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Redefining Curriculum Integration and Professional Development: In-service Teachers as Agents of Change

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Calls for curriculum integration in K-12 mathematics and science have seen nominal results. Numerous factors including cycles of practice in teacher development and professional development practices have inhibited the development, dissemination, and implementation of integrated curriculum. This paper examines the characteristics of the professional development standards of both disciplines; considers inherent hindrances to the implementation of integrated curriculum; generates a novel definition for integrated curriculum; argues that the most effective change agent is in-service professional development; and provides guiding notions for effective in-service professional development.

Keywords: teacher professional development, curriculum integration, teacher education, math education, science education, teacher standards

Educational discussions, particularly in mathematics and science education, are continually abuzz regarding student learning, classroom pedagogy, and the need for integrated curricula to support both (Frykholm & Glasson, 2005; Furner & Kumar, 2007; Koirala & Bowman, 2003). Educational organizations such as the School Science and Mathematics Association [SSMA], National Council of Teachers of Mathematics [NCTM], American Association for the Advancement of Science [AAAS] and National Research Council [NRC] provide educational leadership to researchers and classroom practitioners in the call for an integrated math and science curriculum.

Much of the literature and research supporting the integration of mathematics and science curricula is based on real world applications of both subject areas (Frykholm & Glasson, 2005; Rutherford & Ahlgren, 1990), the affect of integrated mathematics and science investigations on student motivation and learning through relevant investigations (*e.g.*, Frykholm & Glasson, 2005; Jacobs, 1989; Koriala & Bowman, 2003) and the belief that integrated investigations promote deeper understandings in both fields (Berlin, 1994; George, 1996; Mason, 1996). Summarily, most rationales in support of integrated mathematics and science curricula argue either that mathematics and science are in some ways similar or that they are complementary. This latter argument is often stated in one of two ways: either "mathematics is the tool through which science is done and science brings a context to mathematics" or "mathematics enhances scientific understanding and vice versa." In a more recent argument, Bossé, Lee, Swinson and Faulconer (2010) state that mathematics and science curricula should be integrated because people learn mathematics and science through similar learning processes. Thus, the concern becomes less one of the content of mathematics and science and more about how people learn in the two fields.

Despite which rationale or call for reform is selected in support of integration, the integration of mathematics and science curricula and instruction are still not commonly seen in our K-12 classrooms and rarely attempted in post secondary education courses. A major stumbling block for creating integrated learning opportunities is the environment in which teachers find themselves. The educational community needs to work together to better offer students integrated math-science curricula. Unfortunately, multidimensional factors continually hinder the development and application of integrated curricula. Herein, many of these factors are considered and, in so doing, this article argues that, to make the change toward integration in mathematics and science curriculum, the fields must first address teacher education through professional development.

Teaching & Learning in Integrated Curriculum

The importance placed upon the need for integrated curricula in mathematics and science has been a consistent theme since the 1930s (Lake, 2003). This is evidenced in the abundance of professional publications touting strategies for integration, projects promoting integration, and research indicating effective learning through integrated curricula. For example, research suggests that: by integrating mathematics and science, students are more likely to find relevance in their learning and are thereby more likely to be interested and motivated to engage in classroom learning events (Friend, 1985; Wolfe, 1990); students will develop a deeper understanding of both subjects as they use science to contextualize mathematics and they use mathematics to explain and model science (McBride & Silverman, 1991); and instructional practices of both mathematics and science education include implementation of inquiry-centered instruction (Hamilton et al., 2003) resulting in many similarities in the way that science and mathematics are generally taught. More recently, it has been demonstrated that there are extensive similarities among the processes through which mathematics and science are learned (Bossé et al., 2010), including principals of argumentation, models, discovery, exploration and problem solving. These shared processes leading to the doing and learning of mathematics and science lead to the development of deep conceptual understanding of the topic. According to *How People Learn* (NRC, 1999) there are three essential components of powerful teaching and learning: active inquiry; in-depth learning; and performance assessment. Exemplars and discussions provided in *How Students Learn* (NRC, 2005) also support an integrated curriculum. These exemplars specifically demonstrate that while the teaching of abstract principles does not provide a bridge for changing misconceptions, abstract principles taught along with quantitative relations or applications in observation and exploration can effectively teach science and math concepts. The totality of these publications argues that integrated curriculum is effective in student learning.

Addressing these concerns, many national organizations leading the charge in educational reform of mathematics and science have focused on the implementation of integrated curricula. This call is manifested in documents such as the *National Science Education Standards* (NRC, 1996) and *Project 2061* (AAAS, 1990, 2009).

Integrating Mathematics and Science Instruction

Mathematics and science are most often thought to be the easiest of subjects to be integrated in instruction as the two disciplines are typically viewed as logically connected (AAAS, 1990; McBride & Silverman, 1991; Pang & Good, 2000). Related literature has revealed four dimensions of mathematics and science learning and discusses how these dimensions can be used as lenses through which to view professional development programs and revise such into models which more effectively address the integration of mathematics and science.

First, recent research has determined that the respective standards for mathematics and science demonstrate significant similarities in learning processes among both disciplines (Bossé et al., 2010). This is based on the analysis of the five process standards from mathematics (problem solving, reasoning and proof, communication, connections, and representations) (NCTM, 2000) and the 5-*Es* from science (engagement, exploration, explanation, elaboration or extension, and evaluation) (NRC, 1996, 2000).

Second, the development of a community of learning is identified in each respective domain as crucial for teachers involved in the teaching of science and mathematics (Hiebert, Gallimore, & Stigler, 2002). Commonalities in discussions within the NCTM and NRC texts regarding social and affective dimensions to learning (Bossé et al., 2010), reinforce the importance of student learning through social interaction and community.

Third, since science and mathematics can both be learned through problem-solving opportunities, the well established four-step problem solving heuristic (Understanding the Problem, Devising a Plan, Carrying out the Plan, and Looking Back) promoted in the work of Polya (1957) can be expanded upon and be applied to reinforce the importance of problem solving in an integrated curricula. Problem solving and problem posing are shared core learning experiences within math and science that transform lessons into critical thinking experiences (NRC, 2005) and transforms students into active learners and investigators (NRC, 2005; Xia, Lu, & Wang, 2008). Within mathematics and science instruction and learning, problem posing and problem solving are neither separate nor linear; similarly, within integrated mathematics and science instruction, the content of a particular lesson may not have a designated linear path; one transforms into the other and can easily transform back (Brown & Walter, 2005).

While these dimensions may argue that the integration of mathematics and science may be somewhat easier than the integration of other topics, and nearly a century of calls for this integration can be recognized in the literature, there remains a dearth of integrated mathematics and science curricula and educational experiences in the classroom. Two primary reasons may be ascribed to this disconnect: inconsistent definitions for integrated curriculum and environmental factors inhibiting the implementation of integrated curricula. These issues are considered in the following discussions.

Definition of Integration

Since the 1930s, progressive educators have advocated for an integrated curriculum, sometimes identified as the "core curriculum" (Vars, 1987). Their arguments were often based on the work of Piaget, Dewey, Bruner and others who held holistic views of learning and constructivist theories (Lake, 2003). In an argument for an integrated curriculum to improve education, Dressel (1958) defined integrative curriculum as planned learning experiences which provide learners with solid instruction in one field while developing their understanding of new relationships through other topical structures.

Unfortunately, the term "integrated curriculum" is generally not well defined, even among organizations who tout the importance of curriculum integration. No particular global definition for integrated curriculum seems to have taken sufficient hold to support the efforts of individual groups. Therefore, identifying what curriculum integration means for any dimension of education is not readily accomplished. Compounding the difficulty of defining integrated curriculum are the myriad of seemingly synonymous terms used in the place of "integration" (Lederman & Niess, 1997); among others, these include: interdisciplinary, multidisciplinary, transdisciplinary, thematic, integrated, connected, nested, shared, webbed, threaded, immersed, networked, blended, unified, coordinated, and fused (Bossé et al., 2010). The employment of such extensive vocabulary regarding integrated curricula has made the discussion, development, and implementation of integrated curricula in the schools unnecessarily complex and may have significantly hindered the progress of educational reform in this direction.

A Novel Definition

Berlin and White (1992) report on the difficulty of the consensus in defining integration. In an interest to improve science and math education, the National Science Foundation (NSF), the School Science and Mathematics Association (SSMA) and the Johnson Foundation, invited community members, experts and leaders in science, math and education to develop a single working definition. After several days of deliberation, and without complete consensus, Berlin and White report on the working definition of integration as the fusion of "…mathematical methods in science, and scientific methods into mathematics, such that it becomes indistinguishable as to whether it is mathematics or science (p. 341)." Unfortunately, this definition seems overly philosophic to be educationally pragmatic in either curriculum development or instructional practice. Recognizing when a classroom learning experience "becomes indistinguishable as to whether it is mathematics or science" may be nonsensical to most curriculum developers and classroom teachers. Thus, while the expert's definition may be philosophically dense and provocative of rich and valuable discussion regarding integration, it may be educationally unusable, manifesting a disconnect between practitioners and curriculum developers. It may be argued that a definition of this form leads to greater confusion, lack of coherence, and a stymieing of the efforts it hopes to promote.

In this paper we pose a new definition for curriculum integration which we argue is more usable by educators:

> Recognizing the strengths, weaknesses, commonalities, and distinctiveness among two or more fields of study, an integrated curriculum uses each field in the experiential learning of the other(s). Integrated curriculum is designed to allow students to simultaneously experience these fields of study in such a manner that students both do and learn important content and concepts in each of the respective subjects and glean further understanding from the gestalt formed among the subject matters.

Notably, this generic definition can be beneficial to educators interested in integrating any number of subject matters. To make this definition more specifically directed to the integration of mathematics and science, we offer the following working example of the preceding definition:

> In respect to mathematics and science, integration is not simply recognition that mathematics and science are complementary or that mathematics is a tool for science and science is a context for mathematics. Integrated mathematics and science should not always begin with a scientific investigation which is then solved mathematically. Truly integrated instruction may begin with a problem scenario posed in either subject, pass through either subject in investigatory phases, and find a resolution in either subject all the while ensuring that neither subject is subservient to the other and that the level of content and conceptual coverage in both areas is at least commensurate with that which would be covered in standalone subject matter courses.

To exemplify this definition, we offer the following scenario of a professional development workshop offered to math and science middle grade teachers. The Classrooms Reaching Enquiry through Astronomy & Telescope Education (CREATE) workshop focuses the learning on an integrated approach for math and science. Teachers build a 4.5 inch mirror telescope from scratch as they learn about the concepts of light. As an introduction, they are given several kinds of lenses and mirrors and asked to observe how they each provide a different kind of observation. Teachers talk about the properties of light and discuss the placement and relationship of the lenses and mirrors in order to build telescopes. They are then introduced to two types of telescopes (reflecting and refracting). Teachers are directed to think about how they might build a reflecting telescope with the mirrors and to determine how they would need to redirect light from a secondary mirror to an eyepiece (science concept). They discuss methods of determining the length of the focal point (science concept), the exact placement of the eyepiece (math concept) and have to convert units between inches to metric (math concept) because the materials are manufactured and sold in different units. The lesson is simultaneously about focal length, the behavior of light in respect to mirrors, performing mathematical calculations and conversions, and algebraic and geometric concepts. The teachers make their plans as to where to cut holes and locate the mirrors in the tubes and argue in support of that placement based on their methods of determining the cut (science and math processes). The discussion is both mathematical and scientific in nature. As the teachers discuss the cuts and placement, they argue over what is actually measured and how that is represented in the equations that they decide appropriately model their understanding. They argue about what it means for the focal length to meet at a given point and why the light should bend or reflect on the secondary mirror at a given point. They argue how the positioning of the mirror changes the calculations for the placement of the eyepiece and the length of the tube. Before any actual cutting takes place, they find several ways to model their ideas and try to convince others of the soundness of their measurements and understanding of light and mirrors. When the teachers have agreed and completed their task of placing the eyepiece, they are asked to explain what to do if the tube was shorter or if the mirror had a different focal length (a combined math and science conceptual confirmation).

Differentiating both this generic definition of integrated curriculum and the mathematics- and science-centric concretization of such from the NSF's definition is an issue of *distinguishability*. While the NSF's definition for curricular integration denotes that the subjects in question become so thoroughly integrated that one becomes indistinguishable from the other, the definition and example provided in this discussion embraces the fact that any two subject areas have sufficient distinctiveness such that one subject can accentuate the interaction with, and learning of, the other subject.

Furthermore, rather than simply stating that methods from two subjects can become indistinguishable, this new definition seeks to emphasize that instructional investigations in integrated curricula between two subjects may be initiated alternately with an inquiry from one or the other subject, use either subject in the investigation of the problem scenario, and be finally resolved in either one of the subject areas. Altogether, denoting the two subjects as A and B, this can lead to the following variations in the problem posing-problem solving-solution sequence of the process: AAA, AAB, ABA, ABB, BAA, BAB, BBA and BBB. Thus, from only two subjects, at least eight scenarios are possible in solving a problem in an integrated curriculum – although some may argue that combinations such as AAA and BBB fail to exemplify integrated models. If the problem solving process is understood to include a greater number of processes, the possible combinations of these sequences grow very rapidly. The previous scenario (CREATE Project) is an example of a sequence of AABBAB; a reflection of a *nesting of integration* (Fogarty, 1991).

With a solidified understanding of, and unified definition for integration, curriculum development and applications have a greater possibility of affecting education reform, curriculum development, and classroom practices. This understanding of integrated curriculum can be the foundation upon which future professional development can be launched.

Perpetuation of Traditional Learning Environments & Approaches

Numerous factors work in tandem to further inhibit the development and implementation of integrated curricula in K-12 schools. Among others, these include environmental factors, the current framework of state standards and high stakes testing in K-12 schooling, and collegiate pre-service educational programs. Most importantly is the issue of pragmatic compartmentalization in the learning and teaching of mathematics and science. Some of these dimensions are expanded upon in the following discussions.

Teacher Experiences

As with students, what teachers bring to the classroom is built upon prior knowledge (Bramald, Hardman, & Leat, 1995; Carin, Bass, & Contant, 2005); what teachers have previously learned, their own beliefs and ideas, and their previous experiences in education will affect what they will learn and what they will teach (Loucks-Horsely, Love, Stiles, Mundry, & Hewson, 2003). Like all learners, teachers need to have their knowledge integrated (Davis & Krajcik, 2005). However, virtually all teachers are the products of educational systems in which mathematics and science were compartmentalized and segregated. Thus, K-12 students envisioning entering education as a career are already programmed and predisposed to recognizing the separation of mathematics and science in the schools and curricula.

Upon entering the teaching profession, novice teachers return back to an environment where segregation of mathematics and science instruction is prevalent. Unless participating in relatively unique projects, most teachers will only see minimal examples of science and mathematics integration throughout their entire careers. Intensifying the problem, state standards in all subject areas are written in isolation with no reference or use of common language regarding integration. Teachers are mandated to teach their individualistic state standards under the pressure of high stakes testing. This forces teachers to focus their curriculum on their tested content, causing teachers to adopt instructional strategies to increase student test scores (Cimbricz, 2002; Marchant, 2004; Paris & Urdan, 2000), increase their instructional time spent on test preparation, use instructional and assessment approaches more likely to resemble the tests (Marchant, 2004), and avoid both topics that are not covered by the tests and innovative teaching methods (Cimbricz, 2002), such as integration. Teachers, especially novice teachers, are likely to perceive subject integration as impractical in light of accountability to standards and high stakes testing. Drake and Burns (2004), argue that teachers' misperceptions of their inability to work with integrated curricula to meet the requirements of high stake testing while addressing student standards is partially attributable to their unfamiliarity of other disciplines' content and standards: teachers who teach math are not likely to have a strong understanding of science or science teaching standards. However, if teachers were exposed to learning about content and teaching standards in multiple subjects and to understanding those subjects, they could more easily identify how to chunk the standards into meaningful clusters both within and across disciplines (Drake & Burns, 2004).

Some might argue that integration is occurring in elementary schools, since elementary teachers are responsible for teaching all subjects. While the elementary grades may seem like an optimal opportunity to teach through integration, elementary teachers almost universally teach segregated topics, aligning discrete class times to discrete subjects (*e.g.*, English, math, and science) each day (Lewis, 2010). Many elementary teachers teach science only once a week or during one quarter and even when elementary teachers *think* they are integrating science and math, they are most likely lacking the conceptual connections between subjects and instructional strategies that promote integration (Douville, Pugalee & Wallace, 2003).

Altogether, the *status quo* for teacher experiences creates a block to teachers having the experiences necessary for them to understand and implement integrated curriculum in their classrooms.

Pre-Service Teaching Experiences

Sandwiched between these two K-12 educational experiences of student and teacher are the few years of pre-service teacher development programs. Unfortunately, pre-service programs rarely do much to foster an understanding of the core processes (*i.e.*, the nature of science) (Lederman, 2006). The value and application of integration of mathematics and science instruction, when addressed in a pre-service program is likely to be perceived as contrived (Cady & Rearden, 2007). When pre-service teachers begin their collegiate pursuits, identification of mathematics or science is placed on respective plans of study. Each plan of study is usually heavily weighted in content and methods specific to either field. While some pre-service programs allow students to be certified in one subject area and encourage students to choose a concentration that requires more content and methods in another subject, this is not a universal programmatic design. A query for integration and course requirements for elementary teacher programs in a National Association for Research in Science Teaching [NARST] and Association of Science Teacher Educators [ASTE] listserv returned a rare case when integration was purposefully designed and in which content courses were heavily loaded in the program requirements for elementary pre-service teachers. Many certification programs for elementary education require little more than a single mathematics or science content course with one methods course. Exacerbating the balkanization of mathematics and science seen in the K-12 educational setting, collegiate pre-service content courses are even more emphatically segregated. Mathematics and science content areas are generally in different departments and the rare purposefully planned integrated courses are not likely to be effectively integrated experiences by students (Cady & Rearden, 2007). Additionally, dual certification in math and science was rarely connected to the notion of integration; rather students were required to complete disjointed coursework to increase the disconnected understanding of science and math content.

Returning to the premise that the greatest majority of teachers are predisposed to teach in a manner similar in which they have themselves experienced learning, it is dubious if our future teachers will implement integrated curricula. Since few classrooms or programs actually engage students in an integrated learning environment, those entering into our teacher education programs will not have the experiences upon which to build their teaching skills and pedagogy in a manner that includes integration. Most teachers enter the profession experiencing approximately seventeen years in classrooms where learning has been compartmentalized and science and mathematics instruction has been lecture-based or teacher-demonstrated. During student teacher internships, pre-service teachers visit the classrooms of expert teachers, observe topically segregated instruction and curriculum, witness lecture-based instructional techniques, and infrequently observe integrated curricular practices.

Without some change in the experiences and preparation of teachers, future teachers cannot be expected to teach in an integrated manner. Based on factors which perpetuate the *status quo* and the fact that both the K-12 system and university pre-service system are simultaneously monolithic and immutable, it seems unlikely that efforts to make changes in our educational curricula will occur at the K-12 and pre-service education levels. Although research continues to demonstrate that integration of math and science are important in teaching and learning, this research does not seem to be reaching and affecting students, classrooms, and practicum experiences of pre-service teachers (Beck & Kosnik, 2002) and the philosophy of teaching and learning supported by research is not reaching campus programs and practicum experiences (Darling-Hammond, 1999; Zeichner, 1996). These educational institutions (K-12 education and pre-service teacher programs) have historical relationships to philosophies, politics, procedures and structures that are difficult to change. On the other hand, institutions for professional development remain less formalized in their relationships with political bodies, such as professional organizations and accreditation agencies, and are consequently easier to evolve and change.

Therefore, in order to break this perpetuation of the traditional cycle of teaching and learning, educational designs need to provide teachers with the necessary experiences to promote integrated thinking and practices. It seems most reasonable that in-service teacher professional development be targeted as the primary point of intervention to provide teachers these pro-integration experiences. In addition, it has become more acceptable for research faculty to be involved in professional development designs (Darling-Hammond, 1999) which further promote opportunities for the research supporting integration to reach the practice of teachers. The remainder of this paper addresses in-service teacher professional development and provides ideas to promote the integration of mathematics and science instruction.

Focus on Professional Development

At this point, it may seem that professional development is being promoted as the solution to increasing integration of mathematics and science in K-12 education. However, professional development itself also contains inherent hindrances to the dissemination of integrated curriculum. Thus, before considering the benefits of professional development in this goal, its weaknesses are investigated.

Weaknesses of Professional Development

Prior to considering the nature of professional development needed to promote integrated curricula in mathematics and science, the authors thought it appropriate to investigate the recommendations, standards, and goals for professional development provided by various leading organizations which are recognized as pertinent to this discussion. Standards are lists and descriptions of benchmarks and milestones which form the specifics of goals that lead to the vision or mission (Loucks-Horsley et al., 2003). The standards documents included in this investigation are: NCTM (1991), NRC (2000) from the developers of the Science Standards for teachers through the National Science Teachers' Association [NSTA], NBPTS (2004), and NSDC (2001). Altogether, these documents consider mathematics, science, pre-service, and in-service teacher education and hold the imprimatur of their respective organizations. Therefore, throughout this paper, the association is considered synonymous with its respective publication.

Although other organizations address standards for teacher education (*e.g.*, Mathematical Sciences Education Board [MSEB] and Interstate New Teacher Assessment and Support Consortium [INTASC]), analysis was delimited to these four documents and organizations as they specifically offered standards for teacher professional development, are highly respected among math and science education fields, and are a fair representation of the guidelines used to structure and design professional development in math and science. The National Council for Accreditation of Teacher Education [NCATE], another leading organization that offers standards for teacher education related to professional development, provides guidance for teacher education entities and professional development schools which paralleled recommendations from the four selected documents. Since this study intended to evaluate professional development in respect to integrated curriculum rather than professional development schools, the simultaneous finding of redundancy and the misalignment of professional development schools versus professional development itself allowed for this investigation's omission of NCATE's standards without the loss of the study's integrity or completeness.

Loucks-Horsley et al. (2003) identify four areas of goals which are essential for professional development, if professional development is to be linked to student achievement: *student learning*, *teacher learning*, *teaching practice*, and *the organization*. Among all standards from the four documents investigated, these four themes, along with an additional theme related to community centered goals (found in NBPTS and NSDA), were readily recognized. However, analysis found that the goals for teacher learning and teacher practice were often combined in such a way that discerning a distinction was difficult. For example, the NBPTS standard that "teachers think systematically about their practice and learn from experience" is focused on both teacher learning and teacher practice. Therefore, this study combined teacher learning and teacher practice goals to form a *teacher-centered* goal.

Each of the four sets of documentary standards were analyzed and compared regarding their respective emphasis on four foci (*student-centric*, *teacher-centric*, *programmatic-centric*, and *community-centric*) according to the number of individual goals described by each set of standards. A synthesis of this analysis is represented diagrammatically in Figure 1.

While the standards from the four organizations display a broad panorama of the many concerns which must be filled in order for professional development to be successful, the inconsistency among organizations and the varying emphases of foci may make it difficult for professional developers to create programs which will accomplish all these goals. Table 1 provides an alternate summary of the findings in Figure 1.

Together, Figure 1 and Table 1 indicate that each organization focuses their standards more toward one theme than any of the other themes and that none of the organizations agrees entirely with the emphases of goals

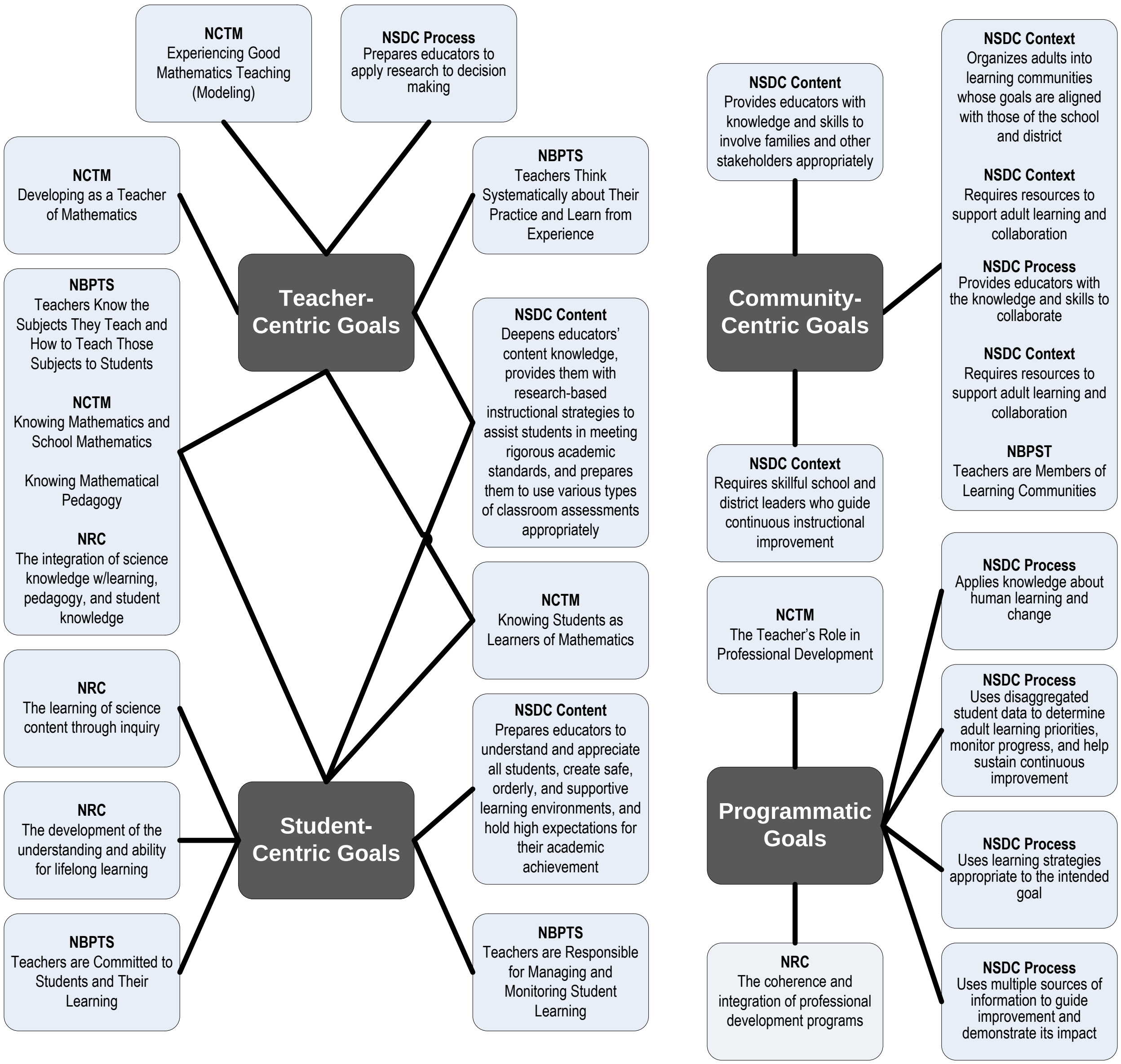

Figure 1. Foci of respective organizational recommendations for professional development.

Table 1

Numeric Breakdown of Foci in Professional Development Standards for Respective Organizations

	Goals			
Organization	*Teacher-Centric*	*Student-Centric*	*Community-Centric*	*Program-Centric-*
NCTM	5	2	0	1
NRC	1	3	0	1
NBPTS	2	3	1	0
NSDA	2	2	6	4

proposed by the other organizations. For example: NCTM has five goals that are specific to *teacher-centered* needs, while NRC only has one; NSDC has six goals focused on community needs, while the NCTM and NRC have no goals in that theme; and NBPTS has zero programmatic goals, while the NSDC has four. This inconsistency can be problematic for the developers of professional development. For instance, while professional development coordinators in mathematics will design their programs to meet the goals and emphases provided by NCTM, these programs may not support the same emphases in goals for science educators who will work to design goals provided by the NRC. Thus, they will feel compelled to offer separate professional development programs to meet their field's respective needs and may miss the opportunity to design professional development which fulfills a more global set of goals.

Beyond the inconsistencies in foci among standards from the four organizations, curricular integration is a focus in none of the standards documents. Thus, even if any educational enterprise successfully created a professional development program which fulfilled all the standards of the four organizations, curriculum integration may still not be valued.

The finding of the four foci emphasized in the standards documents may further speak to why integrated curricula are so problematic to implement in K-12 schools. For example, it may be that one organization emphasizes *teacher-centric* components because they feel that teachers need more development in that area than other foci; or an organization may believe that emphasis on one particular focus is more essential in positively affecting student achievement. In either case, this reflection of differing philosophies or perceived needs may interfere with subject matter integration in classroom instruction.

Summarily, the *status quo* for the vast majority of professional development for mathematics and science education may inherently possess a greater number of obstacles to curricular integration between the two fields than it does to facilitate such. Only if professional development is revisioned and reconfigured can it make a positive impact on the field. This is addressed in the following discussions.

The Positive Side of Professional Development

While professional development may necessarily differ across K-12 grade levels, it is herein argued that in-service professional development provides a sufficiently positive and nuanced platform to appropriately meet respective needs of classroom teachers and break the cycle of experience and teaching that has previously prevented integration between science and mathematics education. In-service professional development is the point of intervention that is most likely to have an effect in changing teaching practices and experiences and change the nature of K-12 mathematics and science instruction toward a model which includes greater curricular integration. However, to alter professional development into successful models, new frameworks and rationales must be considered upon which to create these professional development projects. A number of these rationales are addressed sequentially.

Promoting educational change through in-service professional development. It was previously mentioned that altering either the K-12 educational system or pre-service teacher education programs toward integrated curricular models is extremely difficult. Thus, no opportunity for promoting the changes in teacher understanding, skills, and beliefs, may be as ripe for actualizing these changes as is the in-service professional development of mathematics and science teachers. While practicing mathematics and science teachers have most likely learned how to teach math and science in a compartmentalized manner, using their in-field experiences, professional development programs can address what these teachers recognize is working and what is not. Pre-service teachers rarely have sufficient experiential bases to recognize instructional strategies which are more or less successful. In-service professional development leaders can introduce an integrated teaching approach to practitioners, demonstrate a correlation between integrated learning experiences and student outcomes, and address teacher beliefs about the importance of integrated curricula and instructional practices.

Teachers acquire new knowledge by constructing it for themselves (Carin et al., 2005; Hiebert et al., 2002; Loucks-Horsely et al., 2003) and when they can share their knowledge with colleagues and the public (Hierbert et al., 2002). Professional development can situate teacher learning and experience regarding integrated curricula in their own classroom contexts which they find to be more meaningful and relevant (Hiebert, et al., 2002; Loucks-Horsely et al., 2003). Thereby, as a result of in-service professional development, practicing teachers are able to experiment with different instructional strategies in their classrooms. Possessing experience in assessing student learning, in-service teachers can identify what changes students may experience when the instructional approach changes and in-service teachers will have experience in implementing, interpreting and addressing results from assessments; this affords them the expertise to identify apparent changes in teaching effectiveness and learning, further confirming or denying the effectiveness of the implementation of an integrative curriculum.

Novice teachers. Another rationale for focusing educational change through in-service professional development is related to teacher experiences with classroom management. Novice teachers focus most of their attention in their decisions for instructional practice based on classroom management (Berliner, 1988; Veenman, 1984). Although they may be taught to implement strategies that promote inquiry and integration, they will not transfer this knowledge into practice because they are uncertain as to how to address classroom management while simultaneously focusing on novel instructional practices (Feiman-Nemser, 2001). In-service teachers are more likely to have developed strategies that allow them to have a strong classroom management plan which permits them an opportunity to focus on the instructional decisions that impact their instructional delivery. Some novice science and mathematics teachers feel that, when implementing instructional techniques which focus on either inquiry-based instructional or the integration of mathematics and science, they don't sacrifice classroom control, removing themselves from the focus of instruction (Fogarty, Wang, & Creek, 1983). More experienced teachers are less likely to be discomforted by these experiences.

The teaching cycle. Due to the impact and connection that practicing teachers have on both grade school students and pre-service teachers, addressing a change in practice with practicing teachers affects the entire cycle of teaching. Because teachers learn by watching other teachers (Feiman-Nemser, 2001), most pre-service teacher education programs require an internship through which pre-service teachers observe how experienced educators teach, write, implement lesson plans, and use curricula. As pre-service teachers observe effective and experienced in-service teachers employ integrated curricula and instruction, greater possibility grows that pre-service teachers will later use the skills and techniques associated with integrated curricula which they observed. This cycle of teaching practice impacts the grade school students who may later decide to enter into education. If teachers are not providing an integrated learning experience, K-12 students become trained to think compartmentally and may have difficulty thinking about teaching and learning in an integrated manner.

Some studies suggest that students cannot transfer their learning from one subject to another (Perkins, 1991) and they may resist the change of learning from the compartmentalized teaching to the integrated teaching. Students may be even more resistant to change from compartmentalized instruction to integrated learning if they had previously found some degree of success in the former. With these forces in place, while novice teachers may abandon implementing the changes needed to implement integrated curricula, experienced teachers are more likely to feel confident about their teaching, make necessary modifications of such, and find support strategies as needed to help their students through the stress they may feel with a new learning environment.

Although experienced teachers often do not conduct research on student misconceptions (Hiebert et al., 2002), with the support of researchers providing professional development and the teachers' classroom experience, in-service teachers are more likely to be able to identify student misconceptions. In-service teachers can draw upon their experiences to know what kinds of strategies to implement to address and challenge those misconceptions. This knowledge and skill are developed through improving a teacher's pedagogical content knowledge (PCK). Studies show that pre-service programs do little to change a teacher's PCK and their PCK does not change for the first three years of practice (Luft & Roehrig, 2004). This is primarily because the early career teacher is focusing on the stresses of the job and because PCK is developed with teaching experience, not through instruction (Lee, Brown, Luft, & Roehrig, 2007). To be able to teach an integrated curriculum, a teacher would need to have PCK specific to both mathematics and science. While it is unlikely that a teacher would have a well developed PCK for both mathematics and science (since they are most likely trained in either but not both), it would be less difficult for an expert, practicing teacher with a well developed PCK of at least one of these areas to integrate the lesson and learn to develop the other area of PCK.

In addition, it is unlikely that novice teachers will be comfortable teaching what they do not feel they know. Many researchers suggest that beginning teachers tend to rely more heavily on one domain of knowledge rather than drawing simultaneously from all domains, as is the case with in-service or expert teachers (Ball & Bass, 2000; Davis & Krajcik, 2005; Grossman, 1990). This supports that in-service teachers are more likely comfortable with trying new approaches, and are more likely to implement an integrated curriculum that requires more than one domain.

A New Model for Professional Development

Having argued that integrated mathematics and science curriculum is both needed and woefully lacking in K-12 schools and that the most effective timing of teacher support which will most positively affect the implementation of integrated curriculum takes the form of in-service professional development, it must be questioned what unique features or characteristics this professional development must take. The following bullets provide some guidance for a novel framework for in-service professional development which will lead to the integration of mathematics and science instruction.

General Recommendations for All In-Service Professional Development

- Professional development should utilize teachers' classroom experiences in school settings while developing a community of learning among the participants.
- Professional development should be *student-centric*, *teacher-centric*, *program-centric*, and *community-centric*. It should not simply consider how it affects classroom teachers, it should consider how the students and community are affected through the professional development and consider the effectiveness of the professional development as a whole.
- Professional development should attempt to affect the teaching cycle. Whenever possible, experienced teachers should be partnered with pre-service teachers in authentic instructional and practicum scenarios.

This assists in molding the next generations of teachers and showing them the best instructional models as understood through the eyes of the classroom teacher.

- Professional development should occur after teachers are no longer novices and before they become professionally unalterable.

Recommendations for Professional Development in Respect to Integrated Curriculum

- Professional development should focus on problem posing and problem solving in both areas of study.
    - Investigations should not always begin in one field and be solved in the other.
    - Problem scenarios should be posed in either subject, pass through either subject in investigatory phases, and find a resolution in either subject.
    - Problem scenarios should ensure that neither subject is subservient to the other.
    - The level of content and conceptual coverage in both areas should be at least commensurate with that which would be covered in standalone subject matter courses.
- Mathematics and science must be understood as both separate and interconnected fields. Professional development must help teachers develop PCK in both fields.
- Employing the definition for curriculum integration previously espoused, professional development should:
    - recognize the strengths, weaknesses, commonalities, and distinctiveness among two or more fields of study;
    - use each field in the experiential learning of the other, and
    - allow the teachers and their respective students to simultaneously experience these fields of study in such a manner that they both do and learn important content and concepts in each of the respective subjects and glean further understanding from the gestalt formed among the subject matters.

Conclusions

According to our educational leaders, and to the calls for reform in education, our current educational system is broken. The calls for reform suggest that the system be improved upon by developing curricula that is integrated. Current research supports similarities among how mathematics and science is learned. In our educational system exists a cycle of teaching which includes students, pre-service teachers, and in-service teachers; each is an important component in enacting changes in the educational system.

The most effective change agents in instigating educational reform through curriculum integration rests with experienced teachers for three reasons: (1) K-12 students may someday be educators and will need the experience of this sort of learning environment. (2) Pre-service educational programs often rely on the internships to help new and upcoming teachers to develop skills, experiences and models of good teaching. If pre-service teachers do not observe and experience integrated curricula, they will have great difficulty in this environment. Later in their practice, after becoming comfortable in traditionally segregated curricula, they will become even more reluctant to make changes. They need a contextual view of curriculum while they are learning how to teach math and science (Frykholm & Glasson, 2005). (3) Expert teachers have an understanding of assessments and PCK and have developed skills in classroom management that will support their willingness to try new things and their ability to implement new ideas into practice.

Similarities in learning processes among mathematics and science open new dialogues concerning professional development regarding integrated curriculum. Investigations capable of being integrated when necessary and yet distinguishable as distinct pieces, is the most pragmatic approach to view the integration of mathematics and science based on the similarities in learning processes. Decisions of distinction should be determined by the best interest of the discipline in respect to learner needs and student achievement in the existing paradigm. It is hoped that educational leaders will collaborate on revising professional development standards that are consistent in meeting essential components of teaching and learning: addressing the importance and value of integration; the issues of high-stakes and standardized testing; and infused opportunities for in-service teachers to engage in and add to educational research. We recommend that the starting point for promoting integrated mathematics and science instruction and curriculum and the necessary supporting professional development should begin in small incremental steps. Historically, the greatest success in changing curricular practices has consistently been found to occur when the change desired requires noticeable, sustained effort, but is not so massive that typical users must adopt coping strategies that seriously distort the change (Crandall, Eiseman, & Louis, 1986).

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