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Pedagogical Content Knowledge As a Foundation for an Interdisciplinary Graduate Program

The authors offer a working model of a transferable teacher preparation program that is founded upon the concepts of reflective practitioner and teacher as researcher.

Despite the long history of the study of pedagogical content knowledge (PCK), two facts remain obvious. First, there are almost as many conceptions regarding the definition of PCK as there are researchers interested in it. Second, it is largely unclear which methods enable teacher educators to best prepare teacher candidates to use PCK. Recently, two themes have emerged strongly as mechanisms for helping teacher candidates become more accomplished practitioners. These two ideas, reflective practice and teacher as researcher, can be seen in a variety of teacher preparation programs. However, prevailing systems for preparing and accrediting teachers seem to have a strong enough hold over the process that completely different approaches to preparation, centered on these ideas, may have difficulty getting started.

Heibert, Morris, Berk, and Jansen (2007) have proposed one such new framework for teacher preparation. This framework focuses on helping candidates develop competencies in four areas: setting instructional goals, evaluating student performance relative to these goals, hypothesizing connections between the material taught and the material learned, and using this analysis to improve instruction. They acknowledge that their proposal is largely untested and that few studies exist to fully support the reorganization they suggest; however, their argument is compelling. As a further step in the development and analysis of ways in which these skills can be incorporated into teacher preparation programs, we offer a study of the Graduate Program in Mathematics, Science and Technology Education at our school as an example of one way in which these ideas can be used to reorganize teacher preparation programs with the explicit goal of preparing teachers to become reflective practitioners and creating teachers as researchers.

PCK and Domains of Teacher Knowledge

Since Schulman (1986) introduced the concept of PCK, there have been numerous attempts to define the components of PCK and its relationship to other domains of teaching knowledge. Broadly, Gess-Newsome (1999) categorized the literature on PCK as falling on a continuum between the *transformative* and *integrative* models of PCK. In the former, classroom teaching makes use of PCK only, and all other teaching knowledge, whether it is related to content, context, or learners, is transformed into PCK in order to be used in the classroom. In the integrative models, PCK exists as the intersection of the sets of content knowledge, the contexts of learning, and pedagogical knowledge. Specific models of PCK tend to fall somewhere in the middle of this continuum and make use of different components of teacher knowledge. However, these models all tend to agree that there are at least three distinct domains of teacher knowledge: content knowledge, context knowledge, and pedagogical knowledge (Gess-Newsome, 1999). These three components are clearly reflected in the definition of PCK given by the National Council for Accreditation of Teacher Education (2002).

> [PCK is the] interaction of the subject matter and effective teaching strategies to help students learn the subject matter. It requires a thorough understanding of the content to teach it in multiple ways, drawing

on the cultural backgrounds and prior knowledge and experiences of students. (NCATE, 2002, p. 55)

In many models of PCK, these three knowledge categories are present, but in modified forms. For example, Mohr (2006) discussed the framework for Mathematical Knowledge for Teaching (MKT) originally developed by Hill, Rowan, and Ball (2005). In this framework, MKT is the combination of common content knowledge, specialized content knowledge, knowledge of content and students, as well as knowledge of content and teaching. This definition explicitly connects the learners and the teaching process to the content, with no separate category for pedagogical knowledge.

Content Knowledge (CK) includes both deep and broad knowledge of subject matter. This includes the facts and concepts of a subject discipline, as well as multiple ways of thinking about the subject matter (Manouchehri, 1997; Noddings, 1998). This is facilitated when teachers are able to formulate clear connections between the content area in question and other content areas and applications (Manouchehri, 1997). Regarding the content knowledge of mathematics teachers, Lappan (2000) included additional features, specifically that they be good problem solvers capable of uncovering abstractions and generalities. Davis and Simmt (2006) also argued for deep content knowledge in teaching mathematics, claiming that "knowledge of established mathematics is inseparable from knowledge of how mathematics is established" and that "insights into the historical emergence of core concepts, interconnections among ideas, and the analogies and images that have come to

be associated with different principles" are essential aspects of mathematical knowledge for teachers (p. 297). The level of depth deemed appropriate is of critical importance to discussions of teacher content knowledge. Lederman and Flick (2003) addressed this directly by questioning the precise level considered to be *in depth* subject matter knowledge and encouraging teachers go *above and beyond* the level of learning expected of their students. They claim that these questions are largely unanswered in regards to mathematics, science, and technology. As evidence, they point out their belief that the subject matter knowledge needed by different grades is qualitatively distinct, rather than hierarchical. To put it simply, the math knowledge required of a K-6 teacher is not less than the math knowledge required of 7-12 math teacher. Instead, the mathematical concept knowledge required of teachers at those distinct levels varies qualitatively rather than quantitatively.

The domain of context knowledge includes learners, their interests and motivations, their needs, the local (state and national) standards, and expectations of the discipline. Teachers must also possess an intimate understanding of constraints that exist upon teaching, including time, materials, and administrative issues. Another component involves understanding the flow of content from one grade level to the next. This component is connected on a deep level with curricular design issues and the psychological development of learners. Because of the huge impact such a domain of knowledge can have on teaching, Barnett and Hodson (2001) argued that a new category of teacher knowledge, one that subsumes content knowledge,

pedagogical knowledge, and PCK, is needed. Their pedagogical context knowledge is developed as a taxonomy covering four categories of knowledge: academic and research knowledge, PCK, professional knowledge, and classroom knowledge. Oppewal (1993) and Kumar (1999) argued that in order for conceptual change to occur, the role of context and prior knowledge must be part of a quality science teacher education.

Pedagogical Knowledge (PK) includes having a theoretical knowledge of an array of instructional and classroom management strategies. This typically includes examination of educational history, learner development, sociological contexts for teaching, and strategies for teaching diverse learners (Morine-Dershimer & Kent, 1999). Within this set of instructional strategies, teacher preparation programs tend to emphasize strategies and philosophies of a particular nature, such as constructivism and inquiry-based teaching strategies. Often, PK includes general strategies for the integration of technology and other devices, such as manipulatives. The goal of these strategies is to improve the teaching/learning environment and provide deeper contexts for teaching judgments and decisions.

Models Of PCK And Reflective Practice

The transformative approaches to PCK treat it as a separate knowledge domain that emerges when one combines content, context and pedagogical knowledge in the presence of a stimulus. Manouchehri (1997) emphasized this model during a discussion about the need for teachers to "[make] the transition from a personal orientation to a discipline to

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thinking about how to organize and represent the content of the discipline to facilitate student understanding" (p. 203). One implication of these models is that different subject matter may require different instructional strategies to facilitate learning in different contexts. Using this model, Loughran, Mulhall, and Berry (2004) found that PCK varied considerably from teacher to teacher and that it was extremely difficult to get teachers to explicitly express the assumptions and decisions underlying their personal PCK. These difficulties, and the current lack of adequate PCK models for different content, suggest that another approach to developing PCK could be more fruitful and productive.

One such option is the integrative approach, in which the domains of teacher knowledge overlap in PCK. Thus, PCK is not a new knowledge domain. Instead, teachers develop an understanding of the current context in which learning takes place. Based on this knowledge, the teacher can then select specific strategies and information from PK to decide how to approach teaching CK. This integration is often fostered through Reflective Practice (RP) (Jay & Johnson, 2002; Yost, Sentner & Forlenza-Bailey, 2000).

Since every teacher is a part of the context in which learning occurs, PCK remains a personal construct (Loughran, et al., 2004). Therefore, in order for teachers to develop a deeper understanding, they must reflect on their own practice. This process entails the recording of data and the reflective study of that data. Logically, in order for this to be accomplished, teachers must be prepared to undertake this type of reflective work. Halim and Meerah (2002) indicated that most problems with current teaching are caused by a failure to adequately account for student prior knowledge and misconceptions, by misconceptions held by the teacher, or by a lack of sensitivity concerning the content difficulty. The tendency of even experienced teachers to have difficulties with these points serves to emphasize the need to develop PCK in pre-service programs. Even for experienced teachers, the "daily working environment does not facilitate the teachers to identify such knowledge … such as the knowledge of students' conceptions and misconceptions of specific topics" (p. 224). Considering this limitation, we expect that PCK will be difficult to implement once teachers are in the field, unless these teachers have a solid foundation for reflecting on the educational decisions and issues that arise in the course of daily teaching.

Bullough (2001) concluded his historical overview of PCK with a description of suggestions for moving forward by providing teachers with an opportunity to develop professional judgment relating to selection, adaptation and modification of pedagogical strategies based both on the content and the learners involved. His solution clearly defines the notion of reflective practice: "Teachers need to think more complexly about their

practice and the reasons behind their actions in the light of how particular pupils learn and in relationship to specific formal, academic knowledge" (p. 665).

A reflective practitioner considers several aspects of teaching and learning (Yost, Sentner, & Forlenza-Bailey, 2000). One must reflect on one's own content understanding, considering the material that is understood and the ways in which this knowledge was acquired. Teachers must also reflect on student work samples, student needs, and the local context. The best teaching also grows from reflection on the curriculum at all levels, including an understanding of state and local standards as well as the standards from national content area organizations. Teachers must also reflect on curricular materials at all grades in order to understand where students came from and where they need to go. Teachers must also reflect on their own ideas and beliefs about teaching and learning and the connections among these aspects of the teaching environment. Through this process of reflection, teachers transform their inert knowledge into active, classroom practice that continually evolves as they encounter new situations and reconsider past experiences in light of more recent experiences. Manouchehri (1997) emphasized the role of the teacher as a reflective practitioner, paying "careful attention to consequences of their experiments …" (p. 205) in attempting to solve the pedagogical problems they encounter.

Teacher Using PCK

Clearly, one cannot teach a subject well without knowing the content of the subject well. Thus, a strong PCK-teacher is well versed in the content.

This means constantly viewing the material from different perspectives, considering applications of the content, and maintaining an active link with current developments in the field. These teachers make use of constant assessment (formative) to stay informed about the context of learning in which they operate. This also requires them to monitor current standards movements, curricular goals, and the school climate. Constantly updating contextual knowledge means that teachers rarely teach the same material in the same way. Since teachers possess a wide array of flexible strategies for helping learners in many different situations, they can use informed decision-making to adapt previous approaches to teaching in new situations. Informed decision-making (judgment) is built on reflective practice that allows teachers to be aware of the ways that different strategies may impact different learners in different situations. Another noteworthy aspect of this type of teaching is that learners of many different abilities, interests, and levels of preparation are welcome in the classroom, because the informed judgment of the PCK-teacher allows for flexible differentiation (in the sense of differentiating the lessons, the assignments, etc.)

This cycle of instruction and formative assessment will differ greatly from teacher to teacher, content area to content area, and context to context. It is not based upon a fixed time scale; rather it is based upon the teacher's ability to observe and address needs. That is what it means to be a reflective practitioner. Reflective practitioners do not merely use predetermined intervals to reflect and make changes. Instead, they continually reflect on the material that they are teaching as

well as their students' understanding, in order to make ongoing adjustments. One consequence of this cycle is that PCK-based teachers frequently "go outside the teacher's manual," developing their own lesson and unit plans, designing them to meet the needs of the learners that currently comprise their class. Such lessons are not present explicitly in any existing sources; instead, existing materials are developed and modified according to the professional judgment of the teacher.

Developing PCK

In an historical look at PCK, Bullough (2001) speculates that the ultimate success of PCK-driven teacher preparation programs hinges on the answers to questions concerning the definition of PCK and the best ways to split its teaching between pre- and in-service teacher preparation. After a lifetime of different educational experiences, we cannot hope to completely change a candidate's mindset about the nature of teaching and learning all at once. Manouchehri (1997, p. 205) argued "prospective teachers must have the opportunity in their university coursework to strengthen their content knowledge and pedagogical content knowledge while being exposed to the type of teaching consistent with the recommendations of the reform movement" in order to counteract the tendency of instructors to simply teach in the ways they encountered most frequently during their educational experiences as learners.

Tied to this discussion is the nature of subject-specific knowledge. Given that all subject areas lead to unique PCK, we must consider the supposition that candidates would be best served by focused learning within their content

areas. This would necessitate separate teacher preparation programs for each subject, with no common coursework possible, even in pedagogical or professional background. We reject this compartmentalized model for teacher preparation as impractical and lacking of important opportunities for teachers. Instead, it seems that there are enough similarities among certain content areas, such as mathematics, science and technology, to allow for a productive integration. This can occur in several ways. First, we can focus more general pedagogical courses on a subset of disciplines. This allows candidates to compare and contrast their organizations of knowledge with each other. These opportunities for building connections across disciplines eventually lead to greater student learning (Frykholm & Glasson, 2005). Second, we can create courses that are hybrids of content and pedagogy, helping teachers simultaneously enhance their content understanding as well as their methods for teaching that content. These courses would be more content-area specific, but teachers from related disciplines would stand to gain a great deal. For example, after seeing their content from the perspective of an outsider, such as a teacher from a different content area, candidates in our program often remark, "I never thought of it that way. Now it makes sense." Integration of math, science, and technology helps illuminate the connections among the various content areas, allowing participants to reconceptualize the content from a distance. Additionally, participants can consider the effectiveness of the teaching process being demonstrated without being concerned about knowing the specific content. In order to bring about a deep appreciation

for and understanding of PCK, it is not sufficient to simply hope that periodic professional development programs made available after teachers enter the field will provide deep enough experiences to have a lasting impression. Much of this must take place in pre-service teacher preparation or in subsequent advanced degree programs. But it must take place in the presence of specific classroom examples in order to foster the integration of different knowledge domains.

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An example serves to highlight this approach to teacher preparation. Van Driel, et al. (2002) discuss a series of professional development activities intended to help teachers improve their classroom practices. During the activities, teachers looked at recent research on teaching and learning. Consistently, the teachers reported deriving little benefit from the components of professional development that involved simply reading the articles and digesting them in order to improve their PK (knowledge of learning and teaching strategies). Instead, the teachers reported the most value from discussions and activities that encouraged them to apply the research

to classroom practice and consider ways that they may be able to modify the technique for their content area. Teachers also reported high benefits from making use of these papers to evaluate examples of classroom observation in order to make sense of the situations observed. In effect, these instances of reflection pushed the teachers to higher levels of Bloom's taxonomy. Even though reading and understanding a research article (essentially developing PK) may be difficult due to an abundance of specialized jargon or methodologies, it still falls at the lower end of Bloom's hierarchy for thinking skills. However, by evaluating classroom experiences in light of a research article or by thinking about ways to apply an article to a different situation, higher order thinking is accessed, helping teachers transform the knowledge into effective practice.

Another concern is the nature of content specific coursework for teachers. Programs cannot simply offer additional or higher-level courses in the content area. This becomes apparent when looking at masters programs for teachers in New York State. These programs are required to include four content specialty courses**.** However, enrolling these candidates in standard mathematics courses for a traditional masters program will not serve the purpose of this requirement effectively, because the goals of such courses are differently aligned, typically seeking to prepare students to become researchers or practitioners of mathematics. When learning new content, Davis and Simmt (2006) argue that the "deliberate presentation of images and analogies should probably be at center stage when introducing new topics" (p. 302) because one of the key abilities of a good teacher is

to negotiate among these different images and metaphors. The ability to constantly adjust metaphors requires teachers "to *translate* notions from one symbolic system to another" (p. 303). Fluency with different representations of ideas and connections within the content area is a very different focus, and it requires the development of different advanced content courses for teacher candidates.

In addition to helping candidates develop specialized content knowledge, teacher preparation programs must guard against the teaching of overly generalized notions of PCK. These dangers are pointed out by Garcia and Ariza (2004) following their study of a teacher development program. They state "we would question the utility in science teacher education of presenting psychological concepts (or concepts from any another discipline) in a directly academic form, disconnected from the processes of teaching and learning the subject … an academic presentation of the knowledge of a discipline … is neither meaningful nor useful for them to improve their professional knowledge" (p. 1238). Garcia and Ariza reinforce Van Driel's work by noting that in order for teacher education to be meaningful, teachers must have opportunities to explicitly connect theoretical and practical knowledge. This requires more than simply designing units that illustrate applications of particular theoretical constructs, since teachers recognized that teaching units developed in this manner do not accurately reflect classroom realities. These types of teaching units fail to provide solutions to common, practical concerns that arise in the average classroom, and consequently, they are difficult to implement outside the professional development experience (Garcia and Ariza, 2004, p.

1243). In addition, it is not reasonable to assume that we can send candidates into practice with examples of every possible lesson or unit they may be expected to teach; the context is constantly changing, which obviates any static curriculum materials. Teachers must, instead, develop judgment to adapt existing materials and to design new materials that respond to student needs in the moment.

The GMST Program

The master's curriculum of the Graduate Program in Mathematics, Science and Technology Education (GMST) is designed and organized around putting into practice educational theory and research relating to the ways that students learn mathematics, science, and technology. The mission of the program is to prepare teachers of grades 1-12 by endowing them with a strong background in the content of mathematics, science, and technology, as well as understanding of the particular needs of diverse learners with respect to teaching mathematics, science, and technology. Further, the program seeks to prepare leaders in the field of mathematics, science, and technology education so that constructivist, inquiry-based approaches to learning these subjects can occur for all students. Finally, the program is designed to help teachers see the commonalities among subjects in order to foster integrated, research-based instructional approaches that effectively utilize technology, assessment, and other resources.

The aim of the GMST program is to immerse teachers in a constructivist learning environment designed to provide direct experiences with knowledge and skill development in mathematics, science and technology through inquiry-based learning. The program stresses the "connectedness" that exists between the grade levels and among the disciplines, as well as the application of concepts to new situations. The teachers work together in courses that deepen their content knowledge and skills, which include the effective use of discourse and technology to strengthen their expertise in construction of appropriate and effective inquiry-based experiences, assessment of student learning, collaboration in interdisciplinary teams, and application of knowledge in new settings.

The GMST program is committed to providing an experience in which teachers interact with college faculty in an environment that encourages participants to ask, not just answer, questions and pose, not just solve, problems. The theme of the program is *Teacher as Researcher*, in the sense described by Heibert, Morris, Berk, and Jansen (2007, p. 50). If a teacher has experienced the curriculum as a researcher/explorer, then that teacher will, in turn, be able to assist students in the development of inquisitive attitudes and skills necessary to facilitate deeper student learning and skill development in mathematics, science, and technology. The faculty in this program model constructivist/inquiry pedagogical and authentic assessment strategies.

Today's real-world problems are complex, and their comprehension and solutions require knowledge and integration of several subject areas. In order for candidates to become responsible citizens capable of making informed decisions and helping their students to do the same, they must see the relevance of the material that they are learning and understand the possibilities for transferring that information to a variety of real-life situations. Learning experiences must offer the opportunity for candidates to investigate, explore, discuss ideas, develop conjectures, test hypotheses, and apply concepts to real-world problems; in other words, to be a researcher. How can we expect the students in the 21st century to be inquirers if their teachers have not had these same learning experiences in their education? Due to the nature of all real-world problems, teachers must have interdisciplinary experiences in mathematics, science, and technology from which they can develop knowledge and skills that enable them to better assist their students to live and work in a highly technological, interdisciplinary society. This does not diminish the importance of the individual discipline; rather, it acknowledges the symbiosis of these disciplines.

Candidates must complete 30 hours of traditional course work. Out of these, 9 of the units are core courses required of all students, and the other 21 are elective courses that consist of either supporting or content courses. In addition to these 30, there are six hours allocated to a culminating action research project. The required coursework models team-oriented, active learning environments and provides direct experiences with foundations in learning mathematics, science, and technology; methods and processes of inquiry and problem solving; further study of concepts in mathematics, science, and technology; the relationships among the disciplines; working in teams across grade levels and disciplines; research-based pedagogical strategies based on the knowledge of diverse learners; as well as the use of a variety of assessment methods to achieve authentic assessment.

Inquiry and problem solving skills are a key focus for the program, beginning with the first course in the program. This introduction to inquiry in the classroom uses a strong constructivist philosophy to help candidates explore the ways in which learning develops in the framework of their predispositions and history. Later coursework expands on these ideas, integrating across content areas of mathematics, science, and technology. Furthermore, the program helps candidates integrate educational technology into their teaching. Candidates also experience integration between pedagogy and content (PCK) in almost all of their coursework. In addition, technology and curriculum integration is woven throughout the program.

The culminating experience in the program requires a thesis based on action research. Candidates explore ways to improve learning in the classroom by using lesson study. Lesson study provides candidates with an additional data collection tool and reinforces the importance of being a reflective practitioner. This is an attempt to develop leadership qualities and allow candidates to demonstrate their research abilities, as well as an opportunity to step into the role of an activist striving to improve learning for all students. These opportunities result in confident researchers and practitioners. As a result of this program, candidates are able to alter the way they think about teaching and collaboration and share the change in their perspectives with others. Fernandez and Chokshi (2002) describe lesson study as "a Japanese professional development process that enables teachers to systematically examine their practice in order to become more effective instructors"

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(p. 128). They explain the ways that lesson study can be used to improve collaboration between teachers either at one site or across several. Teachers first select a goal and pick a lesson to study. They work together to prepare a lesson plan, then one teaches the lesson while the others observe. The group then reflects and revises the lesson, which is followed by the lesson being taught again with another reflection and revision session. The last iteration is then written up in a reflective report. This process helps teachers to become reflective practitioners. Rock and Wilson (2005) found that teachers valued lesson study as professional development not only because they believed that it encouraged them to grow as teachers, but also because it increased their confidence. They also discovered that lesson study enabled the teachers to provide differentiated instruction, improve their math vocabulary, and better incorporate math manipulatives.

Candidates completing the GMST program receive a Masters of Science degree and initial professional certification in New York State. After completing initial certification, teachers are given five years to attain professional certification. In order

to accomplish this, they must have three years of teaching experience and a related master's degree which must have at least 12 units linking content to pedagogy. As a result of these demands, our candidates are a diverse group comprised of three populations: those who have just completed a bachelor's degree and are now seeking to teach math or science in grades 7-12, career changers who have at least a bachelor's degree but are not prepared to teach, and those who already have certification and are now seeking a master's degree.

The full time faculty in the GMST program is comprised of mathematicians and scientists who also have a significant background in education. All hold a Ph.D. and have extensive backgrounds in mathematics and science education. Most have teaching experience in the K-12 setting. Besides teaching in the GMST program, they also teach undergraduate content courses. GMST also hires qualified adjunct faculty who are experts in their field. In addition to possessing a master's degree, adjunct faculty must also have extensive experience in the K-12 classroom.

Courses In GMST and PCK

Davis and Simmt (2006) made the central argument that pedagogical and content knowledge must be integrated into the content courses for teachers. One of their key conclusions was that in order for teachers to experience processes that help them develop the rich conceptual change needed to continue growth, the programs that service them should proceed by "organizing courses in mathematics-for-teaching around doing mathematics that is new to the doers … [focusing] on, for example, the roles of metaphors and other language in the development

of mathematics" (p. 316). This supports the basic foundation of the GMST courses, especially the content enrichment courses, in which students are expected to struggle with new ideas in order to experience the process of learning mathematics (or science, or technology) as a learner similar to the way their students will experience learning. Since this is a primary focus of the program, all of the courses in the GMST program integrate pedagogical content knowledge. The amount to which PCK becomes a significant part of the course depends upon whether it is a core, supporting, or content course. In the following discussion, several courses are highlighted to provide specific examples for how the program blends the three areas of teacher knowledge.

In the introductory core course of the program, Inquiry, students are exposed to the concept of inquiry as well as some of the ways one can implement it in the classroom. The students explore many types of inquiry-based activities ranging from structured to open inquiry. For instance, they start with a guided inquiry activity, and then they expand that guided activity into an open-ended investigation. This allows them to see the pedagogy of inquiry while also uncovering misconceptions they have with respect to the content. While at the beginning many students struggle with this type of learning, mostly because they have never experienced it before, most see the value and embrace it by the end of the course. Since our candidates typically have never experienced learning in this way, these experiences take them out of their comfort zone. During their exposure to inquiry, they are also delving slightly deeper into the content while reflecting on how they could use this in the classroom.

Toward the end of the semester, they are required to compare the different types of inquiry and reflect on how and when they can be effectively used in the classroom. They also observe the use of guiding questions, as opposed to providing direct answers, employed as a method for helping students overcome misconceptions. A culminating experience in this course requires the students to read a book related to the nature of mathematics and science, and then they must create and implement an inquiry-based lesson based on their chosen book. This enables students to demonstrate their PCK. The pre-service teachers present their lesson to the class, and the in-service teachers must incorporate their lesson into their curriculum. After teaching the lesson, they summarize the experience and provide reflections. They present this to their classmates and provide samples of student work. The entire class then reflects on the process and the lessons. For both groups, this reflection is a significant part of the lesson, because discussion of results may have a greater impact than mere observation of technique.

Teacher educators work in one of the most complex professions in history.

Another one of the core courses, Assessment, focuses on helping candidates to understand how they can effectively assess learning. Candidates struggle to ensure that students understand the content rather than simply being familiar with it. To achieve these ends, they employ formative and summative assessments that include discussions, observations,

use of technology, and traditional paper and pencil assessments. They explore the various types of questions that are used for assessments and develop an understanding of the types of questions that best correlate with assessment of knowledge, understanding or recall in conjunction with Bloom's taxonomy. Students spend time investigating their content and creating ways to engage students while simultaneously effectively assessing learning. Candidates learn quickly that without a strong content base of their own, the task of effectively assessing their students becomes insurmountable.

In the supporting course, Integrating Technology into a Learning Environment, candidates learn about the use of technology, and they become familiar with both practical issues and theoretical implications of its use. The course is project-based and focuses on theoretical research of educational technology, developing usage skills, understanding the technology, and application of the theoretical research base to the development of classroom applications. Each student presents a research paper centered on a question related to technology use, such as "what new literacy skills are required in the digital age". The culminating applications project requires that students research strategies for developing computer-based activities, including program design, and then implement their recommendations. For example, students may develop a Web Quest and explain the ways in which the design of their Web Quest fosters student learning. Students complete projects of their choice at their own pace, allowing them to focus on areas that are most valuable to their current or anticipated situations and needs. Throughout the course,

candidates are developing a new set of instructional tools and conceptual understandings while constantly considering the content in which these tools will be used, thus transforming these ideas into PCK.

In the content course Geometry: Theory, Application and Technology, candidates explore the worlds of non-Euclidean geometries. The course begins by taking the students out of their comfort zone and into spherical geometry. This allows them to experience mathematics the way many of their students do. They then take a step back and explore the axiomatic systems, which lead into Euclidian geometry and other non-Euclidean geometries. The way in which this course evolves allows the candidates to uncover the other geometries by exploring *what if* questions. What if an axiom is not accepted? What does that do to the geometry? What if the metric is changed? How does that affect the geometry? During each of these explorations, there is also time to reflect on the ways that these concepts relate to the 7-12 mathematics classroom. Students create geometric portfolios using technology, manipulatives, and reflection upon classroom use.

Historical Development of GMST

The content areas have always been envisioned as the main driving force of the program. Thus, it was housed within the mathematics department at the college. In order to keep the program relevant and connected to current trends in K-12 teaching, an advisory board was formed from college faculty, K-12 teachers, and administrators. The board meets to review program issues, discuss course development, consider current trends in local education, and evaluate the program. As it is not a cohort-program,

candidates can enter the program at different times and they are allowed some choices in their preparation.

The original program was designed around five strands: interdisciplinary learning, teacher as researcher, inquiry, constructivism, and curriculum standards. Courses were divided into the core, supporting, and content enrichment categories, but two significant changes have taken place as we have gained a better understanding about effective teacher preparation. First, the core courses have undergone a major revision. Originally, the core courses consisted of a foundation in the program strands, a course in problem-based learning (PBL), and a course in inquiry. Since many students in the program are just beginning their teaching experience, the PBL course was difficult for them to comprehend. The foundations course also seemed to be an inefficient use of time. We discovered a need to provide more connection to content and technology. We also recognized the importance of assessment in the learning process. This led us to change the core courses to their current structure: inquiry, assessment, and three areas of technology.

A second major change in the program involved the capstone research experience. As the program grew, from six graduates in the initial class to between 20 and 30 candidates per class, the original design of the research courses broke down. Candidates from the first classes worked closely with a faculty member to develop an action research project. This process was supported with coursework in methodology for conducting action research, and candidates benefited greatly from the experience. The two semesters of closely guided action research led

many of our candidates to grow deeply in their understanding of the program strands as related to their own teaching. Unfortunately, the process was faculty time-intensive, due to the individual nature of the projects. Our solution was to focus the projects. Using a lesson study design, all students now develop a capstone project involving collaboration and reflection. With more focused methodologies, the research courses can now involve more candidates in an efficient way, while still capturing much of the value of the old experience.

At the same time these changes were being implemented, all programs leading to either initial or advanced teaching certificates at our school were undergoing accreditation with both the state of New York and NCATE. The demands of overseeing the program thus increased, which necessitated a slight change in the administrative structure. Formerly, the program was housed in the mathematics department, and the department chair served as the program director. Now there is a separate faculty member serving as program director. This also allowed the director of the program to spend more time on the candidate applications, interviewing each individual prior to admission into the program. Enrollment in the program steadily increased over the next several years, as word of it spread and as the quality of our graduates became apparent. Two local school districts (one a high-needs urban district and the other suburban) now pay for their teachers to complete our program in order to receive professional certification (now required from all K-12 teachers in New York State.), and this buy-in has contributed significantly to the increase in program popularity.

The NCATE accreditation process also highlighted a major issue in program governance. Since the final decision about candidate certification was controlled by the school of education, and our program was housed in the school of arts and sciences, a formal agreement had to be reached in order to allow our program autonomy while still being connected to the process. The college thus formed a separate unit, the Professional Education Unit (PEU), which is composed of members from all certification-related programs. The multidisciplinary nature of the program also led to significant issues in accreditation, both at the state and NCATE levels, since these required separate program submissions for each certification area, and our program can lead to certification for mathematics, biology, chemistry, or physics. Our dual status in both content and teacher preparation led to considerable tension from both education and arts and sciences faculty. The formation of the PEU and the organization of the college into schools significantly reduced this tension.

One major concern throughout the history of the program has been identifying quality faculty. The interdisciplinary nature of the program and the PCK-focus require the faculty to be content specialists with a significant background in education. Since many of the full-time faculty teach in both the undergraduate content majors and the graduate program, adjunct faculty are vital aspects of the program. However, as the program has developed, many of our earlier graduates are now distinguished teachers themselves, and we have been able to bring several of them in as faculty.

The program has continued to grow and develop. It maintains a strong reputation in the area, which is vital, since within 50 miles there are roughly 10 major colleges and universities that offer Education programs. Although the need for highly qualified teachers of mathematics and science is significant, many certified teachers have difficulty finding positions in their content areas locally, but our candidates have not, typically, had difficulty securing positions. In fact, all of the candidates who graduated from GMST in spring 2007 have positions in their content area. Even more significant, we think, is that even though there are many teacher-preparation programs nearby, our graduate program is the only one that certain school districts will pay for their teachers to complete.

Conclusion

Teacher educators work in one of the most complex professions in history. We are preparing teachers to teach in a constantly changing world, and for this reason, preparing them with a fixed, bounded set of skills and concepts seems a disservice. The "Did you know? 2.0" video by Fisch, McLeod, and XPLANE (2007) makes this point quite clearly, drawing on a wide array of data and trend analysis to support its conclusion: teachers are teaching students in a world where the pace of change forces much of the content they learn to be out of date before graduation. In this world, problems that do not now exist will need to be identified and solved. The implications for teachers are staggering, which makes our job as teacher educators even more challenging. Not only do teachers learn from their own practice and continue exploring their teaching so that they can grow and adapt to the changing world, but we must

also continually update our practice in preparing these teachers so that candidates are prepared to teach in this way. This means preparing teachers with base concepts in content and pedagogy, developing skills in implementing various teaching strategies, and understanding the ways in which student learning develops. Most important of all, we have argued, is that teachers need to develop a metacognitive knowledge about the reasons that they are teaching the way they do and ways in which to study their teaching in order to learn more from the process.

It is far too early to know whether any of us are really accomplishing these goals of fully preparing teachers for the 21st century. The GMST program we have discussed began in 1997 and has already experienced a significant reorganization. The fact that the program is growing, has a good reputation, and has received accreditation from NCATE and the state of New York seems to indicate that it is possible to design successful programs around alternative models of teacher preparation. Providing a space where many different models can thrive is of vital importance if we are to ever learn more about effective ways for teachers to learn to teach. Throughout these models, though, we must stress the importance of having programs for teachers that expand on their content while explicitly linking content and pedagogical practices. One efficient mechanism for this is through reflective practice, which is necessary, but not sufficient, for preparing prospective teachers to quickly and effectively adjust to shift in math, science, and technology. We believe strongly that our program is accomplishing this goal by developing strong, reflective teachers.

We have now reached the point in the program where it is possible, and indeed necessary, to perform longitudinal studies. These studies need to follow up not only on recent and past graduates and their students, but they must also focus on exploring the "ripple effect" we suspect our graduates are having on their departments, grade levels, and schools. The reason that we suspect our graduates are positively affecting their communities is that many of our candidates find themselves in positions of leadership (not necessarily authority) shortly after completing the program. One recent student exemplified the leadership capabilities of our graduates when his comments at meetings directly resulted in his spearheading a mission to bring lesson study into the district as their central focus for future professional development. Many of our candidates experience the first glimpse of their new roles as leaders during their student teaching when they are asked to share some of the methods they utilize with which the current teachers are unfamiliar, and some districts have even requested that our faculty meet with them in order to discuss and elaborate on the skills demonstrated by our student teachers.

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