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Reflections on U.S. Professional Development in Mathematics Education

Lee, Soo Jin[1]

In the present reflective study, the research findings of professional development in mathematics education are reviewed and significant ideas that emerged are addressed in terms of (1) building on collaborative effort; (2) focusing on content knowledge; (3) centering on students' learning and bringing forth teacher knowledge; (4) perception-based and conception-based perspective; 5) situating in the context of teaching and sustained over time. Then it is followed by suggesting what components a desirable professional development program needs to include and a possible direction toward which future research on professional development in mathematics education heads.

Key Words: teacher education, professional development, constructivism

I. Introduction

In United States, beginning in the spring of 2009, governors and state commissioners of education from 48 states, 2 territories and the District of Columbia committed to developing a common core of state K-12 mathematics standard. Thereafter, nearly 95% of the entire U.S. states have adopted the new curriculum standards, *common core state standards for mathematics*. The new standards include not only specifications for mathematical competencies for students in particular grades, but also proposes a set of eight standards for mathematical practices which resonate well with the National Council of Teachers of Mathematics (NCTM) process standards (2000). The mathematical practices represent important habit of mind that teachers must learn to incorporate and promote in the classroom (e.g., to construct viable arguments and crtique the reasoning of others, to use appropriate tools strategically). Such mathematical practices have also been stressed by the Korea Ministry of Education Science and Technology (MEST, 2009). The MEST recommends teachers to create a classroom environment which not only takes into account of individual difference in students′ mathematical ability but

1) Montclair State University (leesoo@mail.montclair.edu)

fosters students' ability to reason mathematically/think logically using various approaches and to share their thoughts between each other through discussions. These expectations in U.S. and Korea are significant departure from those in the traditional classroom in that the role of teacher in the latter was to disseminate knowledge and students were to acquire the knowledge through repetitive practices. Improving classroom teaching is hard work. Teachers need opportunities to experience specific practices as learners before they can be expected to enact them as teachers. Teachers need opportunities to construct viable arguments themselves so that they understand what this practice means and are in a better position to consider what this practice looks like in their own classroom.

The change in teacher practice in classroom has been considered to be one of the critical factors that contribute to student learning. The way teachers teach mathematics in their classrooms affects how students view the subject; "What students learn is fundamentally tied to how they learn in" (NCTM, 1989, p.5; NCTM, 1991, p.21). Ferguson (1991) analzyed test score variations in 900 Texas school districts in the context of teacher quality, as measured by scores on a licensing examination, possession of a master's degree and years of experience. Ferguson found that about 40 percent of the measured variance in student test scores in both math and reasoning across grades 1 through 11 was accounted for by teacher expertise. However, it is challenging for teachers to change their own practice without any support and guidance for the reasons such that teachers come to the classroom by many paths - not all of them adequate for building a strong base of knowledge and skills for teaching, and meeting students' needs for skillful teaching and teachers' needs for answers to new puzzles requires continuous learning throughout teachers' careers (Darling-Hammond, Wei, Andree, Richardson, & Orphanos, 2009). Professional development, well-defined and carefully targeted, is the most potent weapon for continuing the growth of well-trained teachers and helping others overcome the gaps that may have been left by inadequate preservice education. This highlights the importance of designing an effective professional development, which enhances and develops teachers' mathematical knowledge for teaching. In spite of a growing number of professional development opportunities for teachers to participate in, scholars (Ball & Cohen, 1999; Hill, 2007; Putnam & Borko, 2000) have criticized that many professional development programs currently available to teachers are woefully inadequate. They are not formulated based on the studies that inform how teachers learn. Contents of the professional development programs are superficial and their forms are fragmented, relying on a collection of workshops and/or course offerings, as opposed to a continuous and ongoing program of professional development for teachers (Miller, Lord, & Dorney, 1994). Although a good deal of money is spent on staff development in the United States, most is spent on sessions and workshops that are often intellectually superficial, disconnected from deep issues of curriculum and learning, fragmented, and noncumulative (Cohen & Hill, 2000; Little, 1994). Cohen and Hill found that teachers reported less change in their teaching practices when their professional development included more generalized teaching strategies as a focus. Just as good education for students bears little resemblance to decontextualized memorization of information without opportunities to apply it, teachers learn well just as students do by studying, doing, and reflecting; by collaborating with other teachers; by looking closely at students and their work; and by sharing what they see (Darling-Hammond, 1999, p.12).

Such questions cast several questions on us like what constitutes effective and high-quality professional development programs for all teachers, which will eventually lead to student achievement. Moreover, as Wayne, Yoon, Zhu, Cronen, and Garet (2008) state, "The literature reveals an informal consensus about the features professional development programs should have in order to make them effective. But the evidence base for this consensus is weak" (p. 477). Thus, in this study, I attempted to provide a list of professional development efforts that targeted on one or two features of effective professional development identified in prior research (e.g., Desimon, 2009; Elmore, 2002; Guskey & Yoon, 2009; Guskey, 2000). To figure out plausible answers for the above questions, this study will be organized as follows. By looking back on professional development programs and research on teaching in mathematics education, the first section will briefly summarize earlier research on professional development, majority of which have been framed under the process-product research. The second section will describe characteristics of effective professional development programs and their ways to influence teachers' practice and their knowledge of mathematics suggested by various scholars in mathematics education. The elaboration will be based on their emphasis on a particular aspect of professional development programs: (1) building on collaborative effort; (2) focusing on content knowledge; (3) centering on students' knowledge and bringing forth teacher knowledge; (4) perception-based versus conception-based perspective, and (5) situating in the context of teaching over time. In conclusion, I will suggest what components a desirable professional development program needs to include and a possible direction toward which future research on professional development in mathematics education heads.

II. Earlier Research: the Process-Product Framework

It seems necessary to embark on describing characteristics of effective professional development programs by briefly discussing research, which had been popular in earlier periods 60s-70s, under the process-product framework. It is known as process-product research on teaching as it searched for relations between classroom processes (teaching) and products (what students learn). The studies under the framework based on observations of classroom processes and reliable measures of student achievement (or attitude or conduct) (e.g., Evertson, 1985; Evertson, Weade, Green, and Crawford, 1985;

Friedman & Stomper, 1983; Gall, Fielding, Schalock, Charters, and Wilczynski, 1984; Good & Grouws, 1979; 1981). Good and Grouws (1979) directed the Missouri Mathematics Effectiveness Project in an effort to improve teachers' practice by controlling the teachers' behaviors in the classroom under the *process-product* research framework. They assumed that teacher's behavior in classroom should influence pupil's behavior, and vice versa. Teacher behavior associated with effective mathematics instruction in elementary schools had been characterized and translated into an instructional program. After they provided two 90-minute workshops on what mathematics teachers were to teach, teachers in the experimental group were provided with instructional guides, which included step-by-step behaviors (e.g., allocations of time for daily review, seat-work, group work, and distribution of homework assignments) they ought to strictly follow in classroom. Good and Grouws found that treatment group teachers implemented more of the program's instructional elements than did control group teachers, and students under the treatment group teachers performed higher score on the achievement test than the students under the control group teachers. Even though the study showed the improvement of students' learning, a number of researchers (e.g. Brown & Borko, 1992) criticized it in that such prescribed instructional practice ignored characteristics of both teachers and students. As a matter of fact, the experimental groups′ education sessions were often relatively highly structured to control any unexpected effects, hence the treatment group teachers in the Missouri Mathematics Effectiveness Project needed to implement the exact step-by-step lesson provided by the project without any change. It ignores ″teacher″ in teaching. The framework is also criticized for assuming that teaching is directly related to learning which is, ″an overly simplified notion of causality that implies there is a one-best-way of teaching for each type of learning″ (Tom, 1984, p. 70). It is true that teaching influences student learning but the meaningful way to interpret the relationship between teaching and student learning is not one-way causal influence but reciprocal.

The trends in current studies have been toward examining the influence of professional development on teachers' practices and their knowledge of mathematics in greater detail by focusing not only on observable matters such as teacher behavior in a classroom but by taking into account of teachers′ cognitive structures encompassing their knowledge and beliefs.

III. Features of Professional Development in Mathematics Education

1. Build on Collaborative Effort

Research shows that strong professional learning communities can foster teacher learning and instructional improvement (Franke, Carpenter, Levi, & Fennema. 2001;

Garet, Porter, Desimone., Birman, & Yoon, 2001; Hiebert, Gallimore, & Stigler, 2002; Stein, Smith, & Silver, 1999; Stein, Glover, & Henningsen, 1996). Stein et al. (1996) explain that teachers learn individually and also as part of a group and thus that good professional development both transforms individual teachers and encourages development of a school culture within which they can grow. The QUASAR[2] project focused on improving instruction in middle school mathematics classrooms through emphasizing the cognitive demand of tasks (Stein, Smith, Henningsen, & Silver, 2000). Through the project a task analysis guide for classifying the cognitive demand of tasks was developed. Stein and her colleagues (1998) found "opportunities were available to QUASAR teachers to participate in collaborative working arrangements-forms of teacher support that presented departures from the conventional forms of teacher education"(p.21). The results of the study indicated teachers began to value community because "something important was happening between and among the teachers" (Stein et al., 1996, p. 28).

Brown, Stein, and Forman (1996) adopted the Vygotskian perspective of *teaching as assistance* of performance through the *zone of proximal development*. In this framework, teaching was considered to be assisting performance and learning as the result of assisted performance. At each school, a chain of assistance among principal, resource partners (mathematics educators), and teachers was formulated and supported teachers' classroom instruction, which eventually led to students' learning. Resource partners worked with the teachers to develop and conduct innovative curricula and instructional practices. Furthermore, teachers were asked to bring a ten-minute video clip among their lessons to discuss with their colleagues, which led another chain of assistance. Brown and Putnam concluded, from their study of one of those sites, that such a chain of assistance fostered both teacher change and student learning. That is, a supportive local community was critical to promote individual teacher practice. These two programs not only supported the value of learning communities but also showed "the development of teacher communities is difficult and time-consuming work" (Borko, 2004, p.7). Moreover, supplying teachers within a well-built local community does not guarantee effective change of their instructional practice if teachers are not equipped with sufficient mathematical knowledge.

2. Focuses on Content Knowledge

The effect of professional development which focuses merely on building collaborative would be limited if it does not put emphasis on developing teacher content knowledge.

2) Quantitative Understanding: Amplifying Student Achievement and Reasoning project (QUASAR) was a mathematics reform project to help middle grade (6-8) mathematics teachers to improve their instruction by supporting six site-based professional development programs in economically disadvantaged communities.

Gearhart and colleagues (1999) contrasted teachers in two different types of professional development programs: Integrating Mathematics Assessment (IMA) and Collegial Support (SUUP). IMA focused on mathematical contents, students' understanding of concepts and problem solving strategies in fractions, measurement, and scale, and their expertise with assessment. Staff developers started the program with a pre-established agenda. In SUUP, teachers built their own professional community and met regularly to discuss the challenges of implementing teachers' newly adopted curriculums and to reflect on their practices with facilitators. Unlike IMA teachers who were studied under the agenda, teachers in SUUP had to come up collaboratively with their own agenda and the facilitator's role was not active. There was a significant difference between the IMA and the SUUP group teachers. Teachers under the IMA, which was a knowledge-based professional development program, offered students more opportunities to engage with numeric representations in ways that helped students build understandings of concepts than teachers under the SUUP. So far, we have looked at professional development, which was built upon community of practice (the QUASAR and SUUP) and enhanced teachers' mathematical knowledge (the IMA).

More recently, Guskey (2003) analyzed a variety of published recommendations for successful professional development and found "the most frequently mentioned characteristics of effective professional development is enhancement of teachers' content and pedagogic knowledge" (p. 9). Sowder (2007) stated one goal of professional development as developing content knowledge and pedagogical content knowledge. Similarly, Garet et al. (2001) reported that professional development focusing on content knowledge, in this case mathematics, "is more likely to produce enhanced knowledge and skills" (p.935). Hill, Rowan, and Ball (2005) shared results of an assessment of content knowledge and student gains and noted "teachers' content knowledge for teaching positively predicated student gains in mathematics achievement" (p.399). Thus, this research supported the notion that focusing on improving teachers' content knowledge in professional development has the potential to positively impact student learning. Cohen and Hill (2000) used a survey instrument to learn about professional development opportunities for elementary teachers relating to state policy changes and if teachers reported practice related to the type of professional development opportunities they participated in. They found empirical evidence to support the importance of content knowledge as the focus of professional development in changing teachers' practices, noting "it seems to help to change mathematics teaching practices if teachers have even more concrete, topic-specific learning opportunities" (p. 312).

3. Centers on Students' Learning and Brings Forth Teacher Knowledge

While early studies in professional development (e.g., process-product paradigm) considered that teachers' ability to assess students' work was not as important as conducting the prescribed lesson plan due to teachers' cognitive demand, contemporary research in the field shows that good professional development should center on students' ways of learning mathematics and bring forth teachers' knowledge (Franke et al., 2001; Hiebert, Gallimore, & Stigler, 2002; Loucks_Horsley, Love, Stiles, Mundry, & Hewson, 2003; Stein et al., 1999). The basic premise under this framework is that just as students cannot learn without any perturbation, significant changes in teacher's knowledge or beliefs would occur only when the teacher sees something problematic in his or her own practices (Mewborn, 2003). That is, teachers learn how to teach (or change/improve their teaching) by critically examining artifacts of teaching and learning in collaborative settings with other teachers. Steffe and Wiegel (1992) emphasize that the most important role of teachers is to learn mathematical knowledge of their children and to harmonize their teaching methods with the nature of that mathematical knowledge. In addition, Ball (1993) stresses that "teachers need to have *bifocal perspective* and perceive the mathematics through the mind of the learner while perceiving the mind of the learner through the mathematics" (p. 159).

An example of professional development that centered on student learning is Cognitive Guided Instruction (CGI) project (Franke et al., 2001) working with elementary teachers. The project worked to establish generative learning in teachers so that teachers would move beyond the ideas about student learning presented in the professional development project and begin to build ideas about their own students' learning. Successful teachers were empowered to teach mathematics by connecting and reorganizing the mathematical structures of their students. As part of the project effort, one-month summer workshop regarding the learning of addition and subtraction concepts[3] was designed to promote teachers' understanding about students' knowledge in that area. In the workshop, teachers were to develop lesson plans based on what they learned from the course with an aid of the facilitator, and implement on their own classroom. Whereas the professional development under the Process-Product framework provided teachers with ready-made instructional design, the CGI let teachers to construct their own instructional design based on their own understanding of students' knowledge. The professional development program involved 40 first-grade teachers whose half of them were placed in the experimental group where they were asked to design their own instruction based on CGI work with children, and the remaining 20 teachers were in the control group where they only worked on problem solving tasks. Classroom observation and pre-post student achievement tests of experimental group teachers revealed that students in the experimental classes performed better than the students in the control group. Moreover, the treatment group teachers spent more time on word problems, and focused more often on the process that students used to solve problems.

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3) CGI conducted laboratory-based research on the children' s development of addition and subtraction concepts and procedures as reflected in their own solutions of different types of word problems (Fennema et al., 1993)

Similarly, Swafford, Jones, and Thornton (1997) adapted CGI study and designed an intervention program to enhance teachers' mathematical knowledge and knowledge about students' learning of geometry. The four-week program consisted of a geometry content course and a research seminar on van Hiele theory, one of research-based findings on student cognition in geometry. Teachers either interviewed students or analyzed instructional activities in their textbooks. Swafford et al. reported that teachers' instructional practice changed as teachers enhanced their knowledge of geometry and research-based findings on student' learning of geometry. Another successful example of the professional development under this category is the Second Grade Classroom Teaching Project (SGCTP), Cobb, Wood, and Yackel (1990) provided teachers with a professional development program that emphasized all components mentioned above. They first conducted a pilot study with a second grade teacher. They provided the teacher with literatures on children's construction of number schemes, and worked closely with the teacher for a year to develop instructional activities that allowed students to construct their knowledge of early number concepts. Pre-established instructional activities were modified during their experiment with children, and new activities were constructed. They found that the teacher was more apt to understand literatures of children's mathematical learning and alter her classroom as she experienced disequilibrium between her actual classroom experience with her own child and her knowledge of children's learning gained from reading literatures. The pilot study was successful and as a consequence the SGCTP was conducted with 10 treatment group teachers, comparing with 8 of control group teachers. The program consisted of a one-week summer institute, and researchers visited to all teachers once every two weeks during the first year of their participation, and weekly-based small group meetings were held for treatment group teachers to discuss their experiences as well as four after-school work sessions. Moreover, Cobb et al. also provided the teachers with opportunities where they could examine new curriculum materials, solve mathematics problems that they would teach to students, and then study student learning in their professional development program. As a result of such experience, treatment group teachers' students performed better on conceptual understanding. The instructional activities that teachers developed together with their colleagues with a support of the facilitators for teaching mathematics gave rise to multiple learning opportunities for the teachers because the activities encouraged students to express rich and varied mathematical thinking. Besides, the teachers also experienced profound changes in their thinking about students' learning of mathematics and their role as a facilitator of that learning.

As we have seen, several professional development programs were conducted to improve teachers' knowledge, and showed improvement of their instructional practice in the classroom. However, few studies were done to reveal what teachers' change of their instructional practice actually meant. In other word, most of the professional development programs that I mentioned so far did show that the programs influenced teachers' change of their instructional practice, but they did not investigate further why the teachers changed their practice and how the modifications of their teaching practice were reflected on students' learning.

4. Perception-Based versus Conception-Based Perspective

Past research indicates that teachers′ conceptions of mathematics strongly affect how they teach mathematics in their classrooms. Schifter and Simon (Schifter, 1998; Simon & Schifter, 1991) set out a professional development program to improve teachers' instructional practice. The study conducted under Simon and Schifter was different from others addressed previously, in that the former study revealed how teachers' perspectives about mathematics and learning influenced their ways of knowing and instructional practice. They conducted Summer Math for in-service teachers for elementary and secondary as a part of the Educational Leaders in Mathematics Project (Simon & Schifter, 1991, 1993) and the Teaching to the Big Ideas (Schifter, 1998) projects and looked at changes in teachers' subject matter knowledge and pedagogical content knowledge that occurred. The study was based on the assumption that fundamental change in teaching necessitates not only change in teachers' beliefs about mathematics and learning (see Goldsmith & Schifter, 1997; Schifter, 1998; Simon, 2000; Simon & Tzur, 1999), but also growth in teachers' subject matter knowledge. Simon (2000) introduced *perception-based* and *conception-based perspective* to articulate teachers' changes. That is, in perception-based perspective, teachers believe that knowing mathematics with understanding involves first-hand experience in perceiving the math and that individual perceives the math in the same way (believing that every child will learn place value using base-ten block.) Simon stated that perception-based approach is different from a traditional perspective in that the former emphasizes direct personal perception and connectedness in mathematics, and teachers believe that students do not passively absorb what they say. Whereas perception-based perspective on mathematics learning still reserves platonic view of learning, the notion of conception-based perspective to the mathematics learning is that mathematical objects and relationships are believed to be constructed by the learner on the basis of the learner's current knowledge and experiences (e.g., using manipulative is an interacting situation in one's experiential reality and thus mathematical knowledge should be structured from one's conceptions or schemes not directly caused by first-hand experience).

In the Summer Math, two weeks summer institute constituted two avenues for promoting teachers' mathematical investigations: exploration of disciplinary content and examination of student thinking. Like other professional development programs, they believed students thinking as a powerful site for teachers' further mathematical development. Staff members weekly visited the teachers' classrooms and provided feedback, demonstration teaching, and opportunities for reflection. They provided additional workshops to share collaborative experiences related to mathematics, learning, and teaching. Simon and Schifter (1991, 1993) concluded that the intervention had a significant influence on teachers' perspectives about mathematics learning and teaching, and that the changes in their perspectives affected their classroom teaching of mathematics. Furthermore, Shifter (1998) supplemented[4)] their previous analysis by observing teachers' classroom practice, and concluded that the activities of the Teaching to the Big Ideas program not only helped teachers to engage in mathematics for themselves and to examine students' thinking but also guided teachers to develop a disposition to inquiry. That is, teachers started to believe themselves not only as teachers but also as researchers who are studying children's ways of knowing mathematics in classroom.

5. Situates in the Context of Teaching and Sustained over Time

Teaching is influenced by knowledge of mathematics and beliefs about teaching and learning (Hill, Ball, & Schilling, 2008; Hill et al., 2005). These knowledge and beliefs are situated in the context of teaching (Putnam & Borko, 2000), which means that the most salient knowledge used by teachers is what is developed in the context of teaching. Situating the change process in the actual teaching and learning where the new ideas will be implemented is an effective strategy for helping teachers changes their practice. Research findings show that teacher training in which teachers investigate their own teaching can be effective in promoting teachers′ growth, especially when provided with ongoing support in addition to summer professional development (Ball & Cohen, 1999; Borko, Mayfield, Marion, Flexer, & Cumbo, 1997; Guskey 2002; Hiebert & Stigler, 2000; Kazemi & Franke, 2004; Putnam & Borko, 1997; Wilson & Berne, 1999).

Moreover, research shows that timespan for professional development and the number of contact hours are significant predictor of impact of professional development as reported by teachers (Garet et al., 2001). This is consistent with earlier comments regarding the importance of connecting to the context of teaching. It is unrealistic to expect changes in teaching to result from short term workshops, which tend to be disconnected from the teaching context and which do not change teachers′ existing repertoires. Ball (1996) states, ″the most effective professional development model is thought to involve follow-up activities, usually in the form of long-term support, coaching in teachers′ classrooms, or ongoing interactions with colleagues″ (pp. 501-502). These are the features adapted after the successful model of the Japanese Lesson Plan

4) ELM reported the result based solely on the writings of and interviews with participating teachers without any observation of teachers' classroom practices; furthermore, the change of participating students' beliefs and attitudes about mathematics was measured by the analysis of survey, and there was no significant change on students' achievement score.

study. Japanese lesson study is a collaborative, school-based professional development that is common in elementary schools in Japan (Fernandez & Yoshida, 2004). It suggests three characteristics in formulating an effective professional development program: (1) a program is more effective when the content of the program is relevant to teachers' curriculum so that they can use the standards that the state employs. (2) a program is more influential when the program is situated in teachers' school because the process of integrating ideas and practices that teachers learn from outside the classroom into each of their ongoing instructional program, is considered hard, and (3) teachers need ample time to accommodate what they learn from a professional development program.

In CGI project, Franke et al. (1998, 2001) followed and observed treatment group teachers' classrooms sporadically for about four years, and verified that half of them continued to learn to teach in distinctive ways than others who were merely using the materials that they learned from the professional development program as tools to apply. By conducting a longitudinal study, CGI described teachers' learning in the context of a professional development program as a self-sustaining and generative process. In addition, several researchers provided teachers with professional development programs at teachers' school sites (see Borko et al., 1997; Kazemi & Franke, 2004). Interestingly, most of the studies adapting Japanese Lesson Plan seemed to be guided under *situated perspective*[5)]. The basic premise of situative perspective is that teachers need to continuously *recontextualize* what they learned from the workshop outside of their school as they engage with their children in the classroom and through teachers' collaborative works. Kazemi and Franke (2004) extended and modified the CGI studies by adapting Japanese Lesson Study; they facilitated weekly work group meetings in each of schools instead of holding out-side workshop. Kazemi and Franke provided rationale for modifying CGI's earlier professional development programs. They commented as follows:

> We did not follow the CGI approach by conducting workshops with the teachers and presenting them with the frameworks, nor did design activities using videos or worksheets for them to make sense of how the typologies for problem types and strategies related to one another. Instead, we introduced CGI principles and terminology as teachers made observations of their own students' mathematical thinking. However, we did provide teachers with common problems to use in their classes, which consisted of CGI word problem types (p. 206).

Kazemi and Franke examined groups' collective activities rather than individual

5) Situative perspective consists of three premises about cognition; first, cognition is situated in particular physical and social contexts secondly, cognition is social in nature; and finally cognition is distributed across the individual, other persons, and tools (Putnam & Borko, 2000, p. 4).

activity in the professional development situation to describe teacher learning because they assumed that a person develops through participation in an activity and students' works play a part of learning as a tool. They tracked changes in teachers' learning by examining shifts in the practices of the workgroup, and found that as teachers brought their experiences with children and discussed as a whole, not only the individual teacher development occurred but also such processes transformed the practices of the community.

University of Colorado Assessment Project (CU) provided the professional development program, which consisted of a yearlong series of weekly workshops for the third grade teachers at each of their schools (Borko et al., 1997). The mathematics educators presented at each mathematics workshop, and facilitated changes in teachers' assessment practices by helping them to think about their instructional goal and the relationships among goals, instruction, and assessment. Besides, the facilitators guided teachers to develop or select assessment tasks appropriate to their goals and to create scoring criteria for the assessment tasks. Such agendas were modified as the teachers worked with materials that they brought, and the materials eventually included instruction as well as assessment. The study concluded that teachers of all three schools made several significant changes in their ideas and practices about mathematics assessment and instruction as a result of participation in the CU Assessment Project. Borko et al. (1997) suggested several important implications for professional development programs as the following:

Situating the change process in the actual teaching and learning contexts where the new ideas will be implemented is an effective strategy for helping teachers changes their practice. Group discussions of instructional and assessment issue can be effective tool for the social construction of new ideas and practices. Staff development personnel and other persons with specific expertise can facilitate change by introducing new ideas based on teachers' current levels of interest, understanding, and skill. When teachers' beliefs are incompatible with the intentions of the staff development team and are not challenged, the teachers are likely to either ignore new ideas or inappropriately assimilate them into their existing practices. Time is a major obstacle to changing classroom practice. (p. 269-270)

IV. Discussion

In this reflective study, I have attempted to sketch out the main characteristics of effective professional development programs that were described by scholars in mathematics educations. To summarize the main points, effective professional development programs are the ones that provide teachers with sufficient knowledge of content and children's ways of knowing mathematics. Moreover, the programs have proven to be more effective when they offered teachers with opportunities and sufficient time to accommodate what they learned from the program. Effective professional development programs seem to support teachers in their school as well as in the workshop by participating in their planning periods or workshops. Situating teachers in a helpful community that consists of facilitator, colleagues, and a principal can be one way of supporting teachers in the school site. The point of formulating community is for teachers to get an opportunity to share new ideas of teaching mathematics or children's learning so that they can keep facing challenges with the way they teach their children and further accommodate better ways to teach mathematics. Finally, for mathematics educators to design an effective professional development program, they need to understand teachers' perspectives or beliefs of mathematics, teaching, and learning because those components are reflected on teachers' instructional practice, and eventually influence students' learning.

The literature is filled with stories of good intentions to change teaching followed by a disappointing return to traditional methods of practice. The worst case is that some teachers believe that they are implementing reformized student-centered class while the evidence from their actual practice often suggests in the opposite way teachers usually deliver mathematical concepts to students rather than developing them, and just focus on organizational features of the classrooms rather than on mathematics like Ms. Oublier in Cohen′s criticism (Cohen, 1990). While she saw herself as a success of the program and believed that she had revolutionized her mathematics teaching, she had in fact maintained very traditional teaching practices. Upon closer examination, Cohen identified her beliefs that were in many ways antithetical to the constructivist views of mathematics teaching and learning that undergird recent mathematics reform efforts. It appears that Ms. Oublier assimilated what she saw from the new standards or curriculum into her perception-based perspective, and there was no support at the time to accommodate her practice to conception-based perspective. Moreover, had she been continued to be supported by a collaborative sustained professional development experience where she could discuss her teaching practices or dilemma with other teachers, mathematics educators, district supervisors, and math coaches, she could have made more meaningful change in her teaching. Discussions around artifacts of teaching allow teachers′ misconceptions to surface, opening them to challenge based on evidence drawn from teaching situations.

Analogy might be applicable to most of the teachers in Korea as well as in U.S; what is increasingly clear is that whenever teachers set out to adopt a new curriculum or instructional technique, they learn about and use the innovation through the lenses of their existing knowledge and beliefs (Borko & Putnam, 1996; Simon, 2000). For that reason, in future research on mathematics teacher and professional development programs, it needs to be included not only teachers' changes in knowledge through a professional development program, but also the influence of their beliefs on instructional practices. In Korea, Oh (2006) reported that teachers′ beliefs about how students learn mathematics have changed toward the more students′ oriented way after participating in the professional community focusing on improving mathematics teaching. Na (2010) conducted activities of learning community on elementary mathematics lesson with 4 elementary teachers, especially focusing on establishing objectives and contents of learning community, writing the critical essay on elementary mathematics lesson, and reflecting on the activities of learning community. She reported that the members of learning community could increase the professional development on elementary mathematics lesson by criticizing the lesson together. Those results imply that participating in the community of practice where teachers can share their practical knowledge and their understanding about teaching and learning of mathematics could play a crucial role in changing their beliefs as well as deepening their professionality.

In addition, it is useful to know that a good professional development program is required to have well-designed content-focused curriculum including analysis of students' mathematics. In order to equip teachers to understand their students' reasoning, teachers are to have a chance to build their own (practical) theories of learning and teaching by reading research literatures and reorganizing the theories through teaching students, rather than only providing teachers with (believed-to-be-right) teaching strategies. If mathematics educators could provide mathematics teachers with situations, where the teachers can investigate their own students' reasoning, the teachers will naturally want to learn more about their own understanding of mathematics, teaching, and other environments that can help their students to learn mathematics.

> To learn mathematics is to learn ways of reasoning, so we automatically include mathematical reasoning. Children do not learn mathematics in isolation of a social context, so automatically we include teachers and teaching. Teachers learn the mathematics they teach, so automatically we include teachers' learning. Explication is part of mathematical reasoning, so automatically we include communication, and thus we include teaching. (Thompson, 1991, p. 240)

As Thompson pointed out, understanding students' reasoning is not limited solely on students but their learning environments, which include teachers, their teaching behaviors, and further discourse and communication among them. If teachers are not familiar with the way their children learn mathematical concepts, they are likely to follow the curriculum aimlessly, which might result in dismal failure. Teachers construct their own understandings of students' thinking (Carpenter et al., 1996; Steffe, 1990, 2007) as students do. Teachers bring informal knowledge about students' mathematical thinking into their classroom, and it is mathematics educators' job to bring forth their spontaneous knowledge about students' mathematical thinking and help teachers to reframe it into well-organized knowledge so that it can play a significant role in making instructional decisions in the future.

Also, it is informative to know that one cannot expect instant effect from a professional development, hence it necessitates the sustained program which could provide teachers with continuous support. As Franke et al. (1998, 2001) suggested, learning to teach is a self-sustaining and generating process; simply conducting the pre-post test to decide teachers' change in their knowledge and conception seems insufficient. Even if studies have attempted to describe what has changed or what has not changed during the course of the program, the previous studies often were not based on explicit commitment to understand the coherence in the teachers' practice at each point in time. Researchers should focus on "qualitative reorganizations of teachers' understanding" (Goldsmith & Schifter, 1997, p. 21). Moreover, Guskey (1986) suggest that teachers will not make permanent modifications in their teaching until they see that the modifications result in benefits to their students. Cobb et al. (1990) also emphasizes that the process of teachers' change, though depending on improved student outcomes, is actually an interactive one. When children begin to show increase of their learning outcomes, teachers continue to implement new methodologies that result in the improved learning, and so the circle continues.

V. Implications

Good teachers form the foundation of good schools, and improving teachers' skills and knowledge is one of the most important investments of time and money that local and national leaders make in education. Yet with the wide variety of professional development options available, methods that have the most impact on student learning are controversial. The five features that are delineated in this study build on the characteristics of effective U.S. professional development identified in prior research (e.g., Desimone, 2009; Elmore, 2002). While most features seemed to be applicable in designing professional development programs in Korea, studies should be conducted to identify characteristics of effective professional development that could foster teachers in Korea.

Moreover, as mathematics educators, we need to establish a model of teacher development processes and re-construct teachers' hypothetical constructs from a long-term perspective (Simon, 1995). "Researchers need to structure their accounts of the teachers' practice using researchers' lenses that define the researchers' foci and guide their interpretations" (Simon and Tzur, 1999, p. 254). Just as researchers' second order model for students is different from the students' first order mathematics in a teaching experiment, the accounts of teachers' practice from researchers' perspective may be different from what the teachers would say about their own practice. Most of the studies mentioned earlier used teachers' self-reports as a measure to confirm the influence of the professional development programs. However, knowledge and beliefs are the results of one's abstracting regularities in the form of relationships between an activity and the effects of that activity through reprocessing mental records of one's experiences. Accordingly, researchers do not learn about a person's meaning-making system by asking the person to explain it, but by observing the way the system actually works from the researchers' perspective. Hence, future studies should contribute to the field by investigating and interpreting participating teachers' intentional behaviors under the well-designed environments for their professional development.

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Reflections on U.S. Professional Developmentin Mathematics Education

미국 수학교사 전문성 신장 프로그램에 관한 소고

이수진[6]

초 록

본 연구에서는 수학교육분야에서 전문성 신장 프로그램 연구 및 수행에 대한 고찰을 통해 드러나는 다섯 가지 중요한 범주들이 기술되었다: (1) 효율적인 지원 공동체 수립, (2) 교사 지식에의 주목, (3) 학생의 학습에 대한 지식을 기반으로 한 교사지식의 구성, (4) 인식기반 및 개념기반 관점, (5) 장기간에 걸친 현장에서의 교사교육. 결론에서는 바람직한 교사교육 프로그램이 포함해야 할 요소들과 앞으로 이 분야에서 이루어져야할 연구방향 등이 제시된다.

주요용어 : 교사 교육, 전문성 신장 프로그램, 구성주의

6) 몽클레어 주립 대학교 (leesoo@mail.montclair.edu)