes of the project reported in the next section are based on the themes that emerged during the data analysis process. The evidence provided in that section are based on open-ended survey questions, interviews, and observation notes.

Findings: Outcomes of the Project

Overall, participant teachers came to base their instruction on knowledge of subject matter, curriculum goals, effective instructional approaches, students, and the community.

Knowledge of Curriculum Goals

Several participants commented on their new appreciation for the standards, as had already been expressed in the class discussions. They were able to demonstrate their familiarity with the standards, benchmarks and grade level indicators and could identify required learning experiences based on standards. They could also evaluate best practices to determine their effectiveness in meeting state and national standards.

> The activities and methods taught in this series of classes have the techniques and materials to implement a nearly 100% hands on program. The importance of the state standards has been heavily stressed during these sessions. (teacher interview)

Instructional Approach

Teachers expressed appreciation for instructors modeling how to implement hands-on activities. They also reported that their time in doing hands-on activities during the workshop sessions was a beneficial element of their development. Teachers described our approach – teaching mathematics by thinking, talking, and doing – as helping them make lessons interesting, exciting and meaningful. They used problems for which there is no immediately obvious method or solution.

> This has made me more aware of how much fun learning can be with hands on activities. It has helped me to try to find more ways to make tutoring students interactive and yet have them

> learn the desired goal. I try to share as much info with other teachers as possible. I also try to do as much group work as possible. (teacher interview)

> I am able to offer more hands on activities to teach concepts, with appropriate structure for on-task. Students are more responsible for their learning. I am more able to release control and let the students teach each other. (teacher interview)

Teachers provided opportunities for students to engage in active and inquiry-based learning. Participants encouraged students to engage with materials in a more in-depth way for longer periods of time, as well as exhibit their understanding of subject matter in both traditional and nontraditional ways.

> Impressed upon me again how important hands on discovery, communication are to understand math. This class has led me to use many more hands-on activities with my students. With the use of hands on activities, students are spending more time with concepts that they only read about in past years. This should lead to greater understanding. (teacher interview)

During the interviews, attendees were asked how the project would help them in their teaching. The project evaluator reported that participants were enthusiastic in their praise of the workshop sessions, both in terms of the content and the pedagogy. Without exception, they looked forward to using many of the activities with their own students. They appreciated the focus on small-group work, but indicated they would not be able to devote as much time to inquiry in their own classrooms as had been done in the institute. They believed that encouraging discussion in small groups would help slower students grasp ideas more quickly and help faster students articulate and solidify their own understanding.

Student-Centered Lesson

Teachers became acutely aware of what is best for students and/or what works for a given student's level, while selecting instructional materials and strategies. Teachers also expressed that, by demonstrating a more inquiry-based approach, this program elevated their expectations of all of their students, which is one of the NCTM Principles (2000). It was noticed that participants appropriately matched instructional strategies and materials to identified students' learning experiences. They also

chose developmentally appropriate mathematics experiences for their students. Students were encouraged to maintain their own goals and data folders for self-assessment and self-monitoring of their own goal setting. Participant teachers fostered critical thinking in students by encouraging students to debate ideas or otherwise explain reasoning.

> This program encourages a more hands-on/experimental approach to understanding math concepts. By incorporating activities like the geoboard, building 3 dimensional shapes, and using different logic games and puzzles, the students seem to better understand the math topic. By having the students explore and discover a concept rather than just telling them how to do a process gives them more ownership and a better understanding of what is going on when they "do math." (teacher reflection)

Awareness of Students in Needs

Teachers also found that a hands-on oriented mathematics class actively engages learners at different levels, while helping the teacher gain a better understanding of an individual student's understanding level. In addition, teachers saw all their students benefit from the variety of materials presented in the program. Based on our observations, participants had created instructional opportunities adapted to the needs of diverse groups of learners.

> I teach a remedial math class. This class has helped me to meet their needs through different teaching styles. Before this class, I was not sure of many things. This class has helped me to reach children through various methods. Teaching is no longer a question of "What am I going to do," but one of "I can't wait to do this. " My students this year seem to learn more, be more enthused, and learn quicker. (teacher survey)

> The hands on activities have been very useful for IEP students who do not deal well with paper and pencil worksheets. Often these students lack confidence in their ability. With hands on activities, they are successful and gain confidence in their own ability. I have many students that ask to repeat a favorite activity and share our activities with their families. I have found

> that, due to these classes, I concentrate more attention on the individual student since I observe difficulty earlier than before.
>
> I don't wait to grade the worksheets to find a lack of understanding. My students love the activities and often say that they now love math. This attitude has already resulted in higher test scores. The activities do not require expensive equipment so all children are able to be involved. (teacher interview)
>
> The Teacher Quality Program helped me to discover different ways to present a concept that may be more appropriate for the students when they are having difficulty in math. Although I teach in a school with very few minorities, we do have a number of LD students and other students who have a difficulty understanding the abstract concepts of math. (teacher interview)
>
> The students who have high needs seem to thrive in the interactive hands on lessons. They are able to use the manipulatives to achieve concepts they were not able to grasp before. I find they are more excited and less hesitant to participate in lessons due to these interactive lessons. (teacher survey)

To meet the needs of a diverse group of students, the consensus was that good teaching is always sensitive to individual differences, though it is not realistically possible to accommodate every difference in every lesson.

Assessment Strategies

Participant teachers expressed concerns regarding the growing state and national emphasis on assessment, but seemed determined to balance their obligation to accountability with respect for enrichment and open-ended investigation. Teachers used information from Ohio's achievement tests and diagnostic assessments, classroom assessments, and national and international assessment in instructional planning and decision-making. They used more open-ended tests, clinical interviews, project-based assessments, observations, portfolios, mathematics reports, and so forth. Also, teachers monitored student performance in mathematics

by applying rubrics and keeping records of alternative assessment results.

Engaging Parents

The majority of teachers expressed a fear of teaching parents mathematics at the beginning of the project. However, they came to realize how important it is to educate parents and inform them about how their children are taught.

> This project definitely helped me realize the interest the parents have in what is going on in the classroom and mathematics in general. As a requirement for this class, I needed to hold a family math night. This was an overwhelming success in our district ... there was a positive outlook at what we do in our classrooms in teaching mathematics as the parents actively participated in classroom lessons ... making them more aware of what we do and why we do it! (teacher reflection)

In sum, the project participants demonstrated growth in the areas of "pedagogical knowledge, personal beliefs and practical experience, knowledge of learners and learning, subject matter knowledge, contextual knowledge, pedagogical content knowledge, and knowledge of general educational goals, purposes, and values" (Ho & Toh, 2000, pp. 2, 10).

Conclusion and Discussion

Some of the structural and core features of the presented program (Figure 1) can be adopted by other professional development programs. The ultimate goal of the model was to facilitate professional growth. Core features of the project were (a) a focus on subject matter content and pedagogical content knowledge, (b) promotion of active learning by using a hands-on, inquiry-based, problem-solving approach, (c) avoiding activities that are disconnected from one another, and (d) incorporating inservice sessions and classroom practices during the project. These identified core features were based on the premise that teaching is about knowing "not just knowing about content and the teaching of the content but also about self and how to know and how to use this knowledge" (Ho & Toh, 2000, pp. 2, 10).

The structural features of the program can be simply described as a combination of traditional and reform types of professional development – workshops, teacher networks, mentoring, and coaching – which work

well for teachers at various stages in their careers. Having mixed workshop days – regular school days, Saturdays, and summer meetings – was suggested by both teachers and administrations. It made it easier for administrators to find substitutes, and participants to balance their commitment to private life and professional development. Clearly, having extended duration was a strong feature of the program (Loucks-Horsley et al., 2003). Lastly, recruitment of teachers from the same school, department, or grade level helped the project team and participants. The project instructors were better able to understand the work atmosphere of the participants and diagnose the needs of the participants' students, which in turn helped guide the choice of topics and issues for discussion. Participants were able to sustain and manage a professional community during and after the project.

Overall, the design of the program was evaluated as being strong in three aspects that are well documented in the professional development research literature. The importance of having multiple participants in a school to serve as a support network throughout the project seems self-evident but is not always achieved. This support network was further strengthened by a second important feature of the design, namely, the assignment for each teacher to plan and conduct either a Family Night for parents or an in-service for colleagues in his or her school. Such activities not only consolidate understanding on the part of each project participant, but they also significantly broaden the benefits of the project (insure communication of the project's benefits significantly) beyond the circle of workshop participants. Teachers from the same building would come to a program with an existing support group, and the team would have strong potential influence the mathematics curriculum in their school system. The third significant feature of the project design was the amount of time each participant spent on workshop activities and the spacing of these activities over the span of nearly a year.

Another focus in evaluating a professional development program must be on participants' professional growth through various means (Table 1). A teacher's professionalism should be measured in two areas: knowledge and using the knowledge. Knowledge includes subject matter knowledge, contextual knowledge, pedagogical content knowledge, and knowledge of general education (Ho & Toh, 2000; Magnusson, Krajcik, & Boroko, 1999; Morine-Dershimer & Kent, 1999). Action, using the knowledge, can be viewed as building a powerful learning environment for mathematics, which includes respecting diversity and being inclusive, valuing authenticity, implementing an integrated curriculum,

building dialogue, constructing active, meaningful, and connected knowledge, understanding students, encouraging involvement in learning and cooperation, and believing in empowerment. This long list of domains of teacher professionalism tells us how complex good teaching is. Kagan (1992) described teaching as "a particular form of self expression in which the artist, the subject, and the medium are one" (p. 164). Therefore, paying more attention to teacher self-assessment can be a way of evaluating a professional development program, as well as a mechanism for facilitating professional growth (Ross & Bruce, 2007).

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