ENGINEERING PROFESSIONAL DEVELOPMENT

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The Math Science Technology Education Partnership (MSTP, 2003) is one of the NSF MSP-targeted projects that has as its primary mission the improvement of middle school mathematics instruction and student learning in mathematics, science, and technology education classes. It is the only MSP project that uses engineering design as one of its key elements. The thesis of the project was simple: with more instructional time devoted to mathematics, and with mathematics taught with current pedagogical practice, student learning should improve. As part of the MSTP Project, we have been refining professional development for science, technology, engineering, and mathematics (STEM) teachers, with a particularly strong focus on mathematics and science teachers. The paper will provide an overview of the three-year evolution in STEM professional development and a detailed examination of the current state.

An important feature of MSTP is that each school district could shape how it provided professional development and how it built an MSTP community. Not surprisingly, there were stronger and weaker professional development models. However, it did provide us with the opportunity to seek the best elements of several programs to evolve to the current strategy.

For all districts, the first year was spent in developing a leadership team for the school: a team composed of mathematics, science, and technology education teachers, a guidance counselor, an administrator, and two university STEM faculty. In the second year the team ran awareness workshops and, with district help, recruited teachers for professional development. All but two districts held the majority of the professional development activities in the summer. Two did the professional development during the academic year. In the more successful of the two, teachers learned mathematics contextualized in science and engineering/technology and then applied their new knowledge in their classes. In the third year, this approach was further refined and teachers began developing lesson plans for implementation in their classes.

Most often professional development involves teachers attending classes to learn new content and pedagogy. Since the experience, however engaging, is disconnected from teachers' classroom experience, new practices are hard to implement in their classes (Martin-Kniep, 2004). In one district, the summer professional development had a different focus that helped inform our professional development philosophy.

The MST Summer Professional Development Academy, created with 55 sixth and seventh grade students and 14 middle school math, science, and technology education teachers, addressed traditional professional development deficiencies. Engineering design was used in the creation of multi-disciplinary projects and strategies for assessing student learning were used as teams of students completed their design projects.

We also sought to break down disciplinary barriers between STEM teachers so communication and mutual understandings could develop. As part of its strategic planning, the district wanted teachers to implement a comprehensive quarterly project for students that coincided with the end of marking periods. This strategy was employed in the first MST Summer Academy. In addition, teachers included an engaging design activity that required the content knowledge from their lesson plans. The project became interdisciplinary and offered teachers the opportunity to create more engaging challenges for students, resulting in teaching for meaning and understanding (McTighe, Seif, & Wiggins, 2004).

During the school year, it is difficult to create and critique a unit, because teachers always need to push ahead to the next topic. This summer experience changed that dynamic. The teachers were placed on grade-level STEM teams with colleagues from their school. Once the multidisciplinary project was conceived, it would be taught and revised several times, allowing teachers to focus on what worked and what did not. Thus they could reflect on student learning, see what was successful and what was not, make changes to their lesson plans, and re-teach the activity.

As part of the MSTP project, we had gathered student performance data and found that percent, measurement, area, and perimeter were concepts students did not demonstrate understanding of on standardized examinations. In part, the difficulty arose from instruction occurring at too low a level. For instance, in asking math teachers how they taught percents, most gave formulaic answers that failed to develop depth of understanding. When discussing area, the approach was the memorization of an equation with a mnemonic.

In this four-week professional development experience, the first week was spent introducing teachers to current middle-school mathematics content and pedagogy. The goal at the beginning of the week was to have all teachers re-learn math concepts that are major obstacles for students in an engaging process. Using methodologies from exemplary NSF materials, teachers were engaged in measuring the areas and perimeters of different shapes and computing the areas. Mathematics teachers were introduced to new pedagogical approaches. Science and technology education teachers were provided with ways to assist students in applying their mathematical knowledge in order to understand a science concept or create a technological design. Following two days of intense mathematics enhancement, the teachers applied mathematical reasoning in science and technology education. They performed several science experiments in which mathematics was essential to the understanding and completion of the activity.

Math infusion in science is one of the features of the MSTP project. Enhanced infusion occurs when students need to apply math, such as in a lab where they need to graph and interpret data or make measurements. Dependent infusion occurs when a topic is introduced in which mathematical reasoning is essential to understanding the science. The use of Punnett squares in genetics is an example. In both instances, enhanced infusion and dependent infusion, the depth of understanding of the science and of the technology is increased. Middle school science courses and technology education courses are primarily descriptive. Adding equations, derived from these descriptions, is very useful in increasing understanding. For instance, when discussing internal combustion engines, an overview of the engine’s heat balance, with percent of energy used in power delivered, exhaust, and cooling water, can be very illuminating.

Engineering design, in particular the informed design process (Burghardt & Hacker, 2004; NYSCATE, 2003), was used in the creation of multidisciplinary projects. The classroom application of design has teams working to create solutions to a problem for which there is no correct answer, but only a correct process. Hence, creativity is encouraged; there is no one solution. Students find this very engaging, as do teachers.

In design projects, there is a design challenge with specifications and constraints. The specifications indicate what the design must accomplish, and typically the constraints are limitations in terms of materials and time. To introduce design, teachers, working in their school and grade-level teams, spent a day designing and constructing model emergency shelters for different biomes that had to satisfy the specifications in terms of scale, protection from animals or insects, and the weather. The specifications required an understanding of science and mathematics, but the team’s particular solution was open-ended.

A key idea in the informed design process is to have scaffolding math, science, and technology activities that “inform” student knowledge before the design is attempted. These activities are called knowledge and skill builders (KSBs). The process is consistent with the “backward design” process advocated by Wiggins and McTighe (2005).

After this experience, the teacher teams were challenged to design their own multi-disciplinary projects that could be implemented in the first or second marking period. The projects were created to reinforce key ideas in science and math that were covered in the marking period and that aligned with the state standards. There was sharing of information about the designs with one another to obtain feedback and improve design solutions. This is a pedagogical feature of informed design. Teachers developed their initial lesson plans for implementation with the MST Academy students. Teachers require support in developing open-ended design challenges. Very often they think of problems that have unique solutions and need guidance on how to expand the challenge. It is important to keep a focus on the understandings the students should be developing and demonstrating, and thinking of how they can be assessed.

In the next three weeks, teacher teams would teach the unit three times in two, three-and-a-half hour sessions. This modeled eight to nine class periods during the school year. After teaching the lessons three times, the plans were refined and the teachers developed new lesson plans.

As DuFour (2004) points out, there are three important factors in professional learning communities. The first factor, and perhaps the foremost, is ensuring that students learn. There was a great deal of focus on what the major concepts were, how teachers could determine if students learned them, and what pedagogical strategies they could employ to improve student understanding. The repetition of the unit allowed the teachers to hone these skills. After two cycles of teaching the activity, the teachers were becoming comfortable with their design challenges, refocusing the KSBs, and guiding the students. However, they, and we, had learning expectations for the students. How could these be assessed? In a summer MST academy, tests and quizzes were not viewed as appropriate. However, honoring teachers' classroom knowledge and their ability to assess student knowledge through questioning was appropriate. While one might think this is easy to implement, and even though teachers agreed they do constantly assess student understanding, they did not initially embrace the approach.

The afternoon workshops also provided teachers with methodologies for analyzing the data, essential to meaningful lesson plan revision. As part of the summer experience and the work of the evaluator and consultants, the project revised its lesson plan template and continued the evolution of professional development, with an eye toward providing sustainable professional development resources for each district.

The Way Forward

Three essential elements have been identified for STEM professional development: (1) guided lesson plan design, implementation, feedback, and revision; (2) academic year implementation; and (3) peer review and learning communities. There are many types of lesson plans, but often the detail is not sufficient for another teacher to implement the plan with extensive expansion.

A model lesson plan template for math infusion in science or engineering/technology is included in the appendix of this paper. Considerable development work, including field testing, revisions, and re-testing went into the design of the template. There are important features to the template that are worth noting. Asking teachers to think about the background knowledge required causes them to reflect on the complexity of the lesson content and can direct them to consider additional support activities in the lesson implementation. Similarly, teachers often know what concepts are difficult for students to grasp, so extended tasks can be designed to reinforce these concepts.

In trying to minimize the investigative effort, the template only requires teachers to identify one or two major math and science content topics, along with the related process and performance standards. Often the lessons were too broad without sufficient depth and focus. Because the MSTP project was focusing on mathematics, the teachers needed to explicitly find the math that would enhance the lesson, not just be an add-on. This is challenging and a reason that learning community support in lesson plan development is vital. An important consideration in the design of the lesson plan is that science, engineering, and technology teachers are responsible for teaching and their students are responsible for learning mathematics concepts. This is a non-trivial consideration and one that requires support of the science, engineering, and technology teachers in terms of math content and pedagogy.

The focus of the lesson plan is on the teaching process. Preceding the teaching process is a checklist of assessment methods that will be used. However, the use is not gratuitous, but must be indicated in the process. The primary focus of the lesson plan is on embedded assessment of student learning in science, engineering, and technology education and mathematics. The lesson plan format also includes any handouts, questions, and rubrics that are used for assessment.

The second element of STEM professional development is to have academic year implementation. Summer academies, even summer academies where teachers work with students, are fine, but having the immediacy of what you learn and create as a lesson implemented immediately is very important. Teachers have a greater investment in what they plan and how they instruct if the instruction is happening the next day or the next week, rather than in two or more months. The focus is on a unit that can be implemented in a short period of time, not a long comprehensive unit. The clear focus on learning objectives and assessment is not made hazy by large themes. Teachers learn to look for detail. As this talent is more ingrained, they will be able to provide the same level of examination to a sequence of lessons or to a unit. However, attention to detail is important, as it is to an artist; each brush stroke must have a purpose.

The final element of the program is to use peer review and learning communities. The MSTP project is holding a two-day training workshop for its leadership team with Giselle Martin-Kneip. The focus will be on peer review and professional learning communities. We have found that it is very difficult, yet critical, for teachers to support and critique one another in a professional manner. This detailed approach is essential in the development of lesson plans where the level of detail is sufficient and clearly presented. It is equally essential in the review of student work, using information from the embedded assessment strategies, so insights into what students understand and do not understand can be explicated. The lesson plans will then be revised based on the explication of student learning.

The district professional development will be a two-step process. On the first day, teachers will come with the beginnings of their lesson plan template filled out, or, minimally, with their current lesson plan. During this first after-school meeting, teachers will work in grade- and discipline-level teams to refine their plans. They will be guided in learning community methodology by the trained district leadership team. At the conclusion of the first step, each teacher will have a two-to-three day lesson plan in science, engineering, technology, or mathematics that they will be implementing in the next week. They will have a detailed teaching process section and their colleagues will have provided comments and questions, so that missing steps are detailed; then embedded assessment strategies are described. In approximately two weeks, the second step of the professional development occurs. The teachers return with their lesson plans, reflections, and with student work, with a record of assessment of student learning. A critique of student work will occur with a peer review format, similar to learning communities, where teachers practice critically examining the quality of the work. Based on student accomplishment and on the achievement of the lesson's goals, the lesson plan is revised for implementation the next time the material is taught. Each two weeks, the process is repeated through much of the academic year.

Conclusions

We believe that Engineering and Technology Education (ETE) should connect to core math and science learning objectives. The complexity of the topics that are addressed by ETE indicates that students need to understand and apply math and science concepts. This level of application may require a higher level of understanding than is provided in mathematics and/or science instruction, which may be done in a procedural manner. In terms of Bloom's (1956) taxonomy, the traditional instruction is often at the knowledge level. In ETE, we require performance ability at the application and analysis level, hence the challenge for instruction and professional development. This expectation is consistent with Wiggins and McTighe's (2005) search for enduring understandings, which underpins lesson plans.

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Appendix

Teacher(s):			**Date:**
Subject: **Science/Technology**	**Grade(s):**	**Time to complete (in periods):**	
Unit:	**Lesson Topic/Title:**		
Student population: ☐ Special Education ☐ LEP ☐ LD ☐ G&T ☐ Academically Average ☐ Low			

OBJECTIVES of the lesson:
[State the SPECIFIC goals of this lesson. What will students know or be able to do by the completion of the lesson? Start each statement with "Students will understand…" or "Students will be able to…".]

BACKGROUND KNOWLEDGE necessary for students before engaging in this lesson:

PRECONCEPTIONS that may need to be addressed:

List 1 or 2 of the overarching NEW YORK STATE <u>SCIENCE/TECHNOLOGY</u> STANDARDS to be addressed in this lesson:	**Write out CODES and PERFORMANCE INDICATORS of RELATED <u>SCIENCE/TECHNOLOGY</u> PROCESSES addressed in this lesson:**

List 1 or 2 of the overarching NEW YORK STATE <u>MATHEMATICS</u> STANDARDS to be addressed in this lesson:	Write out CODES and PERFORMANCE INDICATORS of RELATED <u>MATHEMATICAL</u> PROCESSES addressed in this lesson:

How do the Mathematical understandings listed above INFORM Science/Technology knowledge?

ASSESSMENT Methodologies [Embedded and Summative] planned to demonstrate the degree to which students have mastered the NYS Processes and Performance Indicators indicated above. *Attach COMPLETE EXAMPLES of all methods checked below*
☐ Classroom observation ☐ Whole class discussion (*indicate guiding questions and sample student responses*) ☐ Small group discussions (*indicate guiding questions and sample student responses*) ☐ Individual student interviews (*indicate interview questions and student responses*) ☐ Performance assessments (*indicate type and scoring method; explain development and use of rubrics*) ☐ Journals/Portfolios (*indicate scoring method; explain development and use of rubrics; provide an example of a finished journal or portfolio*) ☐ Homework Assignment (*explain assignment and scoring method*) ☐ In-class worksheet/written assignment (*explain assignment and/or provide example of student* work) ☐ Individual or group presentations (*indicate criteria required; describe student presentations*) ☐ Quiz/Test/Exam (*indicate scoring method; provide an example*) ☐ Others (*describe*)

How does this lesson represent BEST PEDAGOGICAL PRACTICE? (Please check 2-3 best practices that you will focus on while teaching this lesson.)	
□ Focuses on important (standards-based) ideas & skills and promotes conceptual understanding □ Includes key questions to elicit responses that reflect understanding of important content □ Promotes procedural fluency □ Addresses naïve conceptions □ Builds on prior student knowledge □ Aligns curriculum, instruction, and assessment □ Prompts discourse among students and with teacher □ Encourages guided discovery, inquiry, and design □ Promotes group work and team work	□ Establishes cross-disciplinary connections □ Establishes real-world connections for students so that they generalize lesson concepts to MST applications □ Prompts higher order thinking (students analyze, compare and contrast, classify…) □ Prompts students to generate alternative ideas and strategies □ Adjusts instructional methods according to student population and understanding □ Procedure includes summary that focuses on key ideas □ Motivates learning during and beyond the lesson

MATERIALS Needed:

INSTRUCTIONAL PLANNING: PROVIDE A <u>COMPLETE SEQUENCE</u> OF ALL TEACHING PROCESSESS AND STUDENT ACTIVITIES FOR IMPLEMENTING THE LESSON. **This should include ALL teacher explanations, examples, questions, and student activities associated with the delivery of the lesson. Nothing should be left to the imagination. *Other teachers should be able to reproduce this exact lesson using this lesson plan.* Indicate (with an asterisk) where embedded assessments will occur during the implementation of the lesson. Indicate instructional alternatives that may be employed for differentiating instruction for students with special needs.** ****BE SPECIFIC ABOUT HOW MATHEMATICAL CONCEPTS ARE INFUSED INTO THIS SCIENCE/TECHNOLOGY LESSON****

AFTER LESSON IMPLEMENTATION -

REFLECTIONS: Tell the story of what happened in the classroom. Indicate what worked, what you would change for the next implementation, and students' reactions to the lesson.

*** Attach to this lesson template: any and all WORKSHEETS and HANDOUTS, examples of ALL indicated ASSESSMENTS, and SAMPLE STUDENT WORK.***