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Supporting STEM Education in Secondary Science Contexts

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Abstract

Science education scholars emphasize the significance of an integrative, interdisciplinary STEM (Science, Technology, Engineering, and Mathematics) education that encourages students to learn about the natural world through exploration, inquiry, and problem-solving experiences. This article reports on a professional development program aimed at improving a group of secondary science and mathematics teachers' competence in using a problem-based approach in the teaching of STEM. Through surveys, qualitative interviews and focus groups, the study investigated the teachers' understanding and perceptions of problem-based learning (PBL) as an approach to interdisciplinary STEM education as well as their perceptions of the personal and systemic challenges in implementing such an approach in their professional practice. This investigation offers insight into how university-based professional development programs can support secondary educators' understanding of, and ability to use an interdisciplinary problem-based STEM approach in their schools and classrooms. The study concludes with implications for practice and a discussion of how future interdisciplinary professional development can be conceptualized.

Keywords: interdisciplinary STEM teaching, problem-based learning, PBL in STEM teaching, professional development in STEM Education, professional development for STEM teaching

Context

In the last few decades, many reform initiatives have shaped teaching and learning in science, technology, engineering and mathematics (STEM) disciplines. These reform efforts include a shift from teaching students to remember and execute isolated facts and skills, to having students experience learning as scientists, engineers and mathematicians do (American Association for the Advancement of Science, 1989, 1993, 1996; National Council of Teachers of Mathematics, 1989, 2000). Scholars argue that students should engage in learning that allows them to explore, inquire, solve problems, and think critically (Baron et al., 1998; Barrows, 1994, 1996; Barrows & Tamblyn, 1980; Hmelo & Evensen, 2000; Hmelo-Silver, Duncan & Chinn, 2007). To this end, reform efforts within each of the STEM disciplines have focused on such strategies as inquiry learning (Minstrell & van Zee, 2000), project-based learning (Starkman, 2007; Swartz, Costa, Beyer, Reagan, & Kallick, 2007), constructivist learning (Mayer, 2004), problem-based learning (Bottge, Heinrichs, Chan, & Serlin, 2001; Goodnough & Cashion, 2006) and the integration of technology across all STEM disciplines (Clark & Ernst, 2007).

Although these efforts have fostered improved learning outcomes within each of the STEM disciplines (Cichon & Ellis, 2003; Minstrell & van Zee, 2000; Schoen & Hirsch, 2003), many scholars argue that in order for students to be fully prepared for careers in the new millennium, they must be capable of thinking across disciplinary boundaries (Berlin & White, 1998; Berry et al., 2005; Stepien & Gallagher, 1993). This suggests that schools must begin to veer away from treating each STEM discipline as a silo and embrace an approach that blurs the boundaries of these disciplines. It is argued that students who engage in rich cross-disciplinary experiences will have a deeper conceptual understanding of science and mathematics content (Frykholm & Glasson, 2005; Zeidler, 2002), which will improve their achievement in each of the disciplines (Berry et al., 2005). Further, interdisciplinary learning can foster an understanding of STEM concepts in their application to real world problems, problems that by their very nature are interdisciplinary. In traditional school settings, the compartmentalization of scientific knowledge creates boundaries so rigid that they often serve as barriers to any efforts to develop integrative science and mathematics programs (Duch, Groh, & Allen, 2001; Nikitina & Mansilla, 2003).

As part of their reform efforts, many states, including Maryland, have created STEM initiatives designed to increase teachers' and students' competencies in STEM and create learning experiences that will prepare students for the vast array of STEM career fields. The Maryland State Department of Education (MSDE) has supported the creation of STEM academies, high schools or schools within schools that focus on one or more aspects of STEM education. These academies were initiated to provide students with cross-disciplinary experiences that would enhance academic achievement and create a pipeline for future scientists and engineers. MSDE established a series of planning grants to assist local edu-

cational authorities with the creation of STEM Academies, as well as other STEM initiatives, throughout the state. The focus of these planning grants has been on teacher preparation for the implementation of STEM. The preparation of teachers was seen as the initial step towards the institutionalization of STEM academies, but at the time of these professional development efforts the internal reorganization of the schools that is needed to facilitate full implementation had not yet been put in place. This current research was undertaken in the context of a state-funded professional development (PD) experience for teachers and STEM district leaders with the intention of helping them create a framework for designing and implementing STEM academies in their districts and schools. The framework that this PD offered was the teaching of STEM disciplines through problem-based learning (PBL). The intent was not full implementation, but rather an attempt to offer teachers and district leaders the opportunity to begin to think about possible models for full implementation.

Purpose of the Study

The state of Maryland has committed to improve education in STEM by establishing a series of planning grants to assist local educational authorities with STEM initiatives, including the creation of STEM academies. With this goal in mind, The Johns Hopkins and Morgan State Universities partnered to conduct professional development activities for secondary science and mathematics teachers from all the school systems in Maryland, including some schools planning STEM academies.

The context of the present research was thus the provision of PD for teachers and instructional leaders in Maryland in preparation for the implementation of STEM initiatives. The purpose of the study was to examine teachers' initial conceptions of PBL, their response to an interdisciplinary STEM-PBL professional development experience, and their perceptions of what facilitates or hinders implementation of interdisciplinary STEM-PBL in their schools. The research questions that guided this study were:

1. How did teachers' perceptions and conceptions of PBL in STEM education evolve as a result of their participation in this PD?
2. What were some of the challenges they anticipated in implementing STEM-PBL in their classrooms?
3. What directions for future PD in STEM can be derived from the responses from these teachers?

Thus the focus of this investigation was on teachers' experiences of professional development for interdisciplinary teaching in STEM. It was premised on the view that mathematics and science teachers, whose preparation in the content areas has been highly discipline specific, would need focused professional development to equip them to transcend those disciplinary boundaries in order to teach interdisciplinary subject matter. What professional development experiences might be effective in doing so? There was

very little in the literature on teacher professional development to guide us through this specialized area. Further, our focus was on the types of professional development experiences that could help teachers' understanding of an interdisciplinary approach to STEM teaching and learning; however, we did not address questions of classroom implementation. Our study of the effects of the professional development was based on teacher dispositions such as their attitudes and perceptions and how these evolved in response to the professional development. This study will inform the developing literature on STEM education by helping scholars understand the factors that facilitate and hinder teachers from implementing integrated mathematics and science curriculum materials and how teachers' understanding of interdisciplinary teaching can evolve through targeted professional development activities. In addition, this research will highlight teachers' perceptions of the relevance and usefulness of interdisciplinary instruction in secondary science education contexts. Equally importantly, the findings of this research speak to the usefulness of PBL as an approach to the professional development of STEM teachers. Although there is literature that addresses the need for PBL as an approach to education of students, we used this framework in designing and implementation of professional development experiences. Our intention was to have teachers experience PBL and therefore provide them with an experiential understanding of this instructional framework with the goal of helping them understand how to use this approach as an instructional framework that could shape STEM education.

In what follows we discuss (a) the conceptual framework guiding the study design, (b) the structure of the interdisciplinary STEM PD workshop for teachers, (c) study methods, (d) main themes emerging from the data, and (e) implications of the findings.

Conceptual Framework

STEM Education

Over the past several decades, there has been a growing interest in STEM education, particularly in effective strategies to prepare students for advanced study in STEM-related fields (Innovation America, 2008). Consequently, several approaches to the provision of STEM education have been proposed, including school within school models (Atkinson, Hugo, Lundgren, Shapiro & Thomas, 2007), school-based STEM programs (Toulmin & Groome, 2007), distance learning initiatives (Demski, 2009), mentoring programs (Atkinson et al., 2007) and special STEM schools (Cavanagh, 2006). However, these approaches have often failed to reflect the nature of real-world STEM, and therefore have limited potential to prepare students for emerging STEM careers. The practice of STEM, by its very nature, is interdisciplinary and focuses on authentic problem solving. Hence, we argue that organizations and educators interested in developing viable STEM education programs

should design curriculum materials and engage in pedagogical practices that reflect the interdisciplinary, problem-based work in which scientists are engaged (Anderson, 2007; Clark & Ernst, 2007; Marshall, Horton, & Austin-Wade, 2007; Paige, Lloyd, & Chartres, 2008; Park-Rogers, Volkmann, & Abell, 2007). Although very little research has been done on using PBL as a framework in STEM education, many of the learning experiences advocated in STEM education are congruent with the underlying principles of PBL. Hence, PBL in STEM has promise for serving as an organizing framework for K – 12 STEM initiatives.

In a problem-based learning environment, important STEM concepts are embedded in the context of interesting interdisciplinary problems. PBL engages students in solving interdisciplinary real-world problems, thus encouraging them to invoke concepts and ideas drawn from multiple disciplines. PBL, in essence, tries to mirror the processes used by scientists to solve real-life problems (Crawford, 2000; Colliver, 2000) through the active construction of knowledge and the development of social and communication skills (Goodnough & Cashion, 2006; Lieux, 1996) and understandings (Barnes & Barnes, 2005; Frykholm & Glasson, 2005; Loepp, 1999; Moseley & Utley, 2006; Sage & Torp, 1997; Venville, Rennie, & Wallace, 2004). In addition, PBL in STEM advances interdisciplinary learning by breaking down the siloed nature of secondary science instruction. This approach poses challenges both for the teachers who must design the learning experiences and for the students who may not be used to bridging the divide between traditionally separate subjects.

The PBL approach to STEM education has some inherent advantages over traditional discipline-based teaching and learning because it:

- fosters an understanding of connections among principles, concepts, and skills across discipline specific domains (Jordan, 1989; Nikitina & Mansilla, 2003);
- arouses students' curiosity and sparks their creative imagination and critical thinking (Capon & Kuhn, 2004);
- helps students to understand and experience the process of scientific inquiry (Biggs, 2003; Hmelo-Silver, 2004; Ramsey, Radford, & Deese, 1997; Stepien, Gallagher, & Workman, 1993);
- encourages collaborative problem-solving and interdependence in group work (Biggs, 2003; Pease & Kuhn, 2008; Ward & Lee, 2002);
- expands students' knowledge of mathematical and scientific knowledge (Engel, 1991; Tchudi & Lafer, 1996; Torp & Sage, 2002);
- advances active knowledge construction and retention through self-directed study (Dodds, 1997; Stepien & Gallagher, 1993; Ward & Lee, 2002);
- fosters connections among thinking, doing, and learning (Goodnough & Cashion, 2006);
- promotes student interest, participation, and increased attendance (Lieux & Duch, 1995); and

- develops students' ability to apply their knowledge (Boud & Feletti, 1997; Torp & Sage, 2002).

Professional development of teachers for the implementation of such curricula must be informed by existing knowledge of best practices in teacher professional development, by the goals of STEM education, as well as by the nature of problem-based learning.

Studies with high school students in international contexts suggest that student participation in engineering-based STEM contests enhanced their problem-solving skills, critical thinking, and the ability to see connections among various STEM disciplines in the context of the specific problems they were engaged in solving. The problem-based learning approach also fostered a deeper understanding of science and mathematical concepts and their application to real life contexts. Notably, students participating in STEM-PBL activities demonstrated better performance and positive attitudes toward STEM subjects (Chen, 2007; Lou, Shih, Diez & Tseng, 2011; Tsai, 2007).

Characteristics of Effective STEM Professional Development

The literature on teacher professional development has been consistent in its identification of the factors that characterize effectiveness. The American Educational Research Association [AERA] (2004) provides a review of professional development practices in the 1990s. This research analysis revealed that professional development leads to improved student achievement when it focuses on (1) how students learn, (2) instructional practices that are specifically related to subject matter and how students understand it, and (3) strengthening teachers' knowledge of subject matter content. This highlights the importance of having the pedagogical component of professional development firmly tied to subject matter content. In the professional development literature that is specific to science, the consensus is no less strong. Desimone (2009) suggests that high quality professional development must model inquiry approaches and Cohen and Hill (1998) emphasized the importance of a focus on subject-matter content knowledge to deepen teachers' content skills.

In a study of teachers' responses to professional development, Garet (2001) reported that teachers identified a focus on content knowledge as the component of professional development that had the greatest effect on their practice. The other component which teachers identified as impacting their practice was the extent to which the professional development was "coherent." This referred to professional development experiences that were cumulative and built on prior knowledge, were aligned with the Standards to which teachers were held accountable, and provided opportunities to communicate with peers who were engaged in similar efforts to improve their practice. The professional development activities provided in this STEM initiative had all of these elements and will be described in detail in a subsequent section of this paper.

Evaluation of teacher professional development is premised on the view that effective professional development will result in changes in teachers' classroom practice and ultimately in student achievement. In addition, it might be expected that changes would occur in teachers' attitudes about the reform and their level of preparedness to implement it. For example, Supovitz, Mayer and Kahle (2000) found that teachers who participated in the Ohio Statewide Systemic Initiative in science and mathematics and who participated in a minimum of 160 hours of inquiry-based professional development exhibited changed attitudes towards inquiry-based teaching, were better prepared to implement it, and showed greater use of such strategies in their classrooms. In the present study, the focus of our evaluation was on the attitudes and perceived levels of preparedness of the teachers who participated in the STEM problem-based activities, and this focus is reflected in the research questions that guided the evaluation of the professional development program.

Our PD model encompassed elements from several PD design frameworks. Loucks-Horsely, Hewson, Love, and Stiles (1998) identified 15 different strategies that are used for professional development for teachers of science and mathematics which fall into five categories: *Immersion* (involve participants in doing science and mathematics); *Curriculum* (curriculum strategies involve teachers with the actual learning materials they will use with their students); *Examining practice* (PD that focuses on teachers own practice, job embedded learning); *Collaborative Work* (professional networks and professional learning communities); and *Vehicles* mechanisms (structures of PD primarily workshops and institutes). Furthermore, Loucks-Horsley, Love, Stiles, Mundry, and Hewson (2003) expanded that PD design framework by adding important factors, such as connecting PD to student learning, emphasizing a rigorous evaluation of teacher learning and having teachers reflect on the PD experience and its impact on their learning. Similarly, Bransford and colleagues (National Research Council [NRC], 1999) call attention to the crucial significance of several factors while designing PD for STEM teachers, such as: (a) deepening teachers' content knowledge of STEM concepts, (b) developing teachers' pedagogical content knowledge in STEM areas, (c) engaging them in cooperative learning, (d) seeking teachers' input on their learning, and (e) inviting teachers to write about their students' learning to uncover their struggles with learning science and mathematics.

When planning the PD we considered elements of the above frameworks, particularly incorporating opportunities for immersion and collaborative work. Immersion strategies involve participants "doing" science and mathematics both during the PD and outside of PD. Since our focus was to help teachers understand STEM from an interdisciplinary standpoint, we engaged teachers in real world interdisciplinary problems that required interdisciplinary collaboration to solve. During and after their immersion in these problems, they were asked to individually and collectively reflect on essential elements of the problem that reflected interdisciplinary PBL, the science and mathematics content imbedded

in the problems, their problem solving strategies and the ways in which these types of experiences can be used in various STEM related classrooms and contexts. Through these experiences, we believed that teachers' content knowledge in STEM areas as well as their pedagogical content knowledge concerning PBL in STEM would be enhanced and that they would develop positive perceptions about implementing this approach to STEM in their schools and school districts.

We incorporated collaborative strategies for professional learning through creating professional networks both within their schools and across school boundaries. These networks provided teachers with opportunities to share wisdom and build a professional culture that focused on student learning. Further, we developed partnerships with scientists, mathematicians, and mathematics and science educators who provided coaching and mentoring. In addition, we created internet based communities of teachers as a useful tool for "overcoming teachers' sense of isolation" (NRC, 1999) and provided a mechanism through which teachers can collaborate with mentors, coaches and fellow teachers. Frequent opportunities for reflection on learning were built into our PD workshop. Also, teachers' own lessons that they developed during the workshop provided an opportunity to assess their emerging understandings of integrated STEM-PBL approach.

Internal and External Barriers to Interdisciplinary STEM education

Research suggests that there are a number of internal as well as external barriers to developing integrative STEM problems and implementing them in high school settings. While the present study focused on teachers' responses to the PD and did not investigate questions related to implementation of STEM PBL, we discuss some implementation issues here because teachers' preconceptions about these barriers are likely to influence their responses to PD aimed at preparing them for implementation of STEM PBL. The internal barriers encompass issues related to teachers' beliefs, capacity, knowledge, and skills. Secondary science and mathematics teachers may have to confront various limitations in their own practice, such as specialized knowledge of subject content, lack of exposure to other scientific and mathematical domains, little to no experience in engineering and technology skills, and limited familiarity with problem-based learning (Ertmer et al., 2007; Park, Cramer & Ertmer, 2004; Park & Ertmer, 2008). Additionally, teachers may not be equipped with the requisite skills to see and develop "internal connections" among the scientific disciplines and external links between science, mathematics, and engineering and technology (Nikitina & Mansilla, 2003). These constraints pose significant challenges to teachers' ability to create interdisciplinary problems that are: (a) curriculum appropriate, (b) at the knowledge level of secondary students, and (c) connected to students' real lives (Zhang, Lundeberg, Koehler, Eberhardt, & Parker, 2008). In addition, teachers' own dispositions and views about teaching and learning, and their resistance or lack of motivation

to change their beliefs and practice, constitute an important source of internal barriers (Lehman, Park, Cramer, Grove, & Ertmer, 2003). Difficulties with facilitating and managing teamwork by students also seem to present an important obstacle affecting the use of collaborative PBL inquiries in classrooms (McConnell et al., 2008).

The literature also indicates an array of external systemic barriers to an integrative PBL approach. For example, the tension between covering the curriculum content versus the time needed for open-ended PBL tasks, and the issues associated with the expensive, resource-intensive character of PBL make it difficult for teachers to fit PBL into their existing curricula. The lack of adequate instructional materials (e.g., appropriate problems aligned to the curriculum and national standards) adds to the complexity of these challenges. Furthermore, over-reliance on standardized tests and exams to measure students' knowledge limits the effective assessment of students' critical thinking and problem-solving skills (Gordon, Rogers, Comfort, Gavula, & McGee, 2001; Maxwell, Bellisimo, & Mergendoller, 2001; Meier, Hovde, & Meier, 1996). Unfamiliarity with suitable assessment techniques and the difficulty in developing appropriate assessment tools for process-oriented, problem-based tasks further exacerbates the problem (Tchudi & Lafer, 1996). Similarly, developing "self-monitoring guidelines" and rubrics for engaging students in self-evaluation and reflection on the problem-solving process seems to be an important impediment to the assessment of PBL units (Ertmer et al., 2007; Gallagher, Sher, Stepien, & Workman, 1995).

The literature also points to the lack of administrative support and encouragement as a barrier to the adoption of an interdisciplinary approach to STEM (Ertmer et al., 2007; Ertmer et al., 2009; Lehman et al., 2003; Park, Lee, Blackman, Ertmer, Simons, & Belland, 2005). Teachers need a supportive environment to learn and adopt new approaches to instruction and assessment. Administrative support is vital to developing an environment that encourages teachers and facilitates their learning. It involves providing suitable incentives, rewards, and professional development opportunities to teachers to improve their practice. Teachers need access to physical tools and resources to engage in this integrative task. More so, school administrators need to work closely with teachers to create supportive structures to facilitate collaborative work and exchanges across the disciplines (Novak, 1990). The difficulty in creating collaborations across disciplinary silos in secondary contexts appears to be a major impediment to enacting interdisciplinary curricula and instructional approaches. Conflicting visions, understandings, and expectations of PBL on the part of school administrators and teachers may hinder the development of the supportive culture required for the implementation of broad scale PBL initiatives (Park & Ertmer, 2008; Ward & Lee, 2002). While Ertmer and colleagues (2007) argue that external obstacles are more visible and relatively easy to address and fix, we argue in this paper that the internal barriers are also so deeply ingrained in teacher practice and in student assessment that they constitute just as large an impediment.

Relevant studies point to a number of strategies to develop, apply, and sustain the integrative approach to PBL in STEM education (Ertmer et al., 2009; Park & Ertmer, 2008). These supportive structures include developing effective mentoring and coaching systems to prepare novice teachers in PBL-based approaches and methods through ongoing PD and teacher education programs. A school wide approach to interdisciplinary PBL requires greater participation of school administrators in the provision of opportunities for science, mathematics, and technology faculty to work with each other. Administrative support may include (a) providing regular PD opportunities, (b) developing a shared vision and setting up clear goals and benchmarks for the innovation, (c) holding regular faculty and administrative meetings to share experiences and issues related to PBL, (d) providing adequate preparation time for interdisciplinary team work, (e) offering feedback on teachers' work through classroom observations and evaluations, and (e) establishing a system of incentives and rewards for acknowledging teachers' efforts. Our PD efforts could not address the external barriers but we attempted to design PD experiences that addressed the internal barriers.

Interdisciplinary STEM PD Workshop Description

PBL Model

One of the key intentions of this professional development program was to familiarize STEM teachers, school and district level administrators with a viable instructional model that could shape their district-wide STEM initiatives, STEM academies and classroom practice. As the project team consulted various literatures on approaches to STEM education, we agreed that an interdisciplinary approach to STEM education was one that held the most promise in meeting the needs of students and was most aligned with the state of Maryland's STEM initiatives. Hence, several interdisciplinary STEM models were consulted in the planning, implementing and evaluation of the professional development program. Ultimately, the project team felt that Illinois Mathematics and Science Academy (IMSA) PBL instructional and professional development model was best aligned with the goals of the STEM professional development.

In the IMSA PBL instructional model, instruction begins by presenting students, in groups of no more than five students each, with a problematic situation that serves as the organizing center and context for learning. After this "messy" problem has been presented, student groups generate a list of what they know about the problem, what they need to know, and what they must do to solve the problem. Students then create a problem statement and the necessary steps needed to solve the problem they have identified. Students, acting as active problem solvers and learners, gather and share information in order to develop probable solutions to their problems, while teachers serve as cognitive and metacognitive coaches throughout the process. Finally, learners share their tentative

solutions with other students and use feedback from others to refine their solutions, debrief the problem and identify skills and concepts learned through the process. Evident in this model of PBL is that an ill-structured instructional problem serves as the basis of learning, that the learner is self-directed and regulates their own learning, and the teacher serves as a facilitator of learning or as a tutor (Savery, 2006).

Although the IMSA PBL model has commonalities with other approaches such as case-based, project-based and inquiry learning, it is distinct in key ways. Although all of these approaches are student-centered and promote active learning, in problem-based learning, the learning process is more directed by students, and teachers are not encouraged to provide specifications for a desired end product (Supovitz et al., 2000). Specifically in project-based learning, learners are provided with specifications for a desired end-product and the teachers are more likely to serve as expert coaches providing feedback, guidelines and suggestions for more effective ways to achieve the predetermined final product (Savery, 2006). In PBL, there is no predetermined end product which students are required to complete. On the contrary, students identify their own problem to solve in the context of a complex interdisciplinary scenario and they decide how to use their tutors as resources or consultants to solve these learner- identified problems. Hence, in PBL the learners are charged with both defining the problem, developing the solution and identifying the resources to refine their solutions, and the tutor serves as one possible resource to achieve their goals.

In order to equip teachers to employ the IMSA PBL approach to STEM teaching in their own classrooms it was necessary to design the professional development in such a way that teachers could experience the process themselves. Hence, the project team consulted the IMSA PBL professional development model, specifically the model used by the Illinois group for their PBL introductory institutes. We considered this model to be the one best suited for use with our teachers since they had had used little exposure to interdisciplinary PBL in STEM education. Hence, we engaged teachers in ill-structured problems where they worked in interdisciplinary teams to solve these problems. In addition to working on the problems selected by the facilitators, participants analyzed the critical elements of IMSA's PBL problems and applied this knowledge to design problems that could be used in their own classrooms. Thus there were several strands to the PD experience that we provided. Teachers engaged in solving interdisciplinary problems, as well as in the design of such problems. In addition, teachers identified learning objectives linked to state and national standards and benchmarks, developed resource materials and lesson plans, reflected on the role of the teacher in the PBL settings and, explored the ways in which assessment procedures needed to change in the context of PBL. These professional development activities were critical to providing the teachers and district leaders with an initial understanding of the PBL framework and how this framework could potentially be used to guide district-wide STEM initiatives and classroom practices.

The theoretical framework guiding the design of the activities thus drew from ideas related to the nature of STEM as an interdisciplinary enterprise, the nature of PBL, and from literature on effective professional development. Two of the problems chosen for the PD came primarily from the field of engineering, and while on the surface seem to be primarily engineering-based, they provided opportunities for the specialist teachers, working in interdisciplinary groups, to bring interdisciplinary insights to bear on their problem-solving activities. Thus the experiences were in fact interdisciplinary.

A five-day workshop spanning over five months (November 2007–April 2008) was offered to teachers from across the state of Maryland. The specific objectives were to: (1) assist teachers with content knowledge through the process of solving authentic STEM problems, (2) enhance STEM teachers' approaches to problem-based learning (PBL), (3) help teachers navigate their own and their students' resistance to engaging in PBL activities, (4) support teachers' integration of PBL activities into their own classrooms, and (5) create content specific and interdisciplinary STEM problems that could be used in secondary school classrooms.

The PD was collaboratively designed and conducted by mathematics and science education faculty as well as engineering faculty from the partner universities. The researchers participated in designing the PD as well as facilitating different sessions during the workshop. Participants explored how STEM might be connected to problem-based learning through a series of activities, discussions, lectures, and interdisciplinary problem-solving sessions. On the first four workshop days teachers were deeply engaged in solving some exemplary interdisciplinary problems in an effort to give them the opportunity to experience for themselves the outcomes and challenges that their students might experience with this approach. A brief overview of each of the five days of the workshop is provided in the appendix (See Appendix A).

For the duration of the project, an electronic forum was also set up to provide an opportunity for participants to communicate with each other over the course of the workshops. Given the time between workshops, it seemed important to create some way of keeping participants engaged with the content matter. All participants were enrolled in an electronic learning community (ELC), which included opportunities for synchronous and asynchronous chats, the posting of resources, and discussion groups. Workshop participants were given a series of assignments to complete in the time in between workshops, with a new task being assigned about every two weeks. Participants were asked to post their emerging understanding of problem-based learning in the context of integrated STEM approach, ideas for STEM activities and lesson plans and reflect on their efforts at implementation. Several participants posted the interdisciplinary problems they had developed in their groups during the workshop. Many exchanged information about other local and state wide STEM education programs for secondary students. About one-half

of the participants also posted their problem-based lesson plans to seek feedback from other teachers. Most participants reviewed these lesson plans and offered positive and constructive feedback on the problems in terms of integrating relevant concepts and skills from STEM disciplines to further improve them. About 44% of them posted their revised lesson plans (See Appendix B for sample lesson plans and problems) and a few (~ 32%) also implemented them in their classrooms and shared reflections about the implementation process (classroom-based observations of these lessons did not occur). This provided a forum that allowed teachers to apply what they had learned in the PD workshops to the creation of problems that were relevant to the curriculum that they actually taught, were age-appropriate, and were contextualized in the life-experiences of their students. Zhang et al. (2008) list these as three challenges to the design of effective problems. In the view of workshop facilitators, having teachers design problems for use in their own classrooms ensured that their teacher-knowledge would be brought to bear in the design of the problems in such a way as to address these challenges. Workshop evaluations suggested that the online program was generally well received.

Considering the crucial role of internal barriers—teachers’ beliefs, capacities, content knowledge, and skills—in relation to the adoption of PBL-STEM approach, participants were encouraged to articulate and share their concerns through various activities in the workshop sessions (e.g., group discussions, reflection on learning at the end of each session, and ELC discussions). Teachers’ beliefs about this approach were further explored through individual and focus group interviews. Although many participants seemed to appreciate the interdisciplinary problem-based approach to learning STEM, limited subject matter knowledge beyond one’s disciplinary domain in science or mathematics and lack of familiarity with technology skills and engineering design emerged as major challenging areas.

Methods

The case study approach was used to gain a deeper understanding of participants’ response to STEM-PBL during the workshop. A variety of methods were employed (observations, individual and focus group interviews, surveys, questionnaires, online discussions) to collect rich information about teachers’ emerging understandings of this approach and the issues concerning its implementation in actual school contexts (Merriam, 1988; Yin, 2003).

Participants:

Each of the 25 public school systems in the State of Maryland was offered the opportunity to send two teachers to the Professional Development series. A one-page flyer with information about the series was sent to the STEM coordinators for each county, and a

memorandum with much of the same information was sent from the State Secretary of Education to the Superintendents of each public school system. Ultimately 20 of the 25 schools systems sent representatives to the series, with a total of 41 teachers signing up to attend. The teachers who signed up included seven Biology teachers, five Engineering teachers, 13 math teachers, 10 teachers of a science other than Biology, and six technology education teachers. Of these, 25 completed all five days of the series. Teachers who did not complete the program cited a number of reasons for not completing, including illnesses, the need for childcare, other conferences they wanted to attend, and the amount of time required for the sessions.

Data Collection:

Data were gathered through (a) participant observation notes of the activities and discussions during the professional development workshop, (b) focus group discussions at the end of the workshop (60 min.), (c) individual interviews with 12 participants (both impromptu and formal lasting about 15-20 min.), and (d) workshop feedback and evaluation forms. Additionally, a survey was used before the workshop to explore participants' understanding and any instructional experiences related to problem-based learning in STEM disciplines (Appendix C). The individual and focus group interviews probed participants' ideas about the barriers concerning the interdisciplinary problem-based learning approach to teaching science in secondary classrooms. The multiple methods of gathering data throughout the workshop helped in tracking participants' reaction to the interdisciplinary approach as well as their perceptions about the myriad systemic challenges to employing this approach in their current practice. Quantitative survey data were collected using a survey administered at the beginning of the workshop to capture participants' initial conceptions about PBL and their prior experiences and comfort level with using PBL in their instruction.

Data Analysis:

Analytic strategies for data analysis included the coding of interview, focus group and observational data. In the initial phase of data analysis, we followed an inductive approach to allow the codes to emerge from the data (Patton, 1990). Next, we employed the constant comparative method (Lincoln & Guba, 1985) to organize the data into broader categories and themes in relation to our research questions (e.g., teachers' initial perceptions of PBL, emerging understanding of STEM-PBL, implementation challenges, systemic barriers, etc.). Within case and cross-case analyses helped to compare patterns across the participants and to explore thematic and conjunctive relationships among cases in relation to our inquiry focus. Specific analytic questions were developed to further explore and analyze participants' responses, thoughts, and concerns about the applicability of the STEM-PBL approach in science and mathematics instruction, and its efficacy with

respect to meaningful learning. Additionally, multiple discussions among the study team members facilitated a deeper analysis of the data from multiple angles, and helped in addressing the validity issues related to our interpretation of the findings (Patton, 1990; Strauss, 1987; Strauss & Corbin, 1998). Descriptive statistical techniques were employed in analyzing the survey data.

Findings & Discussion

Herein we discuss the major themes that our analysis revealed and their implications for developing and enacting effective teacher development programs using an interdisciplinary PBL approach to STEM education. Our analyses revealed some interesting changes in teachers' conceptions about PBL after the PD experience. In addition, the broad themes that emerged related to implementation of a STEM-PBL approach, and the possible outcomes, of such an implementation.

Participants' Initial Perceptions about Problem-based Learning

Prior to this PD experience most teachers had discipline-specific notions about PBL. As revealed through a survey administered prior to the PD workshop, most teachers conceived PBL as an approach that used problems connected to "real life" situations within their particular STEM disciplines. They were aware of its potential for developing logical and higher order thinking among students through participating in "hands-on" activities centered on problem solving as suggested by their responses.

Problem based learning is working through and investigating a problem through an organized thinking process. Students use higher level thinking to solve problems. This would include inquiries and labs. Students use prior knowledge and apply this to solving a problem.

In PBL learning environments, students learn concepts by solving a problem or completing an activity related to the concept. For example, students complete a lab to determine how pH and temperature affect enzyme activity. In science, problem-based learning usually involves lab work.

Relatively few participants talked about the interdisciplinary nature of PBL approach. They seemed not to have thought about PBL as engaging students in interdisciplinary thinking due to the interdisciplinary nature of real world problems. A small number of the teachers were attuned to this aspect of PBL. One participant noted:

It means that my students will be given a long-range problem to solve which will require them to learn processes, attain information, apply their knowledge and skills, and use higher level thinking skills to find a solution to the problem.

Some problem-based models are designed to be cross curricular which allows for teachers to co-teach concepts.

While pointing out the interdisciplinary character of PBL, another teacher stressed the importance of this approach in terms of facilitating a deeper understanding of the content. In her words:

Using carefully constructed, open-ended problems that require input from a variety of disciplines, and allows for multiple forms of output is a good idea. A problem-based curriculum would allow for greater depth and understanding.

A few participants thought about using PBL approach as a framework to apply mathematics to science while solving problems. The notion of PBL encompassing all the STEM disciplines generally did not surface in participants' responses.

Teachers' Perceptions of PBL in STEM after PD Experience

Teachers' post PD comments focused on the issues of interdisciplinarity, on their own attitudes to the PD experience itself, and on issues related to implementing STEM PBL in their classrooms. Many teachers expressed the view that that they did get a deepened understanding of the interdisciplinary nature of STEM in terms of making connections within the different scientific domains and using the engineering-based approach to integrate concepts and skills across the STEM areas. Using a team approach to solving authentic problems and "modeling" that behavior for students also surfaced as a significant shift in their approach towards STEM-PBL. A physics teacher noted, "We are siloed – people need to have an integrated team approach." Some participants also recognized and appreciated the "open-ended" and "ongoing" nature of interdisciplinary STEM problems. Below we share some participants' reflections on their learning:

We are siloed – people need to have an integrated team approach . . . you can bring the knowledge as a team and solve the problems and model behavior for students. . . . teachers and students cannot now solve problems individually.

Gained some insight as to what STEM is . . . everything in education world exists in functional silos, which is contradictory to what was taught in this workshop.

You can bring the knowledge as a team and solve the problems and model behavior for students to help student make connections across science, math, engineering, and technology, and solve real-world problems.

Problem-solving is an ongoing process that may generate multiple solutions and students will learn that there can be several pathways to resolve a messy problem.

However, without clarity of how it could be implemented or modules that fit directly into the curriculum, many teachers felt it could not work. Most schools have domain specific science courses like biology, chemistry, physics, and these courses have very little integration with other STEM disciplines (engineering, technology, and mathematics). Consequently, it is extremely challenging to offer scientific and engineering problems that are interdisciplinary in nature.

Teachers' feedback on the professional development experience suggests that they felt they had learned something new, the activities were interesting and unique, and learning materials and hands-on proceedings provided a good change from previous PD experiences. Responses to the final evaluation survey indicated that 88% teachers felt that PBL related to STEM education helped them learn new ideas and 91% said that the PBL approach helped them to think critically. About 77% felt that the STEM PD experience was different from the usual science and math PD experiences they had participated in and 86% said that the experience was a good change from the usual PD experiences. The consensus was that the activities fostered critical thinking. Most teachers were not (or did not anticipate being) uncomfortable with STEM-PBL approaches in the workshops or in their school classrooms. Nevertheless, there were some who did. After the first workshop, 20% of participants reported that they either strongly agreed or agreed with the statement "I will be uncomfortable using the PBL approach to STEM in my class;" while 29% either strongly agreed or agreed with the statement "I was uncomfortable using the PBL approach to STEM in this workshop." These numbers had gone down by the end of the workshop series, with only 14% strongly agreeing or agreeing with each statement after the final workshop. However, interviews and focus groups both continued to reveal a great deal of resistance to using a STEM-PBL approach.

Participant observation, interview, and workshop evaluation data reflected participants' concerns about (a) developing STEM based problems in groups during the workshop, (b) applicability of STEM-PBL approach to current teaching conditions, and (c) the efficacy of workshop problems with respect to meaningful learning. Teachers felt that there was not enough clarity in the program about how the content and hands-on experiences provided in these STEM PD workshops were going to fit current school curriculum as well as science/math content and assessment standards. For example, during one of the focus groups sessions, a science teacher asserted:

I already knew about PBL in STEM and I thought I would get lots of stuff to use in my classroom. I don't think that you (the presenters) knew our prior experience, so I didn't get to a new level on my understanding of STEM-based

lessons. I did get some understanding of engineering concepts, but I am not sure how they will fit into what I teach.

Nevertheless, some technology teachers said that technology education is a good place for integrating engineering, technology, and mathematics into science activities. A technology teacher explained:

Technology incorporates engineers and people. Technology education is where it starts tying together! In a tech classroom, let them play and fail! All is pulled together in technology, math, engineering...tools, space, all of materials.

Conversely, another technology teacher said that STEM problems covered in this workshop may be very difficult for students. "It would go over the heads" of most technology education students, but "some students" would find them engaging. "It does hit a few students," he added. Some mathematics and physics teachers suggested that developmentally appropriate STEM problems might engage the students who struggle with abstract mathematical and physical science concepts. A mathematics teacher talked about the problems her students face in understanding algebraic equations and thought that integrating hands-on engineering-based activities with math concepts would be useful for secondary schools.

My 10th grade kids failed algebra . . . equations were hard for them . . . we can do age appropriate, simple things and projects for kids. Have developmentally appropriate problems for 10th graders with engineering ideas. STEM ideas in the modules that the engineering fellows developed are good for 10th graders.

In general, most participants appreciated the focus on real-world interdisciplinary problems and discussed the advantages of using them in science instruction, as reflected in a science teacher's thoughts on STEM-PBL that he posted on ELC.

The advantage of focusing on PBL methods for STEM areas is that these types of problems are what researchers, scientists, and engineers will actually face. Emphasizing PBL gives these students experiences that will prepare them for the 'real world'.

Although teachers' perceptions of STEM PBL after the workshop varied, many of them perceived that using this approach to teaching was "interesting," but they did not see how this could be used in their classrooms.

Implementing a STEM Inquiry Approach: Obstacles and Challenges

In this section of our report, we specifically explore the problems and barriers confronted by teachers while attempting to learn and apply an interdisciplinary PBL approach for the

integration of the STEM disciplines. In the exploration of the major research questions stated earlier, we searched for answers to the following sub-questions: What particular issues did secondary science and mathematics teachers face while engaging in a PD program using the integrative STEM-PBL approach? What kind of barriers did they confront and share in relation to implementing this approach in their schools? What role does the way students and teachers are assessed play in teacher resistance to interdisciplinary approaches to STEM? What kinds of assessment regimes, of both students and teachers, might soften their resistance? Teachers exhibited resistance to the implementation of our model. Participants explicitly shared their apprehensions and concerns about using STEM approach in their instructional settings during workshop discussions, individual conversations, and focus group discussions. Below we discuss three reasons for this, including issues with integrating STEM content with the pedagogy we proposed, problems with the model problems chosen for our workshop, and teachers' perceived barriers to implementing this method into their own practice.

Integrating STEM content and pedagogy

Research suggests that professional development must emphasize a close connection between pedagogy and subject matter content (AERA, 2004; Cohen & Hill, 1998). While the STEM problems were designed to incorporate both the pedagogical approaches and content concepts, the teachers seemed to experience them as somewhat separate. The workshops included content lectures which were intended to provide an introduction to the concepts embedded in the problems, but teachers expressed some confusion over how the content lectures (given by an Engineering faculty member) related to the pedagogical methods under discussion. The workshops also provided explicit instruction in problem-based pedagogy, but some teachers pointed out during the focus group discussions that they did not see a link between the content covered in the content portions of the PD workshop and the PBL approach to content. Upon reflection the presentations on content tended to focus on small pieces of content, such as photosynthesis, bridge building, or using circuits to build a robot. While each problem connected to several disciplines, teachers had trouble connecting these problems both to the individual content standards and to the big ideas in their fields (biology, chemistry, physics, calculus, etc.). Although we gave explicit attention to linking the scientific and mathematical concepts as well as the technology skills embedded in the model problems to the curriculum content standards, some teachers expressed concerns about the lack of a tight connection between the problems that were presented to them and the science concepts linked to those problems. Biology teachers in particular struggled with connecting the electronic circuits and building bridges problems to biology concepts included in the standards. Talking about this issue, a teacher suggested developing STEM modules for teachers that are explicitly and tightly connected to the standards.

I think the way that this is going to work is the modules, but do them in the content that needs to be taught. If you give the teacher a module and tell them that this is how it connects to the standard, then they'll do it. Then there needs to be reflection, because that's how kids learn to think. I would incorporate this into the module.

In future attempts at this kind of PD, it would help both to model the problem-based pedagogy in our approach to teaching content and to more clearly link the sample problems to the organizing concepts in the teachers' disciplines. This latter point, we think, is critical to the successful preparation of teachers for STEM teaching. The focus of both the content enrichment activities, and the model problems to which teachers are exposed should be those big over-arching ideas that are truly cross-disciplinary. This is what would enable teachers, traditionally focused on their own specific disciplines, to make the cross-disciplinary links that is the essence of STEM.

Perhaps our focus on the specific concepts needed by the teachers for engagement with the model problems was too limiting, and prevented teachers from moving beyond disciplinary boundaries. It is when pedagogy is linked to big ideas, as opposed to narrowly focused content that it is likely to be a most effective tool for professional development.

Problems with the model problems

One of the main concerns expressed by the participants had to do with the difficulty of tying the problem-based approach to the content that they were teaching in their own classes. In their curriculum, they have a set of skills and topics from a particular domain (biology, chemistry, physics, algebra) that they are responsible for teaching. While some physics and engineering teachers felt that the problems presented in the workshop were relevant to the content concepts included in their curricula, many biology and chemistry teachers criticized the problems due to their lack of connection and relevance to the specific concepts in their particular disciplines. Teachers expressed a desire for more specific problems that they could use, especially ones grounded in their own discipline.

While our approach was to encourage the teachers to develop their own problems, and the workshops included sessions devoted to having them develop problems in interdisciplinary groups, teachers seemed to find this process very difficult. Many teachers felt that it was hard to develop new problems integrating different STEM disciplines. Reflecting on the difficulties involved in developing interdisciplinary problems drawing on different STEM concepts a teacher noted:

Coming up with PBL ideas was the hardest. Figuring out the complicated ideas in STEM activities [PD workshop] was hard. One needs to have a background in the subject...need to know the topic first.

Furthermore, several participants pointed out the difficulty in “finding STEM problems” and expressed the need for model PBL STEM problems that they could “take back” with them. “We would like modules we could take home, something I would be able to use in my chemistry class,” a chemistry teacher said. Another teacher echoed this concern about the need for model problems. In her words, “I guess we’re looking for the STE and M, but I was never that clear, thought you guys had done the research and were going to provide more models.”

Moreover, many biology teachers wrestled with the problem of developing technology and engineering-based problems in biology and they specifically asked for “engineering problems for biology lessons.” Alternatively, a few interdisciplinary teams were able to draw on their collective knowledge to develop integrated STEM problems during the workshop. As a chemistry teacher explained:

After the team came up with the idea, it grew exponentially...they came up with an interdisciplinary STEM problem using concepts from environmental science, physics, chemistry and math – the topic was volcanoes.

The problems that participants developed for their lesson plans and shared on ELC focused mainly on standard experiments and projects involving concepts from their particular disciplines, although most teachers made an attempt to infuse relevant mathematics concepts and skills in those problems. Nevertheless, only a few physics problems involved technology and engineering-based design explicitly.

While one approach would be to provide more explicit modules for teacher to take home with them, we continue to believe that teachers need to become adept at designing their own problems. Nevertheless, we could have provided some useful STEM problems since some teachers left feeling that they wanted more sample problems that they could pursue with their own classes. PD developers need to think about better model problems that are (a) interdisciplinary in focus, yet obviously connected to concepts in the discipline-specific curricula with which teachers are familiar, and (b) meaningfully connected to their students’ lives (Paige et al., 2008; Park-Rogers et al., 2007; Sage, & Torp, 1997).

Barriers to implementation

We found a fair degree of resistance to the incorporation of interdisciplinary problem-based learning into teachers’ own lessons. Some of this resistance pre-existed the workshop: participants began the PD with some uncertain feelings about the PBL-based approach to STEM. Interviews and focus groups during and after the workshop both continued to reveal a great deal of resistance to using a STEM-PBL approach. At the completion of the workshop, about 14% of participants felt uncomfortable using the PBL approach to STEM in this workshop and about the same number said that they would be uncomfortable using this approach in their own practice.

The sources of this resistance can be traced to at least three external barriers: the structure of schools, the curriculum, and the way education is organized and evaluated at the state level. The resistance based on the structure of schools came from the perception on the part of teachers that working with colleagues in other subject specific areas would be difficult if not impossible given the constraints imposed by the compartmentalized system of teaching in the scientific disciplines and the lack of adequate team preparation time (Ertmer et al., 2009; Ertmer et al., 2007; Park & Ertmer, 2008; Ward & Lee, 2002). There appeared to be a disconnect between the State's desire to create STEM academies and the study participants' current teaching environments. Although teachers are expected to integrate STEM disciplines, academic schedules in schools are not coordinated to create interdisciplinary connections across different STEM subjects.

Several teachers pointed out that since different students would be in different classes, they would not be able to work out an arrangement with a colleague to cover all discipline-specific curriculum material in an interdisciplinary fashion, and that without such an agreement they could not commit the time to interdisciplinary problems because they had too much material to cover. Some teachers were apprehensive of the constraints involved in engaging in interdisciplinary team work at their schools. It is not realistic to expect that we'll go back and work with the other technology teacher, the other math teacher," a teacher noted.

Indeed, some saw STEM as just one more thing that they were now expected to cover, instead of conceptualizing it as a different approach to the implementation of their curricula: "They've added STEM, but they haven't taken anything away." This is related to the final source of resistance: the way education is structured and evaluated at the State level. Teachers pointed out in the workshops themselves, in the interviews and conversations with the instructors and study authors, and in the focus groups that they were evaluated on their ability to teach a particular subject, and that students were tested in that subject (this attitude was especially prevalent among teachers of Biology, as Maryland requires all students to pass an exam in this subject in order to graduate). "There is a great deal of pressure to cover your curriculum . . . to pass the test," a biology teacher noted. Another teacher echoed this concern about testing, "HSAs are focused on a score/end result. Can't see the justification for this [bridge] problem."

Some felt that sacrificing time for interdisciplinary units would take time away from preparing students for the high stakes tests that students must now pass to graduate, and thus resisted what they saw as an attempt to push them towards using interdisciplinary problems. Others, while they believed that an integrative PBL-based approach to STEM would prepare students for these exams, thought that parents and principals would not support such a method. As a participant shared, "I do think this is the right way to do it, but we have a school system that is essentially an assembly line and kids are our product." These issues related to assessment, evaluation, and standardized testing emerging from

this analysis resonate with the issues discussed in the literature (Gallagher et al., 1995; Gordon et al., 2001; Maxwell et al., 2001; Meier et al., 1996; Novak, 1990; Tchudi & Lafer, 1996). Nonetheless, a few physics teachers (2) said that they have been using integrated problems related to physics, engineering, and mathematics in their instruction and were pleased to learn about the problems used in this workshop. They were also keen to use these model problems with their students. Lack of time and good model problems were their main concerns in terms of implementing this approach consistently in their classrooms.

Of course, teachers also exhibited internal barriers to using an interdisciplinary problem-based approach. Some worried about their own knowledge of disciplines outside their primary subject area. Others cited the time it takes to develop good interdisciplinary problems as a barrier to their use of them. A chemistry teacher seemed worried about incorporating mathematics and engineering related concepts into the biology and chemistry concepts:

You have subject specific problems versus STEM problems . . . for example, biology or chemistry problems . . . the structure of glucose, it's a specific problem, how can you incorporate math or engineering into it?

Another teacher shared a similar concern about linking the interdisciplinary STEM problems included in the workshop to the existing curriculum:

Tree activity was more helpful . . . Bridge problem, how to connect it with the curriculum? Don't know how to do that? What curriculum would you put that in?

Challenges involved in assessing students' performance and understanding during and after interdisciplinary lessons were also discussed by some teachers. Issues related to effective assessment of concepts and skills from multiple disciplines embedded in STEM problems came up during workshop and ELC discussions. Some teachers were concerned about assessing students' prior knowledge of science, mathematics, and technology before engaging in integrated STEM problems as described by a chemistry teacher:

Assessing STEM, interdisciplinary lessons is very challenging for me. The challenge seems to arise in the level of prior knowledge each student has about technology, engineering, and math . . . I teach chemistry students who have had anywhere from Algebra I to AP Calculus, which makes it very difficult to make any assumptions that students know concepts from other disciplines.

Nevertheless, the external factors seemed to play a larger role in participants' resistance in this study. To make sense of this fact requires an understanding of the way that both these teachers and their students are assessed in the state of Maryland.

Teachers' resistance needs to be understood in the context of education both in Maryland and in the nation as a whole. After No Child Left Behind passed in 2001, every state was required to develop their own tests to ensure that all children were learning. In Maryland this requirement was met through a combination of tests, including the Maryland State Assessments (MSAs, tests in both reading and math, are given in grades 3-8, while second year high school students take the English 2 test and all geometry students take that test), as well as the High School Assessments (HSAs, given in Algebra, Government, Biology and English). The HSAs have taken on particular significance for the class of 2009, the first who must pass all four HSAs¹ in order to graduate. While both sets of high stakes tests have important consequences for schools as a whole, this requirement that all students pass all HSAs in order to graduate has made the HSAs particularly important to individual students and their families. Participants frequently referred to the accountability issue as the most important barrier to using a STEM-PBL approach in their discipline-specific instructional practice (Park et al., 2005; Park & Ertmer, 2008).

Originally both the MSAs and the HSAs consisted of both multiple choice items and short essays, or Brief Constructed Responses (BCRs). However, recently a decision has been made to eliminate the BCRs from the HSAs. This decision was a direct result of the need to grade the exams more quickly so that students would know if they were going to be allowed to graduate. This makes it more unlikely that teachers will be willing to spend considerable time planning, enacting and assessing interdisciplinary lessons, as their students are evaluated through simple multiple choice tests. As the movement to assess teachers solely by their students' test scores gains strength, and as the possibility of their pay being tied to this measure of performance continues to be discussed, is it any wonder that teachers exhibit some resistance to using an interdisciplinary problem-based approach to teaching STEM?

Many of the internal barriers pointed out by the participants in this study might be overcome through more professional development to familiarize teachers with this approach. Indeed, we found that teachers reported a significant drop in their self-reported discomfort with a problem-based approach to STEM after the third workshop. Teachers would have liked to receive more sample activities and modules that were ready to be used in the classroom rather than having the focus be on teaching them to create their own modules. We feel that it might be useful to develop and present explicit examples of problems showing internal and external connections among the STEM disciplines in their initial training. However, after considerable experience in using these problems for teachers' own learning in PD and using them in their classrooms, it is clear that they need more support to design their own problems or adapt existing problems in accordance with their curriculum.

While these internal barriers can be addressed, changing the factors that contribute to the external sources of resistance would require substantive changes at different systemic levels. It would probably require a change in both the standards (in Maryland, the Voluntary State Curriculum) and the methods of assessing whether students have reached these standards. First of all, as written, the content standards do not easily lend themselves to interdisciplinary problems. While they are not directly opposed to this approach, standards could be written to actively encourage teaching students how to apply scientific and mathematical knowledge to real world, interdisciplinary problems. But perhaps the bigger issue is in the way students are assessed – when the assessments measure knowledge in only one discipline at a time, teachers have no real incentive to teach in an interdisciplinary fashion.

Ironically, prior to NCLB the tests used to assess students' learning in mathematics and science were more aligned with an interdisciplinary approach and were more likely to promote interdisciplinary learning. Maryland used what was called the Maryland State Performance Assessment Program (MSPAP). The Maryland State Department of Education describes MSPAP as follows:

The Maryland School Performance Assessment Program was a test given each May to Maryland's 3rd, 5th, and 8th graders to test their mastery of the basics and how well they applied knowledge in authentic problem-solving situations. MSPAP's primary purpose was to provide information that could be used to improve instruction in schools. It measured the performance of Maryland schools by illustrating:

1. How well students solved problems cooperatively and individually.
2. How well students applied what they learned to real world problems.
3. How well students could relate and use knowledge from different subject areas.²

The emphasis on cooperative problem-solving of real world problems drawing on knowledge from different subject areas is exactly the kind of assessment that might help overcome teachers' resistance to using an interdisciplinary problem-based approach to teaching STEM.

Implications

We cannot claim enormous success in our goal of preparing teachers to use interdisciplinary approaches to the teaching of STEM. Nevertheless, our work has highlighted the enormity of the issues we face when we attempt this paradigm shift. This study points to the need for a broader discussion around important individual and institutional barriers confronted by many science and mathematics teachers while learning and employing the integrative STEM-PBL modules in their practice. This research has generated crucial insights for teachers, school administrators, teacher educators, and researchers in terms

of preparing, encouraging, and supporting teachers to come together and work across disciplinary boundaries. First, an interdisciplinary STEM-PBL approach demands a transformation in the teacher's role from a transmitter of knowledge to that of a facilitator of knowledge to help students to identify and use relevant sources of knowledge to solve real world problems. In order for teachers to make this transition from transmitter to facilitator, there must be substantive changes in the way science and mathematics curricula, pedagogy, and assessment systems are conceptualized, organized and implemented. Secondly, administrators who are interested in interdisciplinary STEM programs need to develop supportive structures and mechanisms for teachers that will help foster their professional growth and competency with interdisciplinary PBL approaches. In addition, administrators must recognize the internal and external barriers that teachers face when trying to implement such an innovative approach and provide encouragement, support and professional development activities that help them overcome these barriers. Also, administrators must encourage interdisciplinary collaborations in order to develop and implement innovative programs such as the ones we have explored in this study. Third, teacher educators must understand these barriers in order to design professional development activities that can assist teachers in overcoming them. In addition, they must understand the nature of teacher change and the types of professional development activities that have the most promise for changing teacher practice. We have learned that even when teachers understand the innovation and see the relevance and value of the innovation, change in teacher practice is highly connected to a variety of school and system wide factors including mandated assessment, curriculum standards, and scheduling. Hence, in addition to addressing pedagogical and content knowledge development, professional development must incorporate ways to examine the effect of larger systemic factors on teachers' practice. Finally, researchers need to investigate the efficacy of STEM-PBL approaches in professional development programs and how school contexts shape teachers enactment of new practices, particularly in STEM education.

Insights gained through this study have implications for teacher preparation programs, ongoing professional development, teacher mentoring and supervision systems. Specifically, the current practice of training teachers in discipline-specific ways is extremely problematic when they are asked to implement curricular programs that require integrating across various STEM disciplines. Although teachers may see the value in such interdisciplinary approaches, their discipline specific training may limit their ability to embrace an expanded view of mathematics and science learning. These challenges suggest that pre-service and in-service professional development needs to be restructured in order to allow interdisciplinary collaborations, lesson planning and new ways of assessing student learning in STEM. While implementing the integrated approach to STEM education, teachers need specific school-based coaching and mentoring in various STEM content

areas as well as instructional and assessment techniques to create and implement their STEM curricula effectively. The development of professional development materials that foster cross-disciplinary learning among STEM teachers is a worthwhile line of research and development that university-based STEM educators could undertake.

This study also brings out critical issues related to the larger accountability and testing systems that may affect any reform initiative focusing on STEM education. Much of the teacher resistance to implementing integrated curricula materials reflected their concerns about how students would perform on state-mandated tests in algebra and biology. Although a strong case was made for improved student conceptual understanding when engaged in interdisciplinary instruction, teachers expressed a great deal of concern about whether they would be able to “cover” the material that was assessed on these discipline-specific tests. This concern for content coverage was grounded in the idea that the only way to insure students’ success on these tests was to teach the specific skills and content that was being tested. In our attempts to allay teachers’ concerns about this, it was not sufficient to show how the interdisciplinary content reflected the skills and concepts that were being tested. Teachers felt that they had to tailor their instruction specifically to the content for which they were being held “accountable.” This focus on “teaching to the test” had negative implications for implementing interdisciplinary curricula and reflects some of the challenges other scholars document when implementing innovative teaching practices in mathematics and science (Shepard & Dougherty, 1991). In addition, teachers had difficulty in developing relevant assessment tools for examining student understanding and skills gained through integrated STEM curricula. Another assessment-related issue was that teachers perceived a disconnect between what the state mandated tests assess and the assessments that are aligned with these kind of curricula. Hence, scholars and policy makers must continue to reevaluate the role of assessment in mathematics and science education and adopt assessment policies and practices that facilitate integrated approaches and the deepening of students’ understanding across disciplines.

Notes

1. Students can also meet this requirement by receiving a high enough score across all four exams, or by completing a bridge project in any area where they have been unable to pass the test.

2. See <http://www.msde.state.md.us/mspap/default2.htm>.

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Appendix A

Interdisciplinary STEM PD Workshop Description

Day 1: Teachers were introduced to the principles guiding the workshop. They were then given a presentation on the nature of STEM and were led in a discussion about the nature of problem-based learning in STEM education. To give teachers a firsthand experience of the kind of interdisciplinary problem that could be used in PBL, they were placed into interdisciplinary teams and asked to devise a method of estimating the total leaf area of a tree, to determine its carbon dioxide uptake. In this activity, teachers learned interdisciplinary content, discussed how the problem exemplified interdisciplinary PBL, reflected on the challenges they faced in solving the problem, and how these challenges might be similar to the ways in which students may experience interdisciplinary PBL.

Day 2: Prior to Day 2, teachers were asked to bring in problems that they believed had potential to be interdisciplinary. In analyzing these problems teachers were asked to identify the big ideas and key concepts in their respective disciplines that were embedded in them. As on Day 1, discussion also focused on the interdisciplinarity of the problems and how their students might experience working on them. The exemplary problem in which the teachers were themselves involved on that day was the task of building a bridge to specifications using everyday materials such as paper and spaghetti.

Day 3: The bridge-building activity continued on this day and the discussion that followed served as the basis for the development of their own problems that could be used in a variety of classrooms. Teacher teams developed problems and revised these problems to be examined on day 4 of the workshop.

Day 4: Teachers discussed their problems, developed lesson plans that reflected interdisciplinary PBL, and discussed some of the barriers they would face in implementing these types of problems in their classes. Interdisciplinary teams, with assistance by content experts, created logic-based electronic circuits to design and control a light-seeking robot. This activity was the exemplary problem for the day, and was specifically chosen as it was thought that it would require the learning of new content for many of the teachers.

Day 5: Teachers reflected on their problem solving, student assessment, and how to infuse interdisciplinary problems into the curriculum. In addition, a group interview was conducted and several individual interviews were conducted in order to understand teachers' conceptions and perception about interdisciplinary PBL, some of the challenges and affordances to implementing this framework in their schools, and to evaluate the overall success of the workshop.

Appendix B

Sample PBL-STEM lessons and problems developed and shared by the participants.

SOLAR CELLS

Core Learning Goal 5.2: The student will know and apply the laws of electricity and magnetism and explain their significant role in nature and technology.

Overview: Students will investigate solar cells and their applications. Students will design and build a solar powered small household toy or appliance. Students will produce a television commercial to promote their new product.

Lesson:

Part I: Investigating Commercial and Homemade Solar Cells

1. Students research homemade solar cells on the internet.
 - Students should identify the material components of each homemade solar cell, and the commercially available cell.
 - o Identify the function of each material.
 - o Compare the cost of each cell.
 - Students should identify pros and cons of using solar power.
2. Students build each of these homemade cells and compare them to a small commercial cell.
 - Have students design and conduct an experiment to compare current produced by each cell.
 - Draw conclusions about whether or not it is possible or feasible to use homemade solar cells to provide power to a small household device. (This will require some knowledge of how much power is necessary to operate a “small household device.”)
3. Students investigate configurations of multiple solar cells to increase current.
 - Have students design and conduct an experiment to determine the best configuration (series, parallel, or combination) for multiple cells. Use commercial cells for convenience and reliability.

Part II. Designing and Building a Solar Device

1. Students brainstorm devices they could make to run on solar cells.
 - Conditions to consider: devices must be able to run on the amount of power the cell can produce; devices must be original; the solar power can come

from commercial or homemade cells, depending on results from Part I; using multiple solar cells is allowed, configuration should depend on results from Part I.

2. Students share their ideas in small groups of 3-4.
 - Students can debate the feasibility, creativity, efficiency, etc. of each idea.
 - Students must choose one device for the group to build.
3. In groups, students design their solar powered device.
 - The designs must be specific and detailed. The design must include:
 - o a labeled drawing to scale
 - o a materials list
 - o an overview of how the device will work and what it will do
4. Once designs have been teacher approved, groups build their device.
 - Every step of the build process must be documented.
 - Students should test components of their design along the way and document testing results and resulting design modifications.
5. Groups present their completed, working devices to the class.
 - The class gives feedback to the group and time is allowed for additional modifications or improvements to the devices.

Part III. Producing a Commercial to Sell the Device

1. In the same groups, students write a script for a commercial to sell the device they have made.
 - Commercials must include a brief description of how the device works.
 - Commercials must be creative and entertaining.
2. Students create their commercials.
 - The device should be the star of the commercial but group members must also appear.
 - The commercial should be 30-45 seconds in length.
 - Students will film using digital video recorders and edit using Movie Maker.
3. Students share their commercials with the class.

Opportunities for Assessment: Teachers can assess students at several junctures in the course of this lesson. Teachers should check the student research in Part I (Step 1) to ensure that the students fully understand the concepts of solar cells. Teachers should check the experimental data and conclusions from Part I (Steps 2 and 3) to ensure that the students have correctly interpreted the results. Teachers should monitor the design and build process in Part II and check group design logs for adequate testing and modifications. Teachers should assess the commercials in Part III for the requirements indicated. Teachers may choose to add an additional assessment to the end of this lesson by requiring students to

write a final paper summarizing the entire process from researching background information to testing existing cells to designing and building their own device.

THE "GREENEST" LIGHT BULB

Combining engineering, environmental science, horticulture, human health and biology: Many of our indoor plants begin as seeds at a commercial growing facility, are propagated there, and are then shipped to our local mega-mart where we buy them as small plants. Sometimes we buy seeds and "start" them indoors under lights until they are sturdy enough to transplant outside. But is all the energy we spend on such plants helping or harming the environment?

It will be your goal to see if such practices contribute to, or help off-set, our carbon footprints.

Part 1: Many plants are started and propagated indoors using costly, energy-intensive high pressure sodium lights.

- compare the energy used by different types of light bulbs in plant production
- design an experiment that will determine the amount of energy consumed by various types of light bulbs. Be certain that the light bulbs are of similar lumen output. (fluorescent, incandescent, LED, and halogen must be included, you may also include others).

Part 2: Are there alternatives that will produce comparable results?

- Design an experiment that will show the effects of propagating a minimum of 3 types of plants under various light sources. You will need to determine a method of assessing "how well" a plant grows. This will likely vary depending on the desired use for the plant. Consider using a variety of plants from a single "genre": vegetables, houseplants, flowers, grasses, etc.

Part 3: What light source(s) are the most productive? Which are the most efficient?

- Review and compare the information regarding spectral output of lights. Is there any correlation to the data you obtained?

Part 4: Carbon use by the plants.

- Determine a method for calculating the amount of carbon uptake/ storage provided by the plants. The difficulty will be in figuring out the possibly subtle differences between different plants.

Part 5: Decision making. Does it make sense (from an ecological stand point) to grow plants this way? Are there other factors that need to be taken into consideration when making this decision?

Appendix C

Survey

What does problem-based learning mean to you?

How do you think about it in the context of math and science teaching? Please provide some examples of science or math problems to illustrate our understanding.

1. I believe that problem-based learning is an important element of teaching science, mathematics, technology, and engineering disciplines.
Strongly disagree Disagree Undecided Agree Strongly agree
2. I already incorporate a problem-based approach to learning science and/or mathematics in my lessons.
Strongly disagree Disagree Undecided Agree Strongly agree
3. I am comfortable using a problem-based approach to learning science and/or mathematics in my lessons.
Strongly disagree Disagree Undecided Agree Strongly agree
4. I enjoy teaching with a problem-based learning approach.
Strongly disagree Disagree Undecided Agree Strongly agree
5. I believe that students' learning is enhanced by the use of a problem-based approach to teaching science and mathematics.
Strongly disagree Disagree Undecided Agree Strongly agree
6. I believe that a problem-based approach to science and mathematics can lead to students missing the learning of important basic facts.
Strongly disagree Disagree Undecided Agree Strongly agree
7. I believe that a problem-based approach to science and mathematics helps students to think critically.
Strongly disagree Disagree Undecided Agree Strongly agree
8. I believe that a problem-based approach to science and mathematics leads to better student HAS test scores.
Strongly disagree Disagree Undecided Agree Strongly agree

9. I enjoy teaching on a team with teachers of other disciplines.
Strongly disagree Disagree Undecided Agree Strongly agree