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STEM Education and Leadership: A Mathematics and Science Partnership Approach

Chris Merrill and Jenny Daugherty

Introduction

The issue of attracting more young people to choose careers in science, technology, engineering, and mathematics (STEM) has become critical for the United States. Recent studies by businesses, associations, and education have all agreed that the United States' performance in the STEM disciplines have placed our nation in grave risk of relinquishing its competitive edge in the marketplace (e.g., *Rising above the gathering storm*, 2007). A Congressional Research Service (2006) report stated that, a "large majority of secondary students fail to reach proficiency in math and science, and many are taught by teachers lacking adequate subject matter knowledge" (Congressional Research Service, 2006, p. 1). Students lacking in STEM skills will not have the ability or skills to enter in the professions of science and engineering or areas requiring mathematics, science, and technology literacy.

To counteract these circumstances, multiple STEM-based initiatives and funded projects have been developed. Two particular initiatives that have and will impact technology education are: (a) the National Science Foundation funded National Center for Engineering and Technology Education (NCETE), and (b) the United States Department of Education funded Mathematics and Science Partnerships (MSP). Based on the lessons learned through NCETE, efforts were leveraged into developing a successful MSP grant proposal focused on the establishment of a science, technology, engineering, and mathematics (STEM) Education & Leadership Program.

The purpose of this manuscript is to share with the STEM education profession, particularly the technology education community, an explanation of the Federal Mathematics and Science Partnership programs and what this type of funding opportunity can do for technology education's future direction. It is believed that advanced STEM-focused opportunities and experiences, such as those afforded by the MSP program, will strengthen the content knowledge, pedagogy, research (especially action research), and leadership capabilities of teachers. Although the MSP program at Illinois State University has not been

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completed, the resources made available by the MSP program and the activities associated with the initial planning phase have allowed the research team at Illinois State University to build a significant theory base from which to implement a sound program. By sharing the theoretical grounding of the STEM Education & Leadership Program, it is hoped that the field can begin to move in a similar direction to address the needs of students and teachers.

To provide a better understanding of the NCETE and MSP programs, the components of each of these funded projects are outlined next. A review of the related literature is then outlined with particular attention paid to the unique components of the proposed STEM Education & Leadership Program. Following the literature review, an overview of the approach that will be proposed for implementing the program is provided. Given the parameters set by the MSP grant, the related literature, and the STEM Education & Leadership Program approach, potential impacts are predicted for the particular teachers involved in the program and for the future of technology education and STEM education more broadly.

NCETE and MSP Background

The National Center for Engineering and Technology Education (NCETE) was funded by the National Science Foundation as one of seventeen 10 million dollar Centers for Learning and Teaching in the United States in 2004 (National Center for Engineering and Technology Education, 2007). NCETE, headquartered at Utah State University, is a collaborative network of universities (University of Georgia, University of Illinois at Champaign-Urbana, University of Minnesota, Utah State University, Brigham Young University, Illinois State University, North Carolina A&T State University, University of Wisconsin-Stout, and California State University, Los Angeles) with backgrounds in technology education, engineering, and related fields. The mission of NCETE is to build capacity in technology education and improve the understanding of secondary teachers and students in relation to the engineering design process. A significant component of this mission is focused on the professional development of teachers. During the first three years, NCETE's professional development efforts were concentrated on the enhancement of technology education teachers in the area of engineering design. As these initiatives have progressed, NCETE has shifted its focus to the development and testing of a model for engineering and technology education professional development.

In 2003, the United States Department of Education released 100 million dollars for Mathematics and Science Partnerships (MSP) in response to the No Child Left Behind Act of 2001, Title II, Part B. In 2004, the federal appropriation for the MSP rose to 150 million dollars, and by 2005 through 2007, the annual appropriation rose to 180 million dollars (U.S. Department of Education, 2007). The overarching goal of the U.S. Department of Education's MSP program is to increase students' achievement in mathematics and science by increasing teachers′ content knowledge and pedagogical skills. The MSP grant supports partnerships between mathematics, science, and/or engineering faculty of institutions of higher education and high need school districts, in addition to other partners such as schools of education, business, and nonprofit organizations. The MSP program is a formula grant program to the states. Each state administers a competitive grants program, monitors their grantees´ progress, and documents their effectiveness, working with the U.S. Department of Education. State-funded MSP projects report to the federal government on an annual basis.

The MSP program is specifically focused on increasing the math and science content knowledge and teaching skills of classroom teachers to enable them to meet the qualifications for highly qualified status in science and/or mathematics and other educational areas like technology education. In addition, partnerships are also focused on teachers meeting the qualifications for endorsement in teacher leadership. Essential elements of the MSP programs are the processes, principles, and concepts of mathematical inquiry and problem-solving, scientific inquiry, and technological/engineering design. In addition, formative and summative assessment, analysis, and evaluation strategies are built into the design and implementation of the partnerships. Action research conducted by the MSP teachers is an additional requirement of the partnerships. The primary vehicle for accomplishing the goals of the MSP grant is by establishing and maintaining an effective partnership between the school district(s) and the university.

In establishing the partnership, the school district partner must meet certain criteria including that: (a) its standardized, norm-referenced, and/or criterion-referenced data must reflect that achievement in mathematics and science is falling below 60% of students meeting or exceeding the Illinois Learning Standards, and (b) 15% or more of students have to be from low income families. Teachers participating in the program must also be uncertified in mathematics and science and “not-highly qualified” as outlined in the local school district’s annual report for not-highly qualified teachers. In addition, the participating teachers must exhibit leadership potential, have less than ten years of experience, and have fewer than five graduate courses in mathematics or science content or educational methods.

The mathematics and science partnerships are to develop Master Degree programs and professional development designed to: (a) improve teachers’ subject matter knowledge, strengthen their instruction, and promote student academic achievement; (b) promote strong teaching skills through access to the expertise of mathematicians, scientists, and engineers, and their technologies and resources; and (c) increase the understanding and application of scientifically based educational research pertinent to mathematics and science teaching and learning. Given these requirements, individual MSP programs must plan a comprehensive approach that incorporates all of the essential elements. In particular, three of these essential elements stand out as particularly important to the MSP initiative: (a) educational partnerships, (b) teacher leadership, and (c) action research. A review of the literature in these areas is provided next.

Review of the Related Literature

Educational Partnerships

As stated above, partnerships between schools and universities are at the core of the MSP projects. Thus, the development and maintenance of the partnership is crucial to the success of an MSP project. However, as indicated by the literature on educational partnerships, the development and continuation of partnerships is difficult. Cordeiro and Kolek (1996) outlined key elements and processes essential to the development of successful partnerships. These include a common purpose, autonomy, and voluntary links to and from the schoolhouse, emergent leaders, and patterns of interaction within the partnership. Cordeiro and Kolek also argued that certain preconditions need to be present for partnerships to succeed, including leadership, trust, stability, readiness, and a common agenda. With good communication, reciprocity, the alignment and/or pooling of resources, and knowledge of the community, partnerships can be supported and sustained.

Restine (1996) argued that two trends have emerged specifically concerning partnerships between schools and institutions of higher education. One trend is the development of professional communities between schools and universities. The other trend is the strong belief that efforts at professional collaboration and service integration are incomplete without professional pre-service and in-service education. Klein (1990) outlined seven common barriers to the development of these types of partnerships, which included the illusion of consensus, failure to develop a common vocabulary, open conflict over status, too large of a group, equating mission with vision, not designating a leader, and failing to involve all stakeholders (parents, students, etc.). In order to overcome these barriers, Lawson and Hooper-Briar (1994) suggested that partnerships should develop guiding theories of social development, organizational renewal and change, language and communication, education and constituency building, leadership, and assessment, evaluation and research. Essentially, partnerships should develop the “core or bedrock values that define the essence of the work and provide consistency, cohesiveness, and a source of renewal” (p. 38).

Teacher Leadership

Teacher leadership is another important element of the MSP programs. Teacher leaders “mobilize the efforts of their closet colleagues to enhance the school’s program for the benefit of students” (Danielson, 2007, p. 17). The benefits of embracing teacher leadership for teachers, according to Johnson and Donaldson (2007), include: (a) being able to share expertise with others, (b) reducing the isolation, which is prominent in teaching, and (c) offering opportunities to vary responsibilities and expand influence. The roles of teacher leaders can be broken into two categories: (a) formal or (b) informal. Formal roles for teacher leaders include department chair, master teacher, and instructional coach. Principals often appoint teacher roles such as mentor coordinator and data analyst as well. These roles are formalized through an application and selection process. Informal roles are not as structured and typically have no positional authority. These roles often "emerge spontaneously and organically from the teacher ranks" (Danielson, 2007, p. 16).

Teacher leadership is an alternative model of school leadership, which operates under a relational or distributed leadership model (Beattie, 2002). Krovetz and Arriaza (2006) stated that this distributed leadership model is "based on the recognition that many people in a school possess leadership skills and do leadership work and that by utilizing these resources in a coherent way, schools will be more effective in educating students" (p. 25). Teacher leadership, however, must be supported within the school. As Johnson and Donaldson (2007) pointed out, support structures within the school are necessary in order "to reap the full benefits of teacher leadership" (p. 9). These support structures must be established to encourage teacher leadership or else "there will be only a token use of this valuable resource" (Moller and Katzenmeyer, 1996, p. 12). With structures in place, principals can support and encourage a culture that allows for teacher leadership.

Teacher leadership has become an increasingly important concept in education because it is believed teacher leaders are positioned to influence school policies and practices, student achievement, as well as the teaching profession. In order to affect this type of change, teacher leaders must be able to (a) understand and navigate the school organization, (b) work productively with others, and (c) build a collaborative enterprise (Murphy, 2005). In addition, some argue teacher leadership should grow to encompass addressing coherence issues (Krovetz and Arriaza, 2006). Teacher leaders should be equipped and enabled to look at the school's resources, link these resources to the focus and vision of the school, and make decisions about what is likely to impact student learning and what can be discarded as unnecessary. Lambert (1998) also believed an important aspect of teacher leadership is the ability to define issues, collect data, construct meaning, and frame actions for the school. In doing so, teachers not only develop their own leadership capacity, but the school's as well. An important skill to accomplish this role is action research.

Action Research

Action research performed by the teachers within the program is a necessary component of the MSP programs. Education action research can be defined as "continual disciplined inquiry conducted to inform and improve our practice as educators" (Calhoun, 2002, p. 18). The roots of action research reside in Kurt Lewin's theory of action research that was focused on workplace studies in the 1930s. Lewin's process of action research was described as spiraling because it "included reflection and inquiry on the part of its stakeholders for the purposes of improving work environments and dealing with social problems" (Hendricks, 2006, p. 6). Although it took awhile before this spiraling approach to research impacted the classroom, these ideas eventually were connected to Dewey and Count's progressive education movement. Today, education action research, if not mainstream, is widely utilized, appearing in academic journals and developing into networks in the United Kingdom, Australia, Canada, and the U.S.

Action research has been offered as an alternative method of providing empirical evidence for teacher change than the traditional university led research. For example, action research is practitioner-based or as McNiff, Lomax, and Whitehead (2003) stated, “it is insider research” (p. 12). Thus, action research embodies the values of the practitioner. Action research is also focused on change or improvement. Collaboration is also often a key feature of action research. With action research, the “I” is at the center of the research and thus research questions have “a clear intent to intervene in and improve one’s own understanding and practice, and to accept responsibility for oneself” (McNiff, et al., p. 19). Reflection becomes a key component in this approach so the researcher is aware of how to improve his or her practice.

Action research has also been discussed as an avenue for individual professional development, school collaboration, and educational reform. As Calhoun stated, action research “can change the social system in schools and other education organizations so that continual formal learning is both expected and supported” (p. 18). Much has been written about how to conduct action research. Hendricks (2006) outlined a continual process of reflect-act-evaluate to action research. Based on the evaluation, the process continues again. Sagor’s (2005) four-step process to action research also included reflection as key. This process includes:

1. Clarifying the vision and targets of the research.
2. Articulating a theory.
3. Implementing action and collecting data.
4. Reflecting on the data and planning informed action.

STEM Education & Leadership Program

In 2007, Illinois State University’s Technology Education Program was funded for a Mathematics Science Partnership (MSP) project entitled the STEM Education & Leadership Program. As specified by the requirements of the MSP outlined above and the establishment of a partnership at the beginning of the planning process, the STEM Education & Leadership Program has sought to overcome some of the common barriers to partnerships and advance a sense of cohesiveness and trust. The STEM Education & Leadership Program’s design is being guided by the experiences fostered by the NCETE professional development efforts, grounded in the related literature outlined above, and structured around a needs assessment of the partners involved in the program.

The STEM Education & Leadership Program will target measurable increases in STEM-related teacher content knowledge, instructional practices, student achievement, quality of professional development, and organizational support. The team has articulated a model (see Figure 1 below) that is grounded in the literature, which will be used to guide the development and implementation of the program. With the long-term goals of changing the culture of the schools and increasing schools' achievement, specific processes have been outlined for the two key activities: (a) the development of a new Master of Science Degree and (b) the formulation of a professional development program. Both of these components are outlined next.

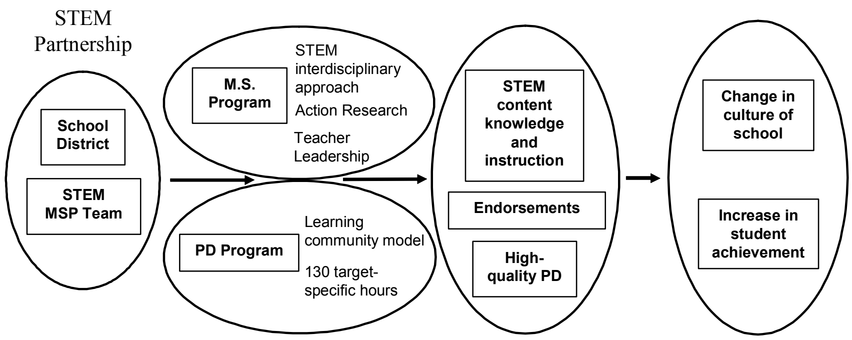

Figure 1. STEM Education and Leadership Master of Science Degree and Professional Development program model

Proposed STEM Education & Leadership Master of Science Degree Program

One of the solutions to addressing the decline in the number of U.S. citizens who are educated in STEM is to assist students in elementary and middle schools to make decisions to pursue engineering and science in high schools and STEM degrees in college. It is therefore imperative to offer more STEM-based courses through the K-12 school system to enable students to be successful in STEM courses at the college and/or university levels. That also means there needs to be more teachers that are qualified to teach STEM courses.

The framework for the STEM Education & Leadership Master of Science Degree program is based on existing programmatic offerings at Illinois State University, findings from STEM-based literature, examinations of other advanced degree programs in the U.S., and the need for participants to earn teaching endorsements/highly qualified status. By integrating field-based experiences and action research projects into the graduate coursework, teachers will be prepared to provide high quality education so that their students' learning is increased and more students will pursue STEM degrees at the post-secondary level. The Master's Degree program, 33 credit hours total, will be comprised of a four-course STEM Education & Leadership core, two-course Research & Cognition core, and student selected cognate areas in mathematics, science, and/or technology education. These course offerings will result in the requisite number of hours for degree and subject-specific endorsements. The proposed program extends Illinois State University's capacity for building connections to school districts throughout the state and will extend the reach of the university's graduate program by integrating a distance education model with a residential option for coursework.

A unique aspect of this Master of Science Degree is its intent to integrate multiple disciplines: science, technology, engineering, and mathematics. Currently, only one other university, Virginia Tech, has developed an integrative STEM program. The emphasis on integrated or multidisciplinary curriculum is emerging as an important avenue for educational reform. As Moss et al. (2003) argued, "subjects in school can no longer be portrayed as isolated content areas in which the memorization of subject-specific material takes precedence" (p. 7). The boundaries between disciplines have been argued to be artificial, primarily serving to structure the public school system. Moss et al. (2003) stated that disciplines should not serve to divide the educational experience but should be portrayed as a perspective or "a way of looking at the world that contributes to a more complete understanding of it" (p. 7). Disciplinary knowledge should be recalled in problem-solving so that an integrated or holistic understanding of the world is developed. As Froyd and Ohland (2005) pointed out, the ability to integrate through processes is "an educational goal, worthy of standing alone, and as a necessary counterbalance to what has been portrayed as a near universal emphasis on understanding via decomposition" (p. 148).

Science has been offered as an avenue of integration, especially with technology, engineering, and mathematics. Moss (2003) argued that considering science as merely one element of human knowledge allows this discipline to be seen as "part of a larger whole with its boundaries blurred among all other disciplines" (p. 61). In addition, design projects "have the potential to help students make connections among subjects, material, and applications" (p. 155). Technological/engineering design, which is an essential element of both the MSP programs and the NCETE's efforts, has been defined as being "of and about the artificial world and how to contribute to the creation and maintenance of that world" (Cross, 2001, p. 54). Within technology education, technological/-engineering design has centered on problem solving and the application of scientific understanding to a given task (Hill & Anning, 2001). An integrated STEM curriculum centered on technological/engineering design is at the core of the STEM Education & Leadership program.

The STEM Education & Leadership Program is utilizing a learning community approach to its professional development. Central to the learning community model is the belief that when "teachers, students, and parents are connected to the same ideas they become connected to each other as well" (Sergiovanni, 1999, p. 18). Once people become connected they share common goals and values and a community of mind emerges. Individual practices are not ignored, but a community of shared practice is developed. A school as a learning community is focused primarily on the culture of the school where learning is seen as important work for the entire school. The aim is to maximize learning for all involved in the community so that the school's capacity to build the knowledge, skills, norms, habits, and values necessary to adapt, renew, rethink, and inform classroom practice is firmly established (Shaw, 1999). According to

Butt (1999), two processes are essential to the creation of a learning community: (1) collaborative school-based professional development, and (2) peer and self-evaluation.

Collaborative professional development is thus an essential aspect of the STEM Education & Leadership Program. High quality professional development has been discussed by many researchers. For example, Loucks-Horsely (2003) identified four clusters of variables that affect the quality or nature of professional development. These clusters include: (a) content; (b) process; (c) strategies and structures; and (d) context. Further, high quality professional development must include "a focus on content and how students learn content; in-depth, active learning opportunities; links to high standards, opportunities for teachers to engage in leadership roles; extended duration; and the collective participation of groups of teacher from the same school, grade, or department" (Desimone, Porter, Garet, Yoon, & Birman, 2002, p. 82).

Thus, the STEM Education & Leadership Program is pursuing high quality professional development through a learning community approach. The composition of the learning teams (community) will consist of a technology education/engineering teacher, a mathematics teacher, a physical science teacher, the principal, a guidance counselor, and a parent from the same school; STEM faculty from within and outside Illinois State University; and related professionals from the STEM community. The professional development will be continuous throughout the school year and summer months. In total, the learning teams will partake in a minimum of 130, target-specific hours per year. The targeted outcomes of this sustained effort are to conduct high quality professional development that will ultimately affect the culture of the school and student achievement in a positive manner. It is believed that the composition of the learning teams (teachers, principals, guidance counselors, and parents) is best situated to achieve these targeted outcomes based on the literature. Below is a brief discussion of this literature which supports principal, guidance counselor, and parental involvement.

Principals

Studies exploring the role of high school principals have largely concluded that they are crucial to school success. A consistent finding in studies about principals is that high performing schools have strong, competent leaders (Rodgriguez-Campos, Rincones-Gomez, & Shen, 2005).

Principal leadership can be analyzed through interactions or the overt actions, covert deliberations, and physical presence of one person that influence others. Hart and Bredeson (1996) outlined three elements of interactions that are important to principal leadership, including: (a) motivation, (b) interaction processes, and (c) structuring processes. Through the structuring processes of interactions facilitated or dominated by a principal, an organization's culture is developed or altered. In other words, organizational culture is the outcome of interactions among group members and includes the behaviors, norms, dominant values, philosophies that guide policy, and unwritten rules of the school.

An emerging and important role for principals is as the instructional leader for the school. In addition to managing the school's day-to-day operations, principals are increasingly expected to be effective leaders in areas such as instructional approaches that engage the staff in renewing their own approaches (Rodgriguez-Campos, Rincones-Gomez, & Shen, 2005). As Hart and Bredeson (1996) stated, principals are expected to "master not only the knowledge base current at the time of their professional preservice education but the skills necessary to develop professional habits of learning and of tying their constantly expanding knowledge to their professional actions" (p. 26). Principals should then continuously upgrade their educational skills so as to be effective leaders and positively impact the culture of the school. By engaging in professional development, principals can upgrade their skills, gain new knowledge and skills, and model self-improvement. The STEM Education & Leadership Program will necessitate the active participation of the teachers' principals in the professional development efforts.

Guidance Counselors

In addition to principals, guidance counselors will be recruited to participate in the STEM Education & Leadership professional development so a learning community can be better established. Guidance counselors serve an important function within schools. For example, the American School Counselor Association (2004) defined professional school counselors as individuals "who deliver a comprehensive school counseling program encouraging all students' academic, career and personal/social development and help all students in maximizing student achievement" (p. 2). As indicated by this definition, the roles of guidance counselors have come to encompass the personal, social, educational, and occupational development of an individual student. Sears (1993) pointed out that guidance counselors "are being asked to assume a greater role in the lives of their students and the students' families" from offering parenting classes, to trying to prevent substance abuse, to helping student learn test-taking skills (p. 384).

Anderson and Reiter (1995) argued that the "quintessential role of the counselor is to facilitate the primary function of school: helping children to learn" (p. 269). However, many argue that this role has not been fully developed in most schools. Pershing and Demetropoulos (1981) stated that for this to happen "a reorientation of guidance related practices in schools so that the involvement of teachers will be encouraged and facilitated must occur" (p. 455). Davis and Garrett (1998) outlined four methods by which school counselors can ensure mutual understanding with teachers about their role: (a) meeting with the faculty, (b) consulting with teachers, (c) observing classroom dynamics, and (d) enlisting teachers as co-facilitators. By including guidance counselors in the professional development efforts of the STEM Education & Leadership Program, these connections can be further enhanced so that the primary function of schools can be better achieved.

Parental Involvement

Similar to the significant impact that principals and guidance counselors have on student achievement, parents also have a tremendous influence. Thus the approach of the STEM Education & Leadership Program is to also involve parents in its professional development efforts. Hoover-Dempsey and Sandler (1997) pointed out that within "a range of studies, there has emerged a strong conclusion that parental involvement in child and adolescent education generally benefits children's learning and school success" (p. 3). This positive impact includes "improved school attendance and behavior, more positive perceptions of classroom and school climate, stronger self-regulatory skills, stronger work orientation, and higher educational aspirations" (Hoover-Dempsey, Walker, Jones, & Reed, 2002, p. 843). For example, in a study investigating the impact of parent involvement on student's improved academic achievement, 220 parents of elementary students from a largely minority, low-income, but high-performing schools were surveyed. Results indicated that "a link exists between parent involvement in children's education and the educational outcomes of their children" (Ingram, Wolfe, & Lieberman, 2007, p. 494).

Hoover-Dempsey, et al. (2005) offered a list of strategies to increase a school's capacities for involving parents. This extensive list included: creating an inviting, welcoming school climate; empowering teachers for parental involvement; learning about parents' goals and perspectives on child's learning; and offering a full range of involvement opportunities. Another strategy the researchers offered is for schools to create a dynamic, systematic, and consistent approach to improving family-school relationships. Comer and Haynes (1991) agreed, stating that "parent involvement programs are most effective when they are part of an integrated ecological approach to school enhancement" (p. 277). After implementing a successful parent involvement program in an inner-city school, Hara and Burke (1998) offered some suggestions for individuals planning to develop a parent involvement program including ongoing staff development, reviews of school and district policies and procedures, joining a network of schools, and obtain related guides and parent involvement materials.

Conclusion

As discussed, the STEM Education & Leadership Program is a comprehensive MSP initiative focused on impacting teacher quality and student achievement in the STEM disciplines. At the time of this manuscript submission, the MSP was in its first year of a five-year funded project. The entire first year must be spent on planning the MSP program, with the following years being used for implementation. The development of an educational partnership focused on enhancing teacher leadership and action research capabilities are the major components of all MSP initiatives. In addition, the proposed STEM Education & Leadership Program includes an integrated approach to its Master's Degree and a learning community approach to its professional development. The STEM Education & Leadership Program at Illinois State University is attempting to answer the call to produce more highly qualified teachers in science, technology, engineering, and mathematics so as to increase student achievement in these disciplines by not only increasing teachers' content and pedagogical knowledge, but also impacting the culture of the school.

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