

The Journal of Mathematics and Science:

COLLABORATIVE EXPLORATIONS

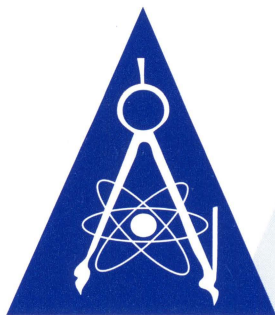
Volume 11, Spring 2009

PART I: SPECIAL ISSUE

Mathematics and Science Partnership Institutes

National Science Foundation

PART II: REGULAR JOURNAL FEATURES



Virginia Mathematics and Science Coalition

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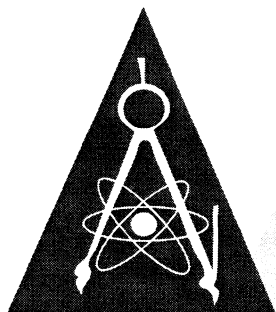
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SPECIAL ISSUE National Science Foundation Sponsored Mathematics and Science Partnership Institutes

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Virginia Mathematics and Science Coalition

Preface

The Mathematics and Science Partnership (MSP) Institutes supported by the National Science Foundation's MSP program are designed to provide high quality professional development to the participating teachers. Perhaps more importantly they serve as models and standards for professional development nationwide and conduct research on effective and innovative ways to increase teachers' content and pedagogical content knowledge and to improve student learning.

The work of the Institutes is being disseminated through the MSP net, and it is anticipated that at the conclusion of each project the research findings will be described in scholarly publications. In addition, we believe that the publication in this Special Issue of the "*Journal of Mathematics and Science: Collaborative Explorations*" of refereed papers describing work in progress and preliminary research findings will have great value to the field.

We received support to dedicate this Special Issue of the *Journal of Mathematics and Science: Collaborative Explorations* to the work of the MSP Institutes. With the support of an Editorial Advisory Board for the special issue we invited leaders of the 12 MSP Institute projects to submit papers. Papers were solicited in the following categories:

- **Research Results and Preliminary Findings.** We were interested in the impact of particular approaches of professional development on the knowledge and perceptions of the teachers who are participants in the Institute, on their classroom practices, and on the learning by their students. While some findings may be preliminary at this stage and may call for future study, these papers add to the research base in this area.
- **Descriptive Reports of Effective and Innovative Approaches to Professional Development.** While these reports typically contain quantitative data and evaluative information, they focus on describing particularly interesting and promising aspects of projects of interest to others designing professional development programs.

A three person Editorial Advisory Panel for the Special Issue assured that the high standards of the Journal were maintained. The members of the panel solicited papers and worked with the

leaders of each MSP Institute to assist in defining appropriate articles from each project and utilized the Editorial Board of the Journal and the broader MSP community to referee the articles.

Advisory Panel members:

Reuben Farley, Professor Emeritus, Virginia Commonwealth University;
Editor of *Journal of Mathematics and Science: Collaborative Explorations*

Tom Dick, Professor of Mathematics, Oregon State University;
PI of Oregon Mathematics Leadership Institute Partnership

Larry Gladney, Professor of Physics and Astronomy, University of Pennsylvania;
PI of University of Pennsylvania Science Teachers Institute

BUILDING MIDDLE-LEVEL MATHEMATICS TEACHERS' CAPACITIES AS TEACHERS AND LEADERS: THE MATH IN THE MIDDLE INSTITUTE PARTNERSHIP

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Abstract

This article describes professional development for middle-level mathematics teachers offered through the Math in the Middle Institute Partnership, a National Science Foundation-funded project to build teachers' capacities to improve mathematics learning for all students. An overview of the project, including descriptions of its goals and curriculum are provided. Detailed descriptions of two mathematics courses and one pedagogy course are offered. The mathematics courses included here are the introductory course to the Math in the Middle Institute, as well as one of the final math courses of the Institute in which participants apply mathematical knowledge and processes to real-world problems. The pedagogy course features curriculum that enables teachers to acquire an understanding of the nature and purpose of action research, and launches teachers into planning and implementing systematic inquiry in their own mathematics classrooms around topics of their choosing. The varied abilities of teachers, as well as growth in teachers' mathematical and pedagogical capacities, are represented by several samples of student work provided within the article. In addition, mathematical and pedagogical products of student work are also provided through the project's URL links.

Improving teacher quality is identified as a national need in mathematics education and one many universities and schools across the country are working in partnership to try to address. This article describes a professional development project aimed at improving mathematics teaching and learning in the middle grades. An overview of the project, along with a close look at several of its course offerings, are presented highlighting mathematical and pedagogical goals, challenges, and accomplishments.

Introduction

The Math in the Middle Institute Partnership (M^2) is a partnership among mathematicians and mathematics educators at the University of Nebraska-Lincoln (UNL), and mathematics

teachers and administrators in the Lincoln Public Schools (LPS) and Nebraska's Rural Educational Service Units (ESU's). The aim of the Partnership is to develop intellectual leaders in middle-level mathematics (fifth through eighth grades) by investing in strengthening the capacities of teachers. This will, in turn, improve student achievement in mathematics and hopefully reduce achievement gaps in the mathematical performance of diverse student populations in Nebraska. The work of M^2 is informed by and provides evidence-based contributions to research on learning, teaching, and teacher professional development. The endeavor is funded by the National Science Foundation (NSF) and led by four co-principal investigators: W. James "Jim" Lewis, UNL Department of Mathematics; Ruth Heaton and Tom McGowan, UNL Department of Teaching, Learning, and Teacher Education (TLTE); and, Barbara Jacobsen, Curriculum Director for the Lincoln Public Schools.

The Math in the Middle Institute Partnership includes three major components. One is the M^2 Institute, a multi-year institute that offers participants a coherent program of study to deepen their mathematical knowledge for teaching and to develop their leadership skills. The second one is the use of mathematics learning teams, led by M^2 teacher participants and supported by school administrators and university faculty, which are intended to develop collegiality, help teachers align their teaching with state standards, and assist teachers in examining their instructional and assessment practices. The third and final component is a research initiative that transforms the M^2 Institute and the M^2 mathematics learning teams into laboratories for educational improvement and innovation.

Because more than half of Nebraska's population is located in rural areas and in towns of less than 25,000 people, Math in the Middle also focuses attention on the challenges and opportunities faced by mathematics teachers who teach in rural communities. We have established partnerships with sixty-seven school districts and fifteen of the seventeen ESU's across the State of Nebraska (the two ESU's not included in the Partnership represent urban school districts). The priority that Math in the Middle gives to concerns of rural education will permit it to make a unique contribution to the needs of students in rural schools and research in mathematical education [1].

The research agenda has two main foci: one is on understanding teachers' capacities to translate the mathematical knowledge and habits of mind acquired through professional development opportunities of M^2 into changes in classroom practice; the other is on understanding how changes in mathematics teaching practice translate into measurable improvement in student performance. We are particularly interested in how M^2 teachers support

one another, as well as other staff, in their individual schools in improving mathematics instruction. A description and preliminary findings from collaborative research with the Distributed Leadership Studies project are presented in an article also appearing in this *Journal* issue [2]. Although the learning teams and research initiative are significant features of the project, this article focuses on the M² Institute.

The Math in the Middle Institute

The M² Institute is designed to offer content rich courses intended to develop teachers' mathematical knowledge and knowledge of effective classroom pedagogy, and to conduct an action research project, thereby building their capacities as teachers and positioning them to be leaders among their peers. The Institute culminates in one of two degrees: a Master of Arts for Teachers (MAT) with a Specialization in the Teaching of Middle-Level Mathematics from the College of Arts and Science; or, a Master of Arts (MA) degree from the College of Education and Human Sciences. The participants go through the 25-month program in cohorts. To date, two cohorts of participants have completed the program, with the third and fourth cohorts scheduled to complete the program in Summer 2008 and Summer 2009, respectively. Across the four cohorts, 136 teachers were accepted into the program. The M² Institute has seen very few drop-outs as sixty teachers have already earned a master's Degree and seventy more remain active in the program.

The Curriculum

The *Principles and Standards*, *The Mathematical Education of Teachers*, and *Foundations for Success*, guide our goals for the pedagogical and mathematical content for teachers across the curriculum of the Math in the Middle Institute [3-5]. The Institute consists of twelve courses, including seven in the Department of Mathematics, one in the Department of Statistics, three in education offered by TLTE, and a capstone course that can be taken through either the Department of Mathematics or TLTE, depending on an individual teacher's master's program. Descriptions of each course can be found on the M² website [6]. The following is a list of these M² Institute courses:

- MATH 800T: Mathematics as a Second Language
- MATH 802T: Functions, Algebra, and Geometry for Middle-Level Teachers
- MATH 804T: Experimentation, Conjecture, and Reasoning
- MATH 805T: Discrete Mathematics for Middle-Level Teachers
- MATH 806T: Number Theory and Cryptology for Middle-Level Teachers
- MATH 807T: Using Mathematics to Understand Our World
- MATH 808T: Concepts of Calculus for Middle-Level Teachers
- STAT 892: Statistics for Middle-Level Teachers

TEAC 800: Inquiry into Teaching and Learning
TEAC 801: Curriculum Inquiry
TEAC 888: Teacher as Scholarly Practitioner
Capstone Course: Integrating the Learning and Teaching of Mathematics

In mathematics, we chose to create eight new mathematics courses designed to offer a challenging curriculum for middle-level teachers. The Department of Statistics developed *Stat 892: Statistics for Middle-Level Teachers*. In the Department of Teaching, Learning, and Teacher Education (TLTE), three courses are required of all students who earn a master of arts degree (*TEAC 800, 801, and 889*). Faculty from TLTE approved a plan to offer special sections of each course (as well as *TEAC 888*, a course in action research) that meet the goals of these courses, but when possible, do so in the context of mathematics teaching and learning. The *Capstone Course* is an integrated mathematics and pedagogy experience that assists teachers in transferring the mathematics and pedagogy they have learned at the Institute to their classroom practices, and helps teachers plan for their emerging roles as leaders.

Across all of the mathematics courses is an overarching goal of helping middle-level mathematics teachers develop *mathematical habits of mind*. Mathematical habits of mind represent a deeper view of what it means to do mathematics, based on orientations mathematicians bring to their work, and the expectations for mathematical understandings for preK-12 students [7-9]. As a project, we continue to construct and reconstruct our own understanding of the phrase. Here is the project's current working definition, presented as a set of skills and dispositions of a mathematical thinker. A mathematical thinker with well-developed habits of mind:

- Understands which tools are appropriate when solving a problem;
- Is flexible in his/her thinking;
- Uses precise mathematical definitions;
- Understands that there exist multiple paths to a solution;
- Is able to make connections between what one knows and the problem;
- Knows what information in the problem is crucial to its being solved;
- Is able to develop strategies to solve a problem;
- Is able to explain solutions to others;
- Knows the effectiveness of algorithms within the context of the problem;
- Is persistent in the pursuit of a solution;
- Displays self-efficacy while doing problems; and

- Engages in meta-cognition by monitoring and reflecting on the processes of conjecturing, reasoning, proving, and problem solving.

We are also working to understand mathematical pedagogical habits of mind, an extension of the construct, as a means of understanding the dispositions teachers may bring to their development of these ways of thinking with their middle-level students [10].

There are essentially two types of courses taken by Math in the Middle participants: on-line courses (taken during the school year), and on-site courses (completed during the summer months). The distance courses are completed over the length of a standard semester while the on-site courses are completed in one to two weeks' time. Regardless of which type of course, they have several features in common.

In all M^2 courses, homework is assigned, collected, reviewed, and graded (in some fashion) on a regular basis. Homework assignments include a variety of problems, including ones that are computational in nature to "Habits of Mind" problems which require extensive problem solving, explanation, and mathematical justification. Participants are encouraged to collaborate on assignments in whatever groups are convenient, but to submit their work individually.

Most M^2 courses divide the class into subgroups, each assigned to a member of the instructional team. These groups convene daily (during on-site courses) in order to discuss homework and other course content. These small groups are an important feature for the courses, as participants who are hesitant to present their work or ask questions before the entire class are frequently more comfortable doing so in the smaller setting.

The M^2 courses typically culminate in a course portfolio containing the following: 1) a set of problems and solutions selected by the student to be representative of course accomplishments; 2) student written reflections about the nature of course learning; and, 3) solutions to what is referred to as an "End-of-Course Problem Set." Because our goal is to help teachers reach a point where they can successfully solve the problems we assign, we permit the teachers to submit solutions, receive feedback, and revise.

The one- or two-week Summer Institute courses are inspired by the system used by the Vermont Mathematics Initiative [11]. Courses meet eight hours each day for five days with homework assigned each evening. We believe this approach to instruction is respectful of the many demands on a teacher's time. The academic year courses are best described as "blended distance education courses." By this, we mean that there is an on-campus component and a

distance education component for each course. For the two on-campus days, the class meets eight hours each day with a homework assignment overnight. Ideally, this portion of the course will cover about 40% of the course, thus making the distance education portion of the course a reasonable “add-on” to the teachers’ other duties.

For the distance education portion of academic year courses, we use *Blackboard*®, PC NoteTaker™, e-mail, and Macromedia Breeze communication network software in working with teachers. Use of technology is also embedded in many of the courses, whether they are on-line or face-to-face. Each participant receives a TI-84 Plus Silver Edition calculator and uses it for several purposes, one of which is to graph more complex functions (e.g., exponential functions, trig functions, higher degree polynomials) to promote the idea that a calculator can be a tool in exploring more complicated mathematics than they might otherwise be able to study.

An Expanded Examination of the Institute: A Look at Three Courses

In order to convey a range of ways we try to meet our goals—offering challenging mathematical and pedagogical content to teachers, supporting teachers to be successful, integrating mathematics and pedagogy, and making central the idea of developing habits of mind of a mathematical thinker—we offer a closer look at three courses within the Institute. These courses are: *MATH 800T: Mathematics as a Second Language*; *MATH 807T: Using Mathematics to Understand Our World*; and, *TEAC 888: Teacher as Scholarly Practitioner*.

Mathematics as a Second Language

A primary focus of *Mathematics as a Second Language (MSL)*, the first course of the Institute, is on understanding mathematics as a language. This course lays the foundation for developing the “habits of mind of a mathematical thinker.” Course goals include understanding numbers (arithmetic), developing number sense, and introducing algebra as a means of communicating mathematical ideas; that is, thinking about numbers as adjectives, and the nouns those adjectives modify. This course stresses a deep understanding of the basic operations of arithmetic, as well as the interconnected nature of arithmetic, algebra, and geometry. The following topics are included: a comparison of arithmetic and algebra; the process of solving equations; an understanding of place value and the history of counting; an understanding of inverse processes; an awareness of the geometry of multiplication; a recognition of the many meanings of division; a comparison of rational and irrational numbers, and an understanding of the 1-dimensional geometry of numbers. We borrowed this course and its content materials from

the Vermont Mathematics Initiative [13]. One “innovation” offered by our Institute is the introduction of what our teachers have come to call, “Habits of Mind” Problems.

As the first course of the Institute, we are challenged to begin to understand who these teachers are as learners of mathematics, what their mathematical strengths and needs are, and how best to meet their varied needs. Participants teach fifth through eighth grades, yet enter the Institute with differing mathematical backgrounds and teaching experience. While some participants enter having been a college math major and teach grades 7-12 (including some who teach calculus), the majority have degrees in elementary education and many may have only taken one or two college mathematics courses.

As the course progresses, participants are assigned problem sets that reinforce the course topics. In addition, participants work special “Habits of Mind” problems that challenge them to develop their problem solving and adaptive reasoning ability. “The Triangle Game” is one such problem [14]. Students were asked to respond to the following five parts of the problem: 1) Find a way to put the numbers 1-6 at each point on the triangle to create equal side sums; 2) Is there more than one way to get equal side sums? 3) Is it possible to have two different side sums? What are the smallest and largest possible sums and why? 4) What side sums are possible? 5) What is a possible generalization of The Triangle Game? In The Triangle Game, one must use the numbers one through six, placing one number at each vertex and edge midpoint in such a way that each side (two vertices plus one midpoint) has the same sum. Two of the possible solutions for part one are shown below in Figure 1.

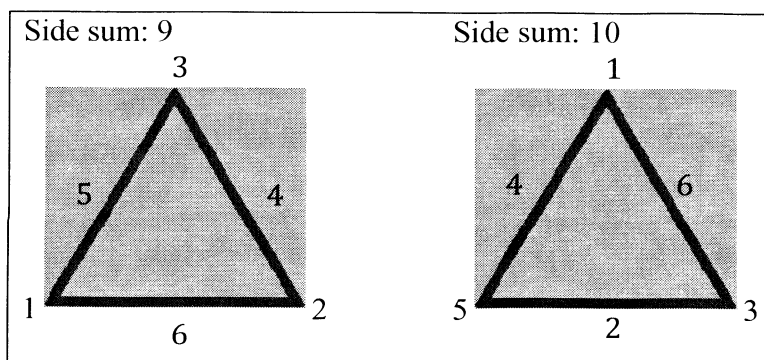


Figure 1. Two possible solutions for The Triangle Game.

Students’ work across The Triangle Game problem varied tremendously, ranging from teachers who gave partial answers or grappled with what it means to justify and generalize solutions, to

those who already had great capacity to reason and communicate their ideas. Three variations in student work are shown in Figures 2-4. Figure 2 represents the only work Student A did on the five parts of the problem.

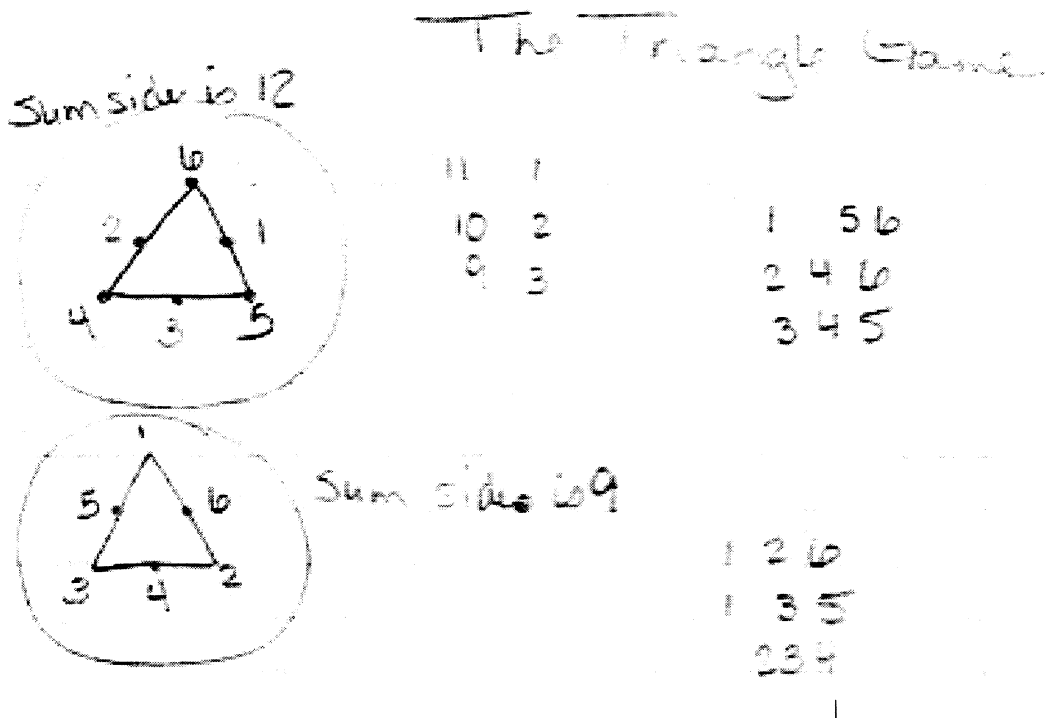
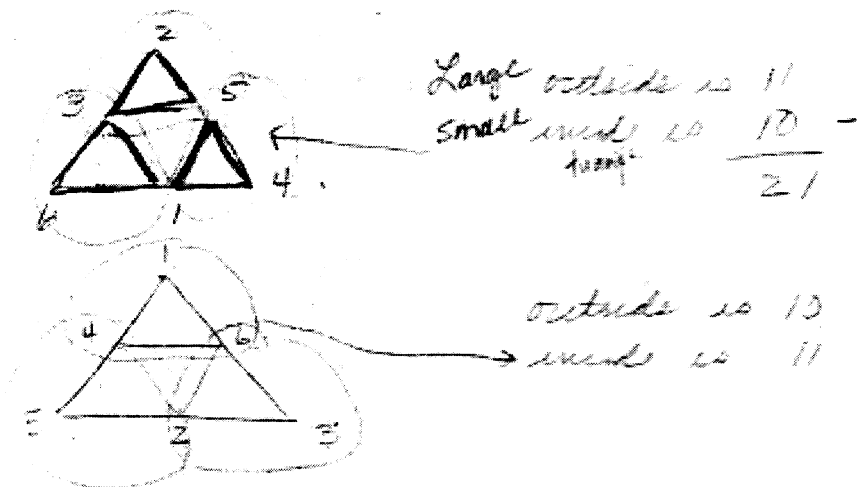


Figure 2. Student A's work on The Triangle Game.

She was elementary certified and entered the program with very few formal mathematics courses and low mathematical self-efficacy. Her solution shows efforts to explore numbers to find two possible solutions. Figure 3 represents the work of Student B, a middle-level certified teacher, who teaches fifth and sixth grade mathematics.



Generalization - There seems to be a connection between outside + inside numbers. The sum of the outside numbers + sum of inside numbers in each case equals 21 which is the same as adding the 6 numbers - so I had to find 1 combination of numbers to equal 21

9 + 12
 10 + 11

8 + 13 and with these no combination make 8 + 13.

8 + 13 and with these no combination make 8 + 13.

Figure 3. Student B's work on part 5 of the Triangle Game.

Student B's work explores an interesting relationship among the arrangement of numbers in the solutions that she found. While this may be evidence that she came to our program with a stronger mathematics background than Student A, she still misuses the term "generalization" and she uses terms, such as "large outside," without defining them.

A third participant, an eighth grade teacher with a secondary certification offers evidence of even better mathematical sophistication at this early point in our program (see Figure 4). Her solution included the following justification that nine is the smallest possible side sum.

To get the "side sum" with the SMALLEST value for the sum, you would have to put the 3 smallest numbers at the vertices. The 3 larger numbers would then be put at the midpoints by placing the largest (6) between the smallest (1 and 2), the next largest (5) between the next smallest (1 and 3). That leaves only one place for the 4 to go (between the 2 and 3). This creates a side sum of 9.

5.) A possible generalization of The Triangle Game would be:

To get the the 'side sum' with the SMALLEST value for the sums you would have to put the 3 smallest #'s at the vertices. The 3 larger #'s would then be put at the midpoints by placing the largest (6) between the smallest (1+2), the next largest (5) between the next smallest (1+3). That leaves only one place for the 4 to go (between the 2+3). This creates a side sum of 9.

To get a larger side sum, reverse that process. Place the 3 largest (4, 5+6) at the vertices. Then the midpoints would be placed with the smallest (1) between the largest pair (6+5), then (2) between (6+4) and finally the largest of the smaller #'s (3) between the smallest sum of the pair of larger #'s (5+4) to create sums of 12.

Figure 4. Student C's work on Part 5 of The Triangle Game.

The goals of this course and across the Institute as a whole are to meet these varied mathematical needs of the participants by making mathematical content accessible to all students, guiding the development of sound mathematical reasoning, and providing rigorous mathematical challenges. Generally, students are positive about the course and find that they are capable of doing challenging mathematics and experiencing success. When asked in a course evaluation what contributed most to their learning, participants offered a variety of responses, including group work, challenging yet feasible assignments, and looking at problems from multiple perspectives. One teacher wrote:

It stretched my thinking so much that I was physically sore—I called it a mathematical hangover. However, it was welcomed. I felt like I knew many of the concepts (not all), but showing why was the key.

Using Mathematics to Understand Our World

Using Mathematics to Understand Our World (UMW) is one of the final mathematics courses offered within Math in the Middle. It is offered in the second spring semester as a distance learning class, designed around a series of projects in which participants examine the mathematics underlying several socially relevant questions which arise in a variety of academic disciplines (i.e., *real-world* problems). Participants learn to extract the mathematics out of the problem in order to construct models to describe them. The models are then analyzed using skills developed in this or previous mathematics courses. One key challenge for this class is learning to deal with the “messiness” inherent in using mathematics to model real-world problems. Such mathematical models frequently entail difficult mathematical ideas—ones frequently not encountered by elementary and middle-level teachers.

The primary goal of the course is to broaden students’ mathematical perspectives by exposing them to a variety of interdisciplinary settings to which mathematical topics can be applied. Three additional course goals include the development of mathematical modeling and problem solving skills, an improved ability to read technical reports and research articles, and the refinement of written mathematical communication skills.

For each project assigned during the course, original documentation (such as government reports, data, and research articles) is provided whenever possible so that students develop an appreciation for the very real role mathematics plays in society. An overview of the six course projects can be found on the M² website [6]. Students then work in groups to complete the following basic pattern of activities:

- Study the problem and essential background information;
- Identify mathematical aspects of the problem to develop and analyze an appropriate mathematical model;
- Use the model and its analysis to understand more complex versions of the problem as described in research articles or other documentation; and,
- Submit written reports summarizing results.

Specific mathematical content includes exponential growth and decay, logarithmic functions, Newton's Law of Cooling, simulations, graphing data, making predictions, analysis of the effects of error, probability, and quality control. The disciplines to which the mathematics is applied include biology, medicine, natural science, forensics, finance, and industry.

Teachers strengthen their communication skills in mathematics by working collaboratively, sharing ideas on discussion boards, and submitting written descriptions and justifications of their mathematical models and solutions. Their written reports incorporate mathematics into language intended for non-mathematical audiences, thereby developing teachers' skills in articulating connections between a mathematical study and its concrete applications. The course affords teachers the opportunities to apply the mathematical knowledge they have learned in previous courses to new kinds of problems. While teachers find the course challenging, most appreciate the opportunity to do mathematics in the context of real-world applications. In a final course evaluation, one participant commented:

This class stimulated my thinking and changed my views about how to incorporate real-world problems/projects in the mathematics classroom. I now see how using projects with the math embedded can provide enough student practice of procedures while giving students the experience of how mathematics is used out in the real world.

Teacher as Scholarly Practitioner

Teacher as Scholarly Practitioner introduces participants to the theory and practice of teacher-led inquiry into effective practice. The course prepares teachers to engage in a classroom-based action research project to be conducted during the second spring semester while simultaneously taking the *Using Mathematics to Understand Our World* course. Participants read and synthesize educational research related to their chosen action research topic, and also seek official university approval (Institutional Review Board [IRB]) for their planned projects.

The course provides opportunities to examine the theoretical underpinnings, issues, concerns, and methodologies of practitioner-based inquiry. Intended outcomes include an understanding of the following concepts: 1) teaching as not separate from research; 2) theory and practice as interdependent and constantly shifting in response to the educational environment; 3) inquiry as being central to the education process; and, 4) practitioner research as stemming from educators' questions of and reflections on their everyday practice and desire to improve teaching and learning. Teachers make plans for systematically examining some aspect of their own teaching based on a topic of their own choosing.

Teacher as Scholarly Practitioner builds on the academic reading and writing practiced in two previous M² pedagogy courses: *Inquiry Into Teaching and Learning*, and *Curriculum Inquiry*. *Inquiry Into Teaching and Learning* introduces educational research in a variety of forms. Participants build skills in locating, reading, analyzing, evaluating, and synthesizing educational research. Participants develop professional writing skills and work collaboratively to build knowledge in disciplined inquiry. As part of the ongoing evaluation of M² courses, the *Inquiry Into Teaching and Learning* course was moved from the summer to the spring semester in order to give more time for participants to be immersed in reading and writing. The *Curriculum Inquiry* course focuses on helping participants gain a deeper understanding of mathematics curriculum development, including historical and contemporary issues influencing curriculum planning and educational change. The course challenges participants to see curriculum extending beyond textbooks. Participants engage in detailed curricular analysis of their own mathematics curriculum as they deepen their understanding of curricular issues.

Teacher as Scholarly Practitioner offers participants opportunities to be deeply engaged in academic inquiry. One of the challenges for learners in this course includes learning how to write good research questions that are narrow, yet detailed enough to guide a disciplined inquiry. While each teacher participant chooses his or her own topic for the action research project, most research questions are related to making changes in current practices or trying something for the first time related to the following topics: problem solving, communication (oral or written), cooperative learning, assessment, homework, or vocabulary. Teachers must gather at least three sources of data for each of three research questions they are required to ask. The types of data used include, but are not limited to: pre-/post-surveys, student interviews, examples of student written work (e.g., in class, homework, tests) and teacher journal.

Students plan the course in the second fall semester and carry out classroom data collection in the spring, while also taking *UMW*. Participants are expected to write about their

research studies; for many, this is their first serious venture into scholarly writing [15]. Expectations for the depth of data analysis and length of the paper vary by degree, with TLTE graduates writing in-depth summative projects while graduates from the Department of Mathematics write much briefer reports and, instead, spend much of their time just prior to graduation on individual *Mathematics as a Second Language (MAT)* expository papers and a mathematics exam [16]. Having experienced cycles of inquiry first hand, we hope teachers will continue to try new things while teaching and study what happens based on their learning in the Institute.

Building Capacity

We have observed M² teachers grow tremendously in their capacities to engage in the learning of challenging mathematics across their involvement at the Institute. For example, in one of the *MAT* expository papers, a student was asked to grapple with “The Polygon Game” [16]. Her explanation is outlined here:

Take a regular, n -sided polygon (i.e., a regular n -gon) and the set of numbers, $\{1, 2, 3, \dots, (2n-2), (2n-1), 2n\}$. Place a dot at each vertex of the polygon and at the midpoint of each side of the polygon. Take the numbers and place one number beside each dot. A *side sum* is the sum of the number assigned to any midpoint plus the numbers assigned to the vertex on either side of the midpoint. A *solution* to the game is any polygon with numbers assigned to each dot for which all side sums are equal; i.e., for which you have *equal side sums*. The most general problem we might state is, “Find all solutions to The Polygon Game.”

In assigning this topic, we wanted her to analyze carefully a complete solution to The Triangle Game: reasoning carefully, offering a discussion about the importance of careful definition, and discussing opportunities to use algebra or geometry to solve problems. We hoped she would state and find solutions to “The Square Game” and explore comparable games for larger polygons (see Appendix A). Her work exceeded our expectations in several ways. For example, she argued that for any n -gon, each solution has a “dual solution,” found by replacing the value i by $(2n + 1) - i$ at each point. She not only found all solutions for The Square Game, but also for “The Pentagon Game” and “The Hexagon Game.” These solutions offered new insights. For example, The Pentagon Game has solutions for 14 (and its dual, 19), but no solution for 15 or 18. Furthermore, both 16 and 17 have two uniquely different solutions that are not a transformation of each other. In perhaps the most interesting result in the paper, she uses modular

arithmetic to show that for any n -gon where n is odd, there is an Equal Side Sum solution $S = 5(n+3)/2$.

Conclusion

Readers of this article will be pleasantly surprised to learn that this paper is the work of a fifth grade classroom teacher. The entire article is posted on our website [16]. We offer this as an example, coupled with teachers' earliest work in the Institute on The Triangle Game (see Figures 2, 3, and 4) to illustrate the sort of intellectual growth and mathematical capacity building we see in the participants as a result of the Institute. Understanding how this mathematical knowledge translates into more thoughtful teaching can be seen, to some degree, in the short term, by reading teachers' action research projects [16]. Long-term impact of teachers' new mathematical capacities on classroom practice is yet to be fully understood.

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Appendix A

M² Student Solution to The Polygon Game

Solution to All Polygons

Conjecture: One solution to every polygon will have a side of $n + 2n + 1$, where n = the number of vertices on the polygon, giving a side sum of $3n + 1$. Consider the following examples, all of which are a lower solution of the 2 center solutions in the range of possible solutions:

Triangle: <u>3, 6, 1</u> , 4, 5, 2	Side Sum = 10
Square: <u>4, 8, 1</u> , 7, 5, 2, 6, 3	Side Sum = 13
Pentagon: <u>5, 10, 1</u> , 8, 7, 6, 3, 4, 9, 2	Side Sum = 16
Hexagon: <u>6, 12, 1</u> , 10, 8, 4, 7, 9, 3, 5, 11, 2	Side Sum = 19

Notice that in each example the underlined numbers represent a side sum that is consistent with the expression $n + 2n + 1$. So, to see if this would be true for all polygons, I randomly chose an octagon, fixed the expression as a given side and checked for solutions.

Octagon: <u>8, 16, 1</u> , 13, 11, 12, 2, 9, 14, 5, 6, 4, 15, 3, 7, 10	Side Sum = 25
Decagon: <u>10, 20, 1</u> , 14, 16, 11, 4, 15, 12, 13, 6, 7, 18, 8, 5, 17, 9, 3, 19, 2	Side Sum = 31

The $n + 2n + 1$ still works!

Finally, with this last conjecture, my exploration of the polygon game comes to an end. I have been able to determine all solutions to the triangle game, the square game, the pentagon game and the hexagon game. I have then been able to use that information to find patterns that allowed me to explore n -gons in two different ways, from which I can determine two solutions to any odd sided polygon and one solution to any even sided polygon. Of course I can also use the concept of duality, which instantly doubles the number of solutions that I find!

UNDERSTANDING TEACHER LEADERSHIP IN MIDDLE SCHOOL MATHEMATICS: A COLLABORATIVE RESEARCH EFFORT

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Abstract

We report findings from a collaborative research effort designed to examine how teachers act as leaders in their schools. We find that teachers educated by the Math in the Middle Institute act as key sources of advice for colleagues within their schools while drawing support from a network consisting of other teachers in the program and university-level advisors. In addition to reporting on our findings, we reflect on our research process, noting some of the practical challenges involved, as well as some of the benefits of collaboration.

Introduction

A sizable amount of literature addresses aspects of teacher leadership in schools, including how to develop the leadership skills of classroom teachers [1]. Educating and supporting Teacher Leaders for middle school mathematics is the central goal of the Math in the Middle Institute Partnership, a project developed at the University of Nebraska-Lincoln (UNL) and funded by a Mathematics and Science Partnership grant from the National Science Foundation. The Math in the Middle (M^2) project offers a 25-month master's program for outstanding middle-level mathematics teachers, referred to here as M^2 associates, helping them to become intellectual leaders in their schools, districts, and beyond. As the co-principal investigators of Math in the Middle have described in another article in this issue, the M^2 Institute focuses not just on providing professional development, but also on seeking evidence-based findings about learning, teaching, and leadership development [2].

As part of the M^2 research initiative, the M^2 principal investigators have enlisted help from the Distributed Leadership Study for Middle School Mathematics Education (DLS). This project, centered at Northwestern University and also funded by a National Science Foundation grant, uses the theoretical and diagnostic framework of Distributed Leadership to study school leadership [3]. The project has designed a web-based survey instrument, the School Staff Social Network Questionnaire (SSSNQ), to collect empirical data about leadership practice in elementary and middle schools. Operationalizing leadership as social influence relations, the SSSNQ uses a social network approach to measure leadership interactions.

The SSSNQ captures data that is relevant to two of the M^2 Institute's primary goals. One of the goals of the M^2 Institute is to build teachers' capacities to become intellectual leaders for mathematics instruction in their schools. The SSSNQ social network data from within a school enables us to understand the extent to which M^2 associates act as sources of advice about instruction for their colleagues. In addition, by bringing participants together for intensive summer workshops and academic year courses, the M^2 Institute seeks to build an enduring support network among associates, and between associates and university-level faculty. The SSSNQ data on the social network among M^2 program participants allows us to understand advice seeking behavior that is prevalent outside the school building.

The alignment between the research goals of the M^2 Institute and the survey instrument designed by the DLS created a natural opportunity for collaboration. Working closely together, we administered the survey to all M^2 associates and to the entire staff of ten middle schools where M^2 associates work. In this report, we describe our research process and share some initial findings regarding how M^2 associates act as leaders within their schools. We also reflect on our collaboration, in the hopes that discussing the advantages of collaboration and the practical challenges we encountered might be helpful to others engaged in similar research.

Our report contains the following: a description of the design of the survey instrument and the process of administering it; a discussion of our approach to analysis and our report of the initial results; our description of how we were able to share some findings with the participating schools; and, our concluding remarks.

Instrument (Re)Design

The distributed perspective is a theoretical or diagnostic framework for examining the practice of leading and managing. In contrast to more conventional leadership perspectives,

which tend to emphasize the heroic efforts and personal qualities of individual leaders, the distributed perspective emphasizes the practice of leading and managing. It views leadership practice as taking form in the interactions among leaders and followers, as mediated by aspects of their context, such as organizational routines and tools. Informed by the distributed perspective, the SSSNQ instrument is a web-based survey designed to collect data on interactions among leaders and followers, as well as aspects of the school context. The instrument used in the work reported here is the fourth iteration of the SSSNQ [4].

The SSSNQ operationalizes aspects of the Distributed Leadership perspective by capturing data on interactions between leaders and followers, measured from the perspective of the follower [4, 5]. Interactions are measured using social network name generators, which ask survey respondents to recall interactions where they sought advice from others. For example, respondents who teach mathematics are asked, “In the past year, to whom have you gone for advice or information about teaching math?” For each name that a respondent lists, follow-up questions ask the respondent to describe the role or job description of the person named, and to characterize their interactions with the person in terms of frequency of interaction, influence of advice provided, and content matter of advice provided.

The SSSNQ actually poses several social network name generator questions to differentiate between subject areas because our previous research suggests that the structure of relationships among teachers and the nature of their thinking about their work differ by school subject [6, 7]. All staff members are asked to name people to whom they go for advice about Mathematics and advice about Reading/Writing/Language Arts (RWLA). Teachers whose specialty subject is something other than Mathematics or RWLA are also asked to name people to whom they go for advice about teaching their primary subject.

In the analysis that follows, we focus on the social network name generator part of the instrument. However, the survey also contains several other types of questions that address aspects of respondents’ situations. Respondents are asked about their positions or roles, their formal leadership designations (if any), and their participation in school committees. They are also asked a series of questions about the cultural climate of their school. Based on feedback from teachers who have taken the survey, we have found that the SSSNQ provides an opportunity for reflection about the past school year that many teachers welcome. In all, the survey takes approximately twenty to thirty minutes to complete. A sample version of the instrument can be viewed on our website [8].

The collaboration between the M² Institute and the DLS afforded us a beneficial opportunity for redesigning the SSSNQ. The M² Institute staff from UNL had been working with mathematics teachers in the middle schools we planned to survey, and therefore had a practical understanding of local school cultures and concerns. Drawing on this understanding, we worked together to tailor the wording of survey questions for ease of interpretation in the local school context. Conducting a pilot survey study or cognitive interview study is certainly the best way to field test a survey for reliability and validity [9]. Short of this, using our collaborators' understanding of local school cultures helped us decrease the likelihood that respondents would misinterpret questions in the survey instrument.

Data Collection

Social network survey items present some unique challenges compared to standard survey items, including the need for very high response rates, the need to define a network boundary, and the need to protect participants' confidentiality when using a research design that necessarily lacks anonymity [10, 11]. High response rates are imperative because many network measures, though defined at the level of the individual, are calculated based on peer reports that aggregate responses from many individuals. The reliability of a network measure suffers when response rates are low or even moderate by the usual standards of survey research [12]. In light of these requirements, our strategy for data collection included finding ways to encourage very high levels of participation.

Data collection entailed working with two partially overlapping study populations, each of which has a natural network boundary. First, we surveyed all M² associates in order to understand the social network operating within the program. Here, the network boundary is defined by participation in the M² program. Second, we focused on several schools in a single district (the "Target District") where a number of M² associates worked. For this population, the network boundary is defined by the school building. Using the SSSNQ, we conducted a census of the entire teaching staff in each school, providing peer-report data from the perspective of followers that allows us to understand how M² associates are situated within their schools.

Since the program began in 2004, Math in the Middle has accepted four cohorts of M² associates, with a new cohort beginning the 25-month program every summer between 2004 and 2007. Each cohort consists of approximately thirty-four teachers from both urban and rural

school districts. In addition to middle school teachers, some fifth grade teachers (elementary level) also participate in the program.

Surveying all M^2 associates was straightforward because Math in the Middle project staff knew them personally and had extensive contact with them. During Summer 2007, Heaton contacted all M^2 associates via e-mail, inviting them to complete the SSSNQ and providing a URL link to access the survey. Associates who did not respond to the initial invitation were sent an e-mail reminder, or asked to complete the survey in the computer lab during the first day of the M^2 Summer Institute. Due to the overlapping nature of the study populations, some associates in the Target District had already completed the survey. These respondents were not asked to participate in the survey again; instead, the respondent's original survey response was included in the sample. In all, we received responses from 91% of M^2 associates; Table 1 details the response rates by cohort. As of this writing, we plan to survey all M^2 associates again during Summer 2008.

Table 1
 M^2 Associate Survey: Response Rate by Cohort

<i>Cohort</i>	<i>Number of M^2 associates</i>	<i>Response rate (%)</i>
I	30	77
II	31	94
III	35	91
IV	35	100
Total	131	91

Conducting the census surveys in ten middle schools was less straightforward, and involved both participation incentives and the need for additional data. In order to achieve the high response rates necessary in social network surveys, we offered a combination of incentives: individual participants were offered a gift card for completing the survey, and schools where over 90% of the teaching staff participated were rewarded with an honorarium. In order to identify the sampling frame of relevant individuals to survey and to calculate response rates, we needed an additional data source. We used rosters of all school employees from the state Department of Education, which are updated periodically throughout the school year.

Math in the Middle project staff drew on existing relationships with district staff, including the director of curriculum, who is a co-principal investigator of Math in the Middle, to

gain permission and endorsement to conduct our research. They then met with the school principals to invite their schools to participate in the survey. All ten principals agreed to participate. In Spring 2007, they were sent an e-mail message to distribute to their staff that described the purpose of the survey, outlined the incentives offered, and provided a URL link to access the survey. Over the next three weeks, follow-up e-mails were sent to the principals at least once per week, notifying them of how many staff had completed the survey thus far and allowing principals to monitor their school’s progress toward the 90% participation goal.

In all, we received responses from 85% of all teaching staff during Spring 2007; response rates from individual schools ranged from 69% to 95% (see Table 2). During this round of data collection, M² project staff’s existing relationships and knowledge of local context again proved very useful. Their relationships with district and school personnel gave us all an understanding of the rhythm of the school year and the competing demands on teachers’ time, without which we could not have attained such high response rates in the 2007 survey of Target District staff.

Table 2
Target District Survey: Response Rate by School

<i>School</i>	<i>2007</i>		<i>2008</i>	
	<i>Number of teaching staff</i>	<i>Response rate (%)</i>	<i>Number of teaching staff</i>	<i>Response rate (%)</i>
1	55	89	60	85
2	64	73	66	53
3	68	69	70	56
4	61	80	61	51
5	57	91	58	52
6	73	84	68	43
7	72	94	70	69
8	73	86	72	72
9	59	95	60	92
10	57	89	57	93
Total	639	85	642	66

In Spring 2008, we contacted school principals and invited their schools to participate in the survey a second time. All schools participated, but we maintained less frequent contact with principals, and had less of an understanding of what else was occurring in the schools while we were collecting data. Perhaps as a consequence, we received responses from only 66% of teaching staff during the 2008 school year; response rates from individual schools ranged from 43% to 93% (see Table 2).

Reflecting on our data collection process, we recognize the importance of maintaining the support of the school principals over several rounds of data collection. During the first year, project members met face-to-face with all principals, who expressed curiosity about what they could learn from the SSSNQ. We observed that the principals encouraged their staff to participate in the survey, anticipating that they would gain some useful insights from the data. As we prepared to collect data during the second year, we did not meet face-to-face with the principals again. This may have influenced our response rate. It is also possible that some principals may have been skeptical whether participating in another round of data collection would be worthwhile, because they expected very few changes from the first year. It is possible that if there was less interest in the results of the survey, principals may not have encouraged participation to the same degree.

Data Analysis

For purposes of understanding the leadership roles and support networks of M^2 associates, we focus on data from one social network name generator question in the SSSNQ. The question asks school staff to list people to whom they have gone for advice over the past year about teaching mathematics. We take a twofold approach to analysis of the math advice networks, first using network visualization tools to gain intuition about the network positions of M^2 associates, and then calculating network centrality measures to quantitatively describe their network positions.

Graphical visualization techniques play an important role in the field of social network analysis, and computer algorithms now allow for sophisticated graphical encoding of information in diagrams [13]. We visualize the math advice networks within each middle school and among all M^2 associates using a graphical layout known as a sociogram. In a sociogram, each individual is represented by a shape such as a circle (a node) and a link between two individuals is represented by an arrow (a tie). By representing the relationships of a given type between all members of an organization, a sociogram allows one to see larger patterns or structural features of the social network that would not be apparent by studying the relationships individually.

Typically, layout algorithms such as spring embedding are applied to sociograms so that the shapes representing individuals are placed in such a way as to make the network structure more apparent [13]. Groups of individuals that have many common ties tend to appear near each other, and individuals that are central to the network—meaning that they connect many other

individuals or groups—tend to appear in the center of the diagram. However, network layout algorithms are highly dependent on initial conditions, and produce sociograms that are arbitrary in many respects. Therefore, sociograms should be used to gain intuition about network structures, but not as a rigorous analytical tool. We used the program *NetDraw* to create sociograms for analysis [14]. To lay out the sociograms, we applied a force-directed layout algorithm with node repulsion and equal edge-length bias.

Figure 1 is a sociogram depicting the math advice network within one middle school. It contains additional encoding to represent the teaching role of each individual in the network (i.e., sixth grade teacher, mathematics teacher, administrator, etc.). Individuals who neither sought nor gave advice about math are not pictured.

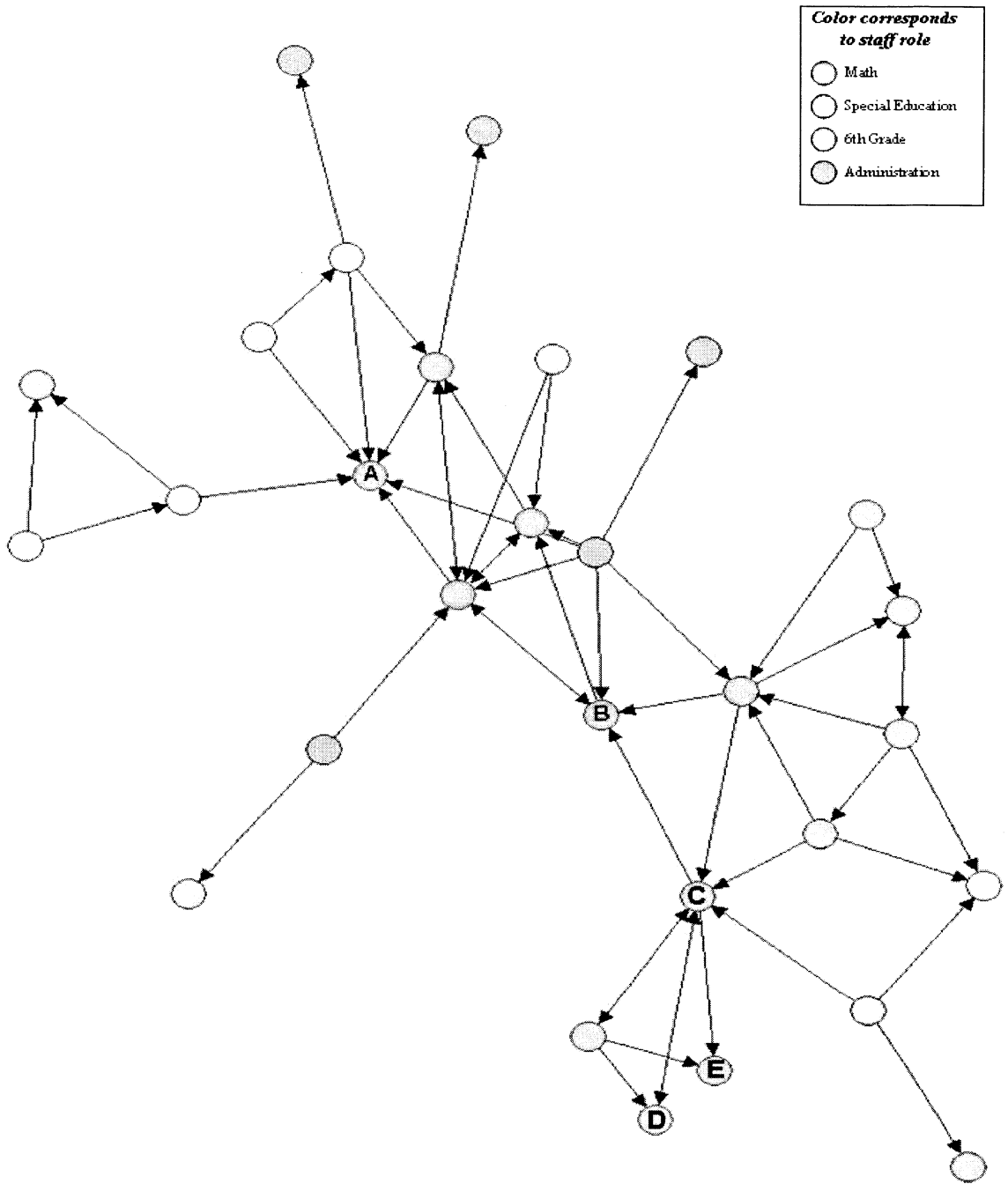


Figure 1. Sociogram of the math advice network within a school.

We have found sociograms to be a helpful tool for gaining insights about the associates with whom the M² Institute works. The sociograms provide rich detail about the network positions of the associates, which we interpret in combination with personal knowledge of the associates. For example, in Figure 1 nodes labeled A through E represent the five M² associates who work in a single school. Based on the sociogram, the M² associates appear to be connected to each other and sought after by their peers, indicating that they are a community among themselves and are seen as leaders within the school. However, some associates appear to have more influential positions than others. Nodes A and B, both from the second cohort, are both highly connected, but to different groups; node A provides advice to special education teachers, while node B provides advice to sixth grade teachers. Node C, from the third cohort, acts as a bridge, facilitating communication between the sixth grade team and the mathematics department. In contrast to these associates, nodes D and E are less connected to the rest of their school, seeking or providing advice mainly with other M² associates. Such detailed analysis of sociograms allows M² project staff to consider how to tailor the professional development of individual M² associates.

In addition to graphical analysis of sociograms, we compute several network centrality measures to quantify the network positions of M² associates in terms of their leadership roles. Among many network centrality measures that have been proposed, we focus on two simple measures: out-degree and in-degree [15].

Out-degree is a measure of the amount of support upon which an individual can draw. It is calculated by counting of the number of people *from* whom an individual *seeks* advice, based on an individual's self-report. We compute a more detailed measure of out-degree by differentiating between ties to individuals internal to the network boundary (e.g., other teachers in the same school) and ties to individuals external to the network boundary (e.g., ties to friends, relatives, university faculty, or teachers in other schools). In Figure 1, node C has four out-going arrows, meaning that she named four other teachers in her school as sources of advice about math; in social network terminology, node C therefore has an internal out-degree of four.

From the distributed perspective, in-degree is an operational measure of an individual's leadership position. In-degree measures the number of people *to* whom an individual *provides* advice. We compute in-degree based only on the reports of other teachers within the network boundary (e.g., within the same school). In Figure 1, node C has five incoming arrows, meaning

that she was named by five other teachers as a source of advice about math; node C therefore has an in-degree of five.

In our analysis of schools in the Target District, we compare the M^2 associates to other teachers who fill similar roles. In the ten schools we study, sixth grade teachers are generalists, providing instruction in several subject areas to the same group of students; seventh and eighth grade teachers are subject-matter specialists, providing instruction in a single subject to several different groups of students. At the time of the survey, twenty-three mathematics and sixth grade teachers from the district middle schools had completed at least one summer of M^2 coursework. We study the role that these M^2 associates play by comparing the seventeen associates who are seventh or eighth grade mathematics teachers to the other mathematics teachers in their schools, and comparing the six associates who are sixth grade generalists to the other sixth grade teachers in their schools. Further, five of the M^2 associates in the Target District are in the most recent program cohort. At the time of the 2007 survey, these associates had been accepted into the program, but had not yet begun the M^2 training; we therefore treat them separately from associates in Cohorts I, II, and III.

Findings from the M^2 Associates Survey

One of the goals of the M^2 Institute is to foster a support network among the associates, and between associates and the university-level instructors involved in the program. We can understand whether this goal is being accomplished by examining the social network data from our survey of all associates.

In Figure 2, we present a sociogram representing the social network within the M^2 program. Associates are represented by circles colored according to their cohort in the program. M^2 Institute staff members, including university faculty and school district personnel, are represented by grey nodes. The nodes lining the upper edge of the figure represent associates and staff who neither sought advice from nor provided advice to other associates in the program; in social network analysis, these disconnected nodes are termed “isolates.”

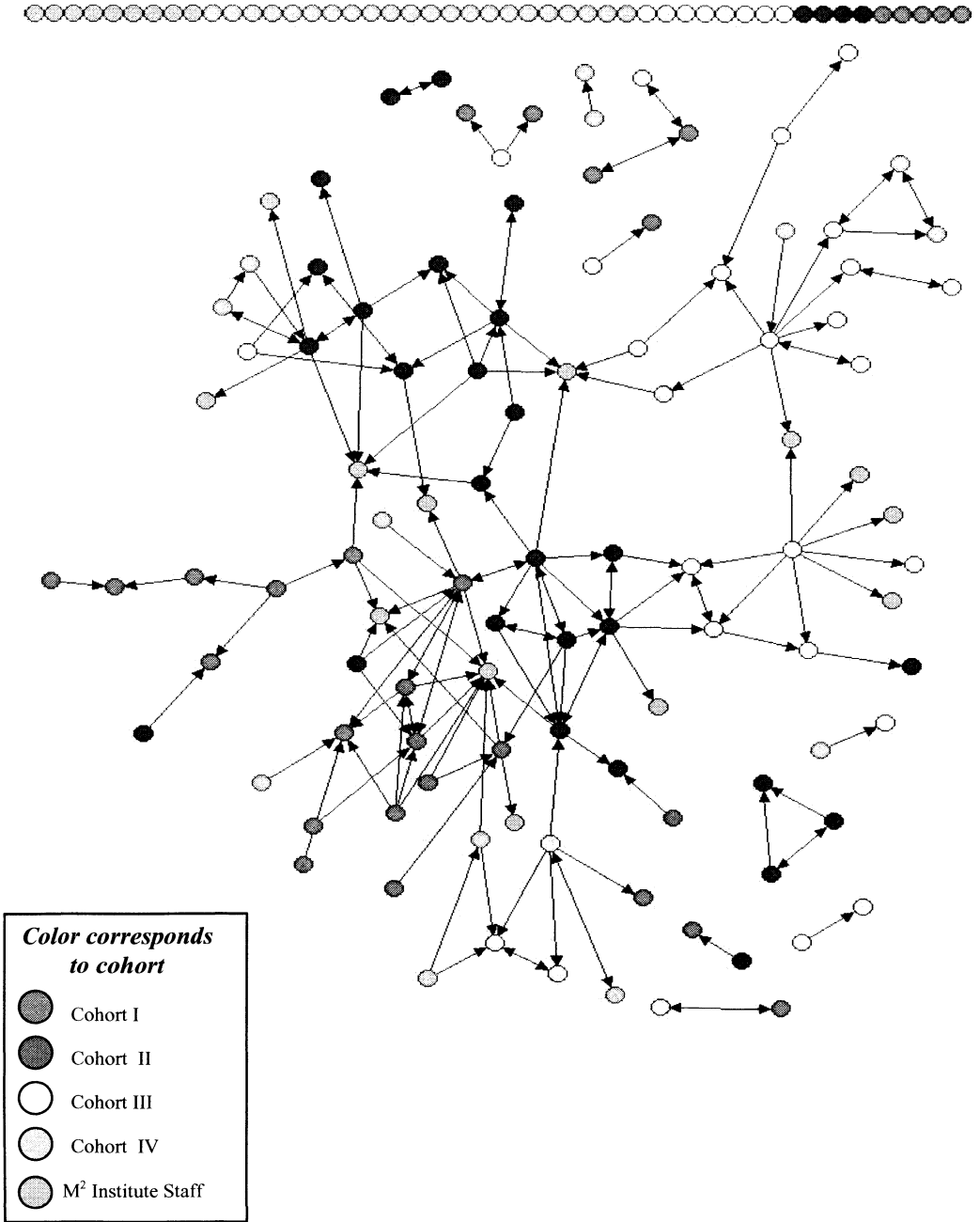


Figure 2. Math advice network among M² associates and M² institute staff.

Figure 2 suggests that many M² associates are participating in the support network of the M² Institute by seeking advice from other associates and from staff involved in the program. In

Figure 2, the nodes appear clustered by color, suggesting that associates tend to seek advice from other associates in the same program cohort. The individual who was most frequently listed as an advisor (by nine different associates) is a district curriculum specialist and M² master teacher. Several other M² staff and associates were listed by five respondents each, including three associates from the first cohort, one associate from the second cohort, one school district program consultant and high school mathematics teacher whose time is divided equally between teaching and working for the project, and one university faculty who is a principal investigator of the M² Institute Partnership.

To gain further insight into the advice network among associates and Institute staff, we calculate the number of other associates and M² staff whom a respondent lists as an advisor (the internal out-degree) and the number of individuals not involved in the M² Institute whom a respondent lists as an advisor (the external out-degree) for every associate who responded to the survey. Table 3 reports the mean internal out-degree and mean external out-degree by cohort, as well as the total out-degree.

Table 3
M² Associate Survey: Average Out-Degree by Cohort

<i>Cohort</i>	<i>Respondents</i>	<i>Mean internal out-degree</i>	<i>Mean external out-degree</i>	<i>Mean out-degree (internal and external)</i>
I	23	1.7	2.1	3.8
II	29	2.0	1.5	3.5
III	32	1.4	1.5	2.9
IV	35	0.5	2.3	2.8

Associates from earlier cohorts list more sources of advice in total. Associates from Cohort I list an average of 3.8 advisors, compared to Cohorts II, III, and IV who list an average of 3.5, 2.9, and 2.8 advisors, respectively.

Recall that at the time of the survey, Cohort IV had been accepted but had not yet begun the M² training. Associates in Cohort IV list mostly external sources of advice (2.3 advisors, on average) and few sources of advice from within the program (0.5 advisors, on average). In comparison, associates from the first three cohorts listed approximately equal numbers of internal and external advisors; the average internal out-degree and the average external out-degree are

both 1.7. This suggests that as associates participate in the program, they make less use of outside sources of advice and rely more on advice from within the M^2 network.

While most associates participate in the M^2 support network, not everyone is involved. Out of twenty-three respondents in the first cohort, six (26%) list no advisors from within the M^2 program. In the second cohort, eight out of thirty respondents (27%) have an internal out-degree of 0; in the third cohort, eleven out of thirty-two respondents (34%) have an internal out-degree of 0.

Most respondents from Cohort IV do not list sources of advice from within the program. Only twelve of thirty-five respondents list one or more advisors from within the program, which is to be expected given that these associates answered the survey before beginning the M^2 professional development program. In fact, the evidence that associates from Cohort IV seek advice from others within the program at all suggests that we should be cautious about attributing connections in the M^2 network entirely to participation in the M^2 program. Instead, it might be that teachers learned about the M^2 program through their existing network of advisors, so associates may have been selected into the program partially due to their participation in the network.

Findings from the Target District Survey

The social network data from the ten middle schools in the Target District lets us address two questions. First, by comparing the subset of M^2 associates working in the district to teachers with similar roles, we can verify our findings from the M^2 associates survey. Second, we can gain insight into how M^2 associates act as leaders within their schools, again by comparing M^2 associates to teachers with similar roles.

To avoid confusion about terms, we should note that our analysis of the Target District survey makes use of a different definition of internal and external advisors. In the Target District survey, we define the network boundary by the school building. Therefore, when calculating a respondent's internal out-degree, only teachers from the same school are included; when calculating a respondent's external out-degree, all advisors from outside the school building are counted. Advice from other M^2 associates might appear in either category. If an associate seeks advice from another associate who teaches at the same school, it would be counted as internal advice. If an associate seeks advice from another associate at a different school, or from an M^2 faculty member, it would be counted as external advice.

The M² associates in the Target District report more sources of advice from outside their school buildings compared to teachers with similar roles. As Table 4 reports, M² associates who are mathematics teachers list an average of 2.1 external advisors in the 2007 survey, compared to other mathematics teachers who list an average of 0.7 external advisors. Associates who teach sixth grade and had participated in the M² institute for at least one year list an average of 1.2 external advisors in the 2007, compared to other sixth grade teachers who list an average of 0.5 external advisors. For both mathematics teachers and sixth grade teachers, the results are similar in the 2008 survey, though the percentage difference is not always as large.

Table 4
Target District Survey: Average Out-Degree of M² Associates and Other Teachers

A. 2007 Survey				
	<i>Respondents</i>	<i>Mean internal out-degree</i>	<i>Mean external out-degree</i>	<i>Mean out-degree (internal and external)</i>
Math teachers				
M ² Cohorts I, II, and III	17	2.5	2.1	4.6
Other teachers	26	2.8	0.7	3.5
Sixth grade teachers				
M ² Cohorts I, II, and III	5	2.4	1.2	3.6
M ² Cohort IV	5	2.8	0.4	3.2
Other teachers	83	2.5	0.5	3.0
B. 2008 Survey				
	<i>Respondents</i>	<i>Mean internal out-degree</i>	<i>Mean external out-degree</i>	<i>Mean out-degree (internal and external)</i>
Math teachers				
M ² Cohorts I, II, and III	11	3.4	2.1	5.3
Other teachers	20	2.9	0.7	3.3
Sixth grade teachers				
M ² Cohorts I, II, and III	4	3.0	1.2	3.8
M ² Cohort IV	3	2.0	0.4	2.3
Other teachers	60	2.2	0.5	2.3

While M² associates seek more advice from outside their school buildings compared to their colleagues, the evidence regarding internal advice-seeking is less clear. In the 2007 survey, M² associates list slightly fewer advisors within their school buildings compared to teachers in similar roles while in the 2008 survey, they list more advisors within their school buildings.

However, the lower response rates to the 2008 survey, in combination with the small number of teachers in each category, means that we should interpret these data with caution.

The Target District survey was administered to the entire teaching staff at ten middle schools, providing us with peer reports of leadership interactions. These data allow us to examine the leadership roles of M² associates in comparison to teachers in similar roles. We find that M² associates act as instructional leaders within their schools by providing advice to many colleagues. Compared to their colleagues, M² associates tend to be named as advisors by more individuals within their schools. In the 2007 survey, M² associate mathematics teachers are named as advisors by an average of 8.8 colleagues; in comparison, other mathematics teachers are named as advisors by an average of 7.0 colleagues (see Table 5). Results are very similar in the 2008 survey: M² associate mathematics teachers are named as advisors by an average of 6.8 colleagues, while other mathematics teachers are named by an average of 5.1 colleagues.

Table 5
Target District Survey: Average In-Degree of M² Associates and Other Teachers

A. 2007 Survey		
	<i>Number of staff</i>	<i>Mean in-degree (within school)</i>
Math teachers		
M ² Cohorts I, II, and III	17	8.8
Other teachers	33	7.0
Sixth grade teachers		
M ² Cohorts I, II, and III	6	5.3
M ² Cohort IV	5	3.2
Other teachers	92	2.0
B. 2008 Survey		
	<i>Number of staff</i>	<i>Mean in-degree (within school)</i>
Math teachers		
M ² Cohorts I, II, and III	17	6.8
Other teachers	32	5.1
Sixth grade teachers		
M ² Cohorts I, II, and III	6	3.5
M ² Cohort IV	4	2.5
Other teachers	92	1.4

In the 2007 survey, sixth grade teachers who are M² associates are named as advisors by 5.3 colleagues, compared to 2.0 for other sixth grade teachers. In the 2008 survey, the difference between M² associate sixth grade teachers and other sixth grade teachers is smaller in magnitude: M² associates who are sixth grade teachers are named by 3.5 colleagues, on average, compared to other sixth grade teachers who are named by 1.4 colleagues, on average.

We should note that the lower response rates to the 2008 survey lessen the reliability of the in-degree measures in that year, and also make it difficult to compare the results from the 2007 survey to results from the 2008 survey. Still, finding differences between M² associates and teachers in similar roles in two separate administrations of the survey lends confidence to the conclusion that M² associates are key resources for advice and information about teaching mathematics.

Share-Back

Though the SSSNQ is designed as a tool for scholarly research, many of the questions it poses are also of immediate interest to school and district leaders. We arranged to share results from the 2007 survey with principals and district officials in the Target District. We believe that “share-back” efforts are a beneficial step in research projects such as ours, because they force us to translate our academic findings into practical, immediately relevant ones. This process of presenting to research participants has sharpened our focus, while also providing us with an opportunity to check out theories and conclusions. Here, we describe our share-back process and note the competing concerns involved.

The share-back process involves striking a balance between the desire to provide helpful, relevant information to school leaders and the imperative of protecting the confidentiality of research participants. Confidentiality must be protected not only to comply with the requirements of Institutional Research Boards, but to maintain a relationship of trust with research participants. *If participants feel that the promise of confidentiality has been breached, they are far less likely to participate in future rounds of research, certainly from our project and perhaps even from other researchers as well.*

The SSSNQ contains a series of questions asking the respondent for opinions about the cultural climate of their school. The questions address topics such as the level of trust among faculty and levels of collective responsibility for student learning. Many of the questions are modeled on a bi-annual survey of schools conducted by the Consortium on Chicago Schools

Research (CCSR), results from which CCSR shares with the participating schools [16]. We modeled our share-back of the cultural climate questions on the CCSR report, presenting aggregate climate measures as well as frequency distributions of individual items. For each item, we presented results aggregated across all respondents in a school in order to protect the confidentiality of the responses from individual participants. We also reported aggregate results from the CCSR survey, providing an external benchmark for interpreting the magnitude of the measures (a template for our analysis is available from the corresponding author).

Several of the questions on the survey ask respondents to evaluate the instructional leadership of school principals. Items in these measures could easily be construed as an evaluation of a principal's performance. We shared results from these items with the principal of each school, allowing him or her to interpret and make use of the data, but we did not allow principals to see results from schools other than their own. We allowed district officials to see only the distribution of results across schools, but did not allow them access to results from any particular school.

The SSSNQ also contains several questions on social networks among teachers within each school. In our experience, social network data can be a valuable tool for engaging school staff in discussions about how the work of leadership and management actually happens in their schools, so we were eager to share results from our survey. Research on organizational social network analysis frequently involves a share-back component, but sharing social network data with participants raises particularly serious concerns about confidentiality [11]. Social network name generators necessarily involve identifying relationships with other individuals, but it is unclear how to consider the confidentiality of relationships involving multiple individuals. For example, if a teacher identifies another teacher as a source of advice, but that teacher has not consented to participate in the research, can that relationship be considered in analysis?

We shared our findings from analysis of the social network data by constructing categories of teachers that were large enough to make it impossible to determine the identity of any individual. Figure 1 is similar to the sociogram depictions used for share-back. Here, circles representing teachers are colored according to the teacher's role, so that there are at least five individuals in any category. Similarly, in quantitative analysis of the network data, we reported averages across categories containing at least five individuals each.

We have observed that, when presented with a sociogram representation of the social network with their school, the immediate impulse of many research participants is to try to put names on each of the nodes. The principals from the Target District proved no different in this respect. While this may seem like a breach of confidentiality, we feel that such activity is speculative at best—the data do not reveal the identities of individual participants, even if they may provoke guessing games. To discourage misinterpretation of the data, we emphasized during our share-back presentation that the social network data, like all survey measures, contain measurement error, and should be interpreted only as a limited representation of relationships within the organization.

Discussion

Our collaborative research project has so far involved determining how the SSSNQ could be used to collect data that would address the goals of the M^2 program, adapting the survey to the local context, administering the survey to all M^2 associates and to the entire staff of ten middle schools, analyzing the data, interpreting the results, and developing methods to share results with some of the participants. Our analysis provides evidence that M^2 associates act as leaders within their schools by providing instruction-related advice to colleagues. Further, we have found evidence that M^2 associates both draw upon and contribute to a support network, the boundary of which is defined by participation in the M^2 program.

Taken together, our findings are an encouraging sign that the M^2 associates are a valuable resource for their schools, building a bridge between their organization and external sources of information and ideas. Research from many different disciplines has demonstrated that access to information from outside of an organizational boundary is beneficial for innovation and productivity [17-19]. By both participating in the M^2 support network and providing advice to other teachers within their schools, the M^2 associates spread the ideas of the M^2 program beyond their own classrooms, acting as instructional leaders within their schools.

However, it is important to recognize the limitations of our findings. As noted above, our research design does not allow us to support causal inferences about the effect of the M^2 Institute Partnership program. With the exception of the M^2 associates from Cohort IV, all of our data collection took place after the associates had begun their training, so we lack baseline data on the participants. Moreover, M^2 associates are selected via a competitive application process, making it very difficult to determine whether their leadership roles and involvement in the M^2 support network are truly the result of program participation, or are due in part to selection effects.

As a collaborative research project, we hope to make use of the data from the SSSNQ to pursue several further research questions regarding Math in the Middle. Social network analysts have been criticized for focusing entirely on the shape and structural properties of networks while disregarding their relational content, even though the type or quality of relationships is crucial to the validity of any claims about outcomes [20]. In addition to data on the existence of advice relationships among teachers, the SSSNQ also collects information on the topics about which teachers seek advice. We plan to study these data to understand whether M^2 associates are recognized as subject-matter specialists for particular areas of teaching practice, such as creating assessments or working with low-performing students. Such detailed information about the content of advice relationships may help M^2 project staff evaluate and improve their professional development curriculum.

We also plan to use data from a second survey of all M^2 associates, to be conducted during Summer 2008, to better understand the determinants of participation in the M^2 professional support network. Qualitative evidence suggests that participation is influenced by prior relationships, social proximity during M^2 Summer Institute sessions, and cohort membership. A better understanding of these factors would allow M^2 project staff to evaluate aspects of the program design in order to better facilitate participation.

Finally, we plan to extend the collaboration between Math in the Middle researchers and the DLS team by linking analyses of social network data to analyses of student achievement data from these same schools. We will begin to study possible relationships between patterns of leadership and student achievement. Certainly, much remains to be investigated.

Acknowledgment

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THE PENN SCIENCE TEACHER INSTITUTE: A PROVEN MODEL

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Abstract

The University of Pennsylvania's Master of Chemistry Education (MCE) program graduated five cohorts of approximately twenty teachers between 2002 and 2006. One year after the teachers in the last cohort earned their degrees, the Penn Science Teacher Institute (Penn STI) initiated a follow-up study to ascertain if the goals of the MCE program had been sustained. For example, were the teachers incorporating updated content knowledge into their lessons and were their students learning more chemistry? A total of seventy-four of the eighty-two graduates participated in some aspect of this study. Because baseline data were not available for the MCE teachers and their students, baseline data from a comparable group of chemistry teachers enrolled in the first cohort of the Penn STI program and their students were used in some analyses. Among other findings, the data indicate that MCE met its goals: 1) to improve the chemistry content knowledge of its teacher participants; 2) to increase the use of research-based instruction in their classrooms; and, 3) to improve student achievement in chemistry (students of MCE graduates scored significantly higher than the comparison group).

Introduction

The University of Pennsylvania's Penn Science Teacher Institute (Penn STI), a National Science Foundation-funded Mathematics and Science Partnership Teacher Institute for the 21st Century, commenced in 2004 and was based on the Penn Department of Chemistry's Master of Chemistry Education (MCE) program. Although the MCE program began in 1999 and continues today as part of the Penn STI, a follow-up study of graduates of the first five cohorts was conducted only recently [1]. The resulting evidence demonstrates the success of professional development that is sustained, rigorous, and content based. Figures and tables within this paper come directly from the *MCE Follow-up Report*. As a result, most conclusions, summaries, and discussions are also from the *Follow-up Report*. This article presents both an overview of the Penn STI and a summary of results of the *MCE Follow-up Report* that will be of interest to

scientists, science educators, and science teachers, especially those who have been involved with NSF's Teacher Institutes.

Overview of Penn STI

The fundamental hypothesis the Penn STI carried forward from the MCE program is that increasing the content knowledge of science teachers, while simultaneously helping them change their classroom practice to a more research-based approach, will increase student learning of and interest in science. This hypothesis drives the Institute structure and evaluation.

The Penn STI structure for increasing science teacher content knowledge is based upon two, 10-course master's degree programs, The Master of Integrated Science Education Program for teachers of middle school science and The Master of Chemistry Education Program for high school science teachers. Both of these programs have common features, such as: 1) cohorts of twenty teachers; 2) eight science/chemistry content courses and two science/chemistry pedagogy courses; and, 3) courses taught over three consecutive summers and during the two intervening academic years. In addition, teacher participants in both programs take two courses during the academic year and in the summer. The specific placement of the two pedagogy courses during the academic years, when teachers are in their classrooms, is also common to both programs. The sixteen content courses were specifically designed by the Penn instructors to meet the needs of in-service science teachers. This is *not* an audience with which a Penn science instructor is familiar. As a result, each course has undergone several iterations before finding the appropriate combination of content depth and breadth.

The placement of the pedagogy courses during the academic year is an important part of the structure that enables the Penn STI to help teacher participants transform their classroom practice. Another strategy used by the STI to affect change in classroom practice is for Penn instructors to utilize instructional approaches in STI science content courses that they do not regularly use in their undergraduate/graduate science courses. To facilitate this change, each program's instructor team meets monthly during the academic year with STI staff and evaluation personnel. In these meetings, the instructors learn about reform-based classroom practices through reading and discussing journal articles, as well as through sharing experiences. This practice results in instructors iterating instructional approaches in their STI courses as they become more cognizant of, and comfortable with, reform-based teaching practices. However, some instructors are more open to using the new instructional practices than others.

The evaluation of the Penn STI is a complex one, collecting baseline, annual, and post-program data on each aspect of its fundamental foci: teacher content knowledge, including teacher understanding of the nature of science; teacher classroom practice; student attitudes toward science; and, student content knowledge. Although similar data were not available for the first five MCE cohorts, instruments used in the external evaluation of the Penn STI were appropriate for the MCE follow-up study. For this reason, Ohio's Evaluation and Assessment Center for Mathematics and Science Education (E & A Center), which conducts the Penn STI external evaluations, was selected to do the post-hoc evaluation of the MCE program.

Methods

The MCE follow-up study employed a mixed methods approach utilizing two instruments developed by the E & A Center and currently used in its evaluation of the Penn STI. The E & A Center's Teacher Questionnaire provided quantitative data on teachers' views of their own classroom practices, while the Student Questionnaire provided data on students' views of those practices. The Penn STI had developed a high school student chemistry concept test for the STI evaluation, and that test provided data on student learning. The program director and internal evaluators at Penn developed an on-line survey for the MCE follow-up study that provided demographic data and, through open-response questions, was a rich source of qualitative data. The on-line survey also provided information concerning teacher content knowledge; that is, teacher perceived benefits of the MCE courses and the use of new content knowledge in their teaching. The survey also provided insights into teacher leadership and collegial collaboration.

Although baseline data on classroom practices and student achievement were not available for the five MCE cohorts, a proxy was available in the baseline data from the first three cohorts of high school teachers in the Penn STI MCE Program (MCEP), a group of teachers with similar demographics to those of the MCE Cohorts I-V. Penn had contact information for eighty-one of the eighty-two MCE graduates. Sixty graduates returned the Teacher Questionnaire and 57 completed the on-line survey. Overall, seventy-four of the eighty-two graduates participated in some aspect of the data collected for the follow-up study.

Findings—Classroom Practice

Proxy baseline data were gathered utilizing the E & A Center's Teacher Questionnaire, administered pre-participation to MCEP participants and post-participation to MCE Cohorts I-V graduates. The two figures below show items from the teaching/learning subscales where there were significant differences using *t*-test comparisons.

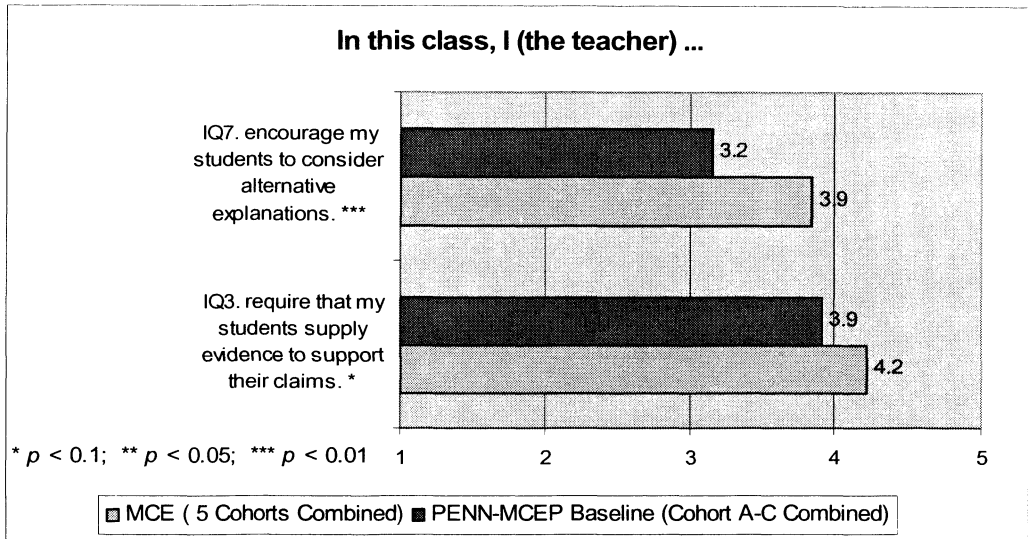


Figure 1. Mean scores for teachers' responses on teacher classroom behaviors subscale: MCE follow-up and MCEP baseline data [1].

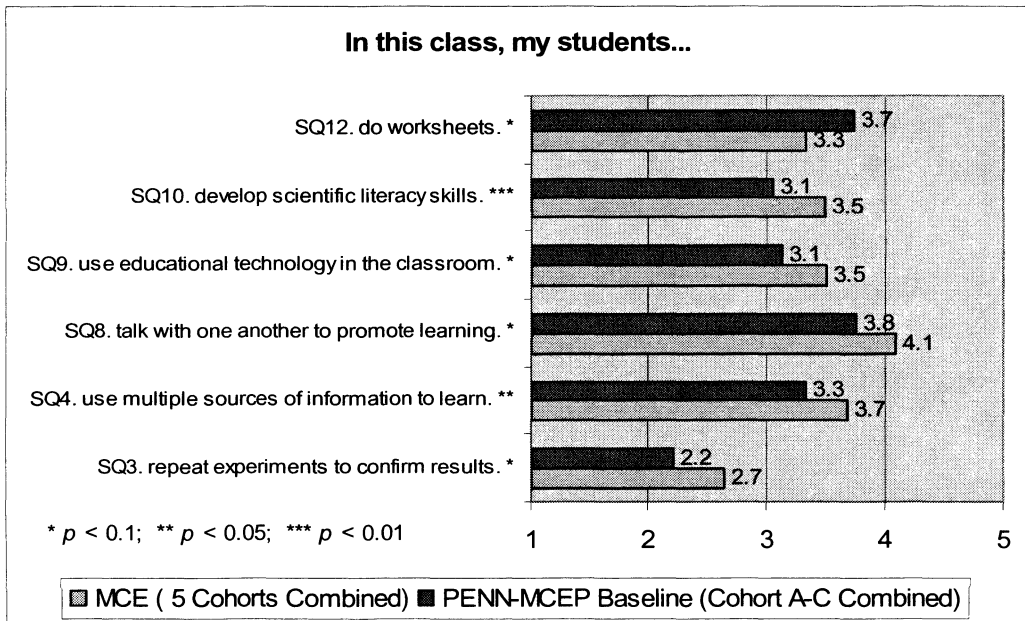


Figure 2. Mean scores for teachers' responses on student classroom behaviors subscale: MCE follow-up and MCEP baseline data [1].

Figures 1 and 2 illustrate that the frequency of use of reform-based teaching/learning strategies was higher for the MCE graduates when compared to a comparable group of teachers before their participation in the MCEP. This analysis suggests that the MCE program transformed teaching/learning strategies employed by its graduates toward ones commonly accepted to enhance student learning in science [1].

Because the Teacher Questionnaire provides self-reported data, the E & A Center's Student Questionnaire was used to assess for self-report bias. The classroom behaviors subscale of the Student Questionnaire contains items paralleling those on the teaching/learning subscale of the Teacher Questionnaire. Statistical analysis was not done on the paired items because different questionnaires were used; however, for the purpose of comparison, the means of similar items are shown in Figures 3 through 5. In each Figure, the wording following the item number is from the Teacher Questionnaire while the wording in parentheses is from the Student Questionnaire [1].

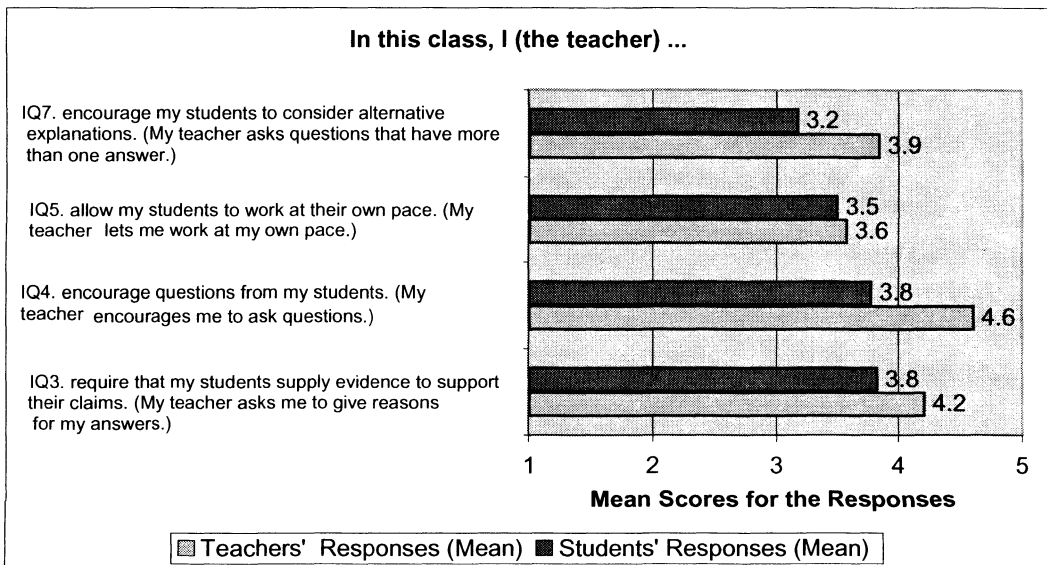


Figure 3. Mean scores for teachers' and students' responses on teacher classroom behaviors subscale [1].

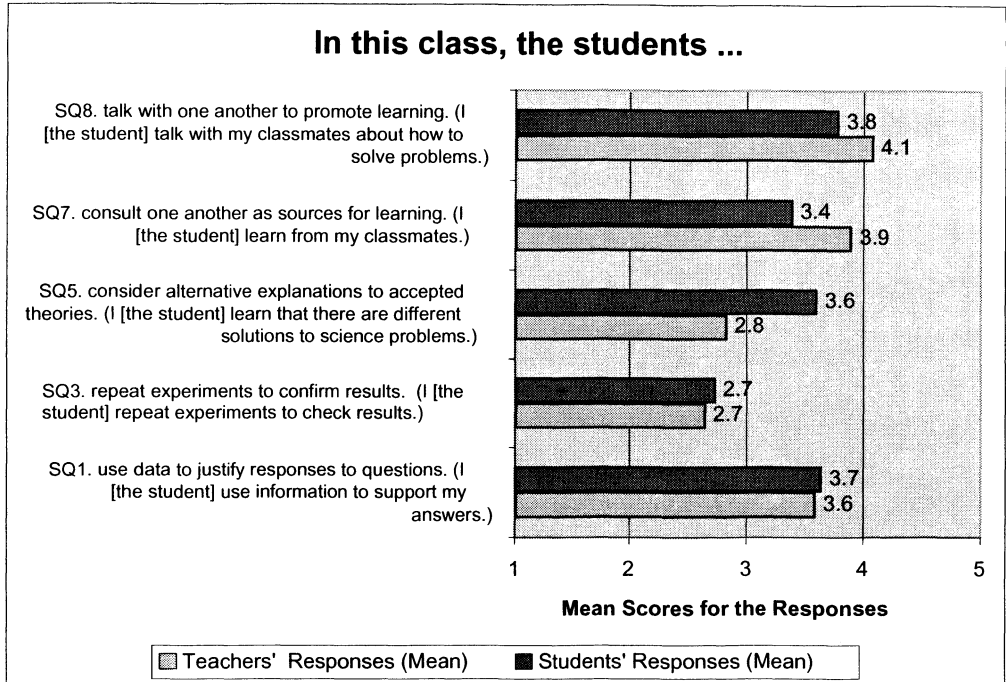


Figure 4. Comparison of scores for teachers' and students' responses on student classroom behaviors subscale (inquiry-based learning activities) [1].

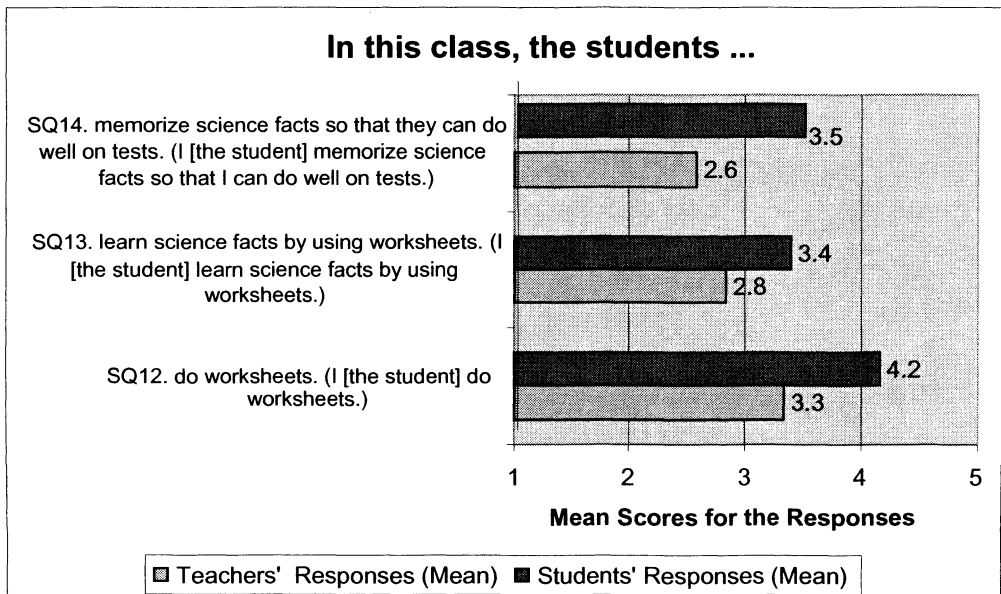


Figure 5. Comparison of scores for teachers' and students' responses on student classroom behaviors subscale (traditional learning activities) [1].

For both subscales, teacher and student views differed for several items. However, on the teacher classroom behaviors subscale (see Figure 3), both students and teachers generally agreed that MCE graduates allowed their students to work at their own pace and required their students to support claims with evidence. On the inquiry-based learning activities subscale (see Figure 4), agreement between students and teachers indicated that, in classrooms of MCE graduates, students consulted one another to help their learning, repeated experiments to confirm results, and used data to justify responses to questions [1]. As expected, students, compared with teachers, responded that they experienced more use of traditional activities (memorization and worksheets) as shown in Figure 5.

The on-line survey provides additional insights on changes in classroom practices through a series of questions on the use of instructional strategies before and after participation in the MCE program. In the following three figures, the instructional strategies from the on-line survey have been grouped for ease of interpretation: strategies recommended by the *National Science Education Standards* (see Figure 6), traditional teaching strategies (see Figure 7), and strategies that did not change (see Figure 8) [2]. Each figure illustrates the number of teachers reporting use of the strategy before and after MCE participation. Although fifty-seven teachers responded to the on-line survey, not all answered each question, resulting in variations in the numbers of responses.

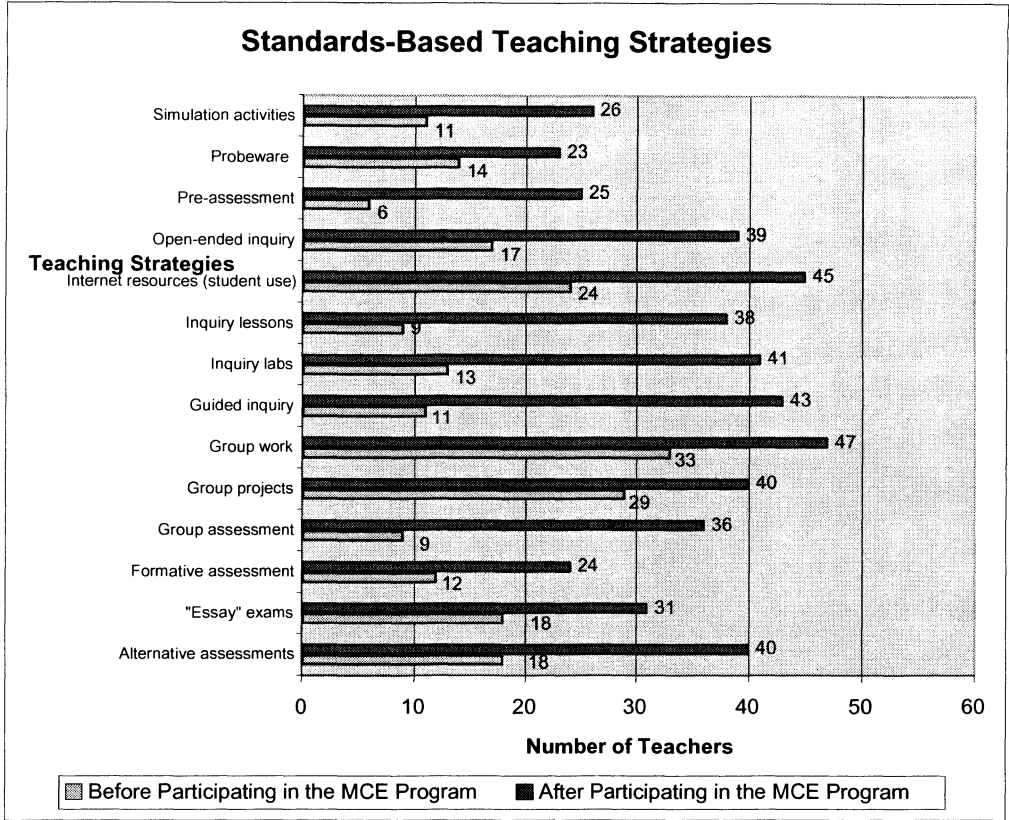


Figure 6. Use of standards-based teaching strategies before and after participating in the MCE program [1].

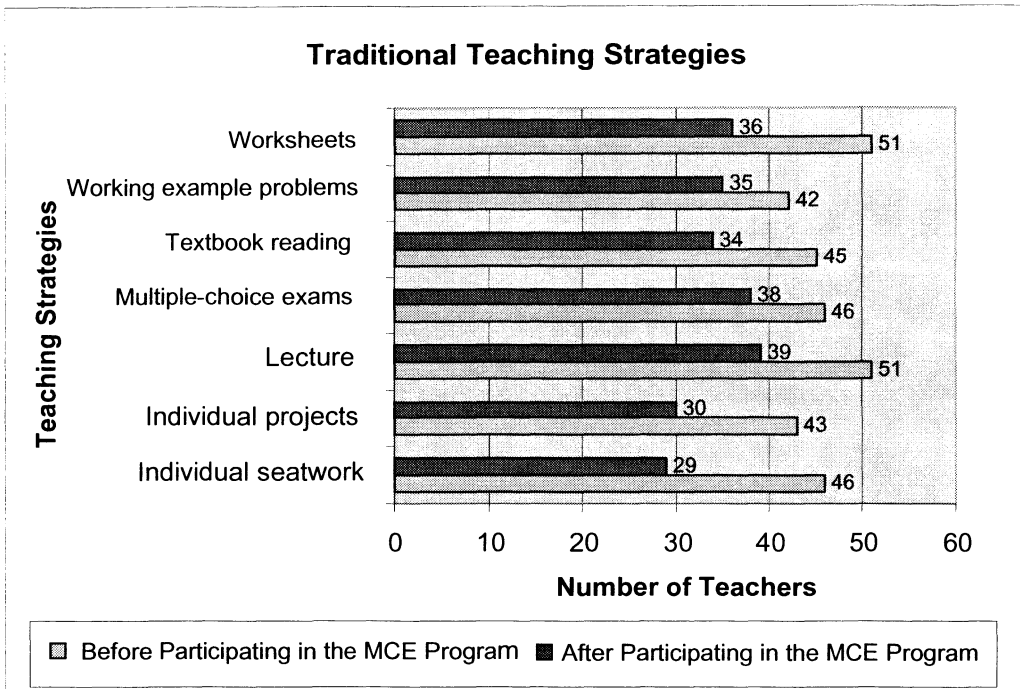


Figure 7. Use of traditional teaching strategies before and after participating in the MCE program [1].

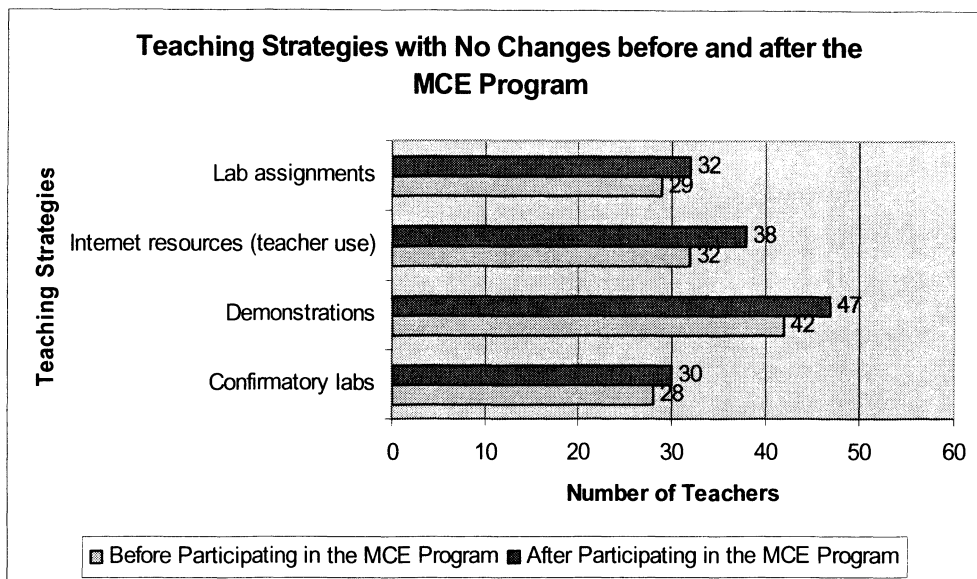


Figure 8. Teaching strategies with little or no changes before and after participating in the MCE program [1].

Figures 6 and 7 taken together indicate teachers believe that, after MCE participation, they have dramatically increased their use of inquiry, group activities, technology, and non-traditional assessment strategies while decreasing their reliance on many traditional instructional and assessment strategies. In Figure 8, where less dramatic changes are seen, strategies are those that are commonly associated with laboratory science classrooms, and therefore would be less likely to change given the nature of high school chemistry curricula [1].

The open-ended response sections of the on-line survey provided additional insights into pedagogical knowledge gained through the MCE program. Eighteen percent of respondents listed the “importance of small groups” while “PIM’s,” “POGIL’s” and “various forms of inquiry” were reported by 16%, 11% and 5%, respectively. The “Penn Inquiry Model” (PIM) is an inquiry teaching-learning model developed for the Master of Chemistry Program in 1999. It is based on how research scientists carry out their research, and was developed for the purpose of helping Penn instructors understand the meaning of “inquiry” as used in science education [3]. The acronym “POGIL” is used to describe “Process Oriented Guided Inquiry Learning” [4]. Both small group collaboration and inquiry teaching and learning strategies are stressed in all

MCE content and pedagogy courses. Pedagogy gained through MCE and reported in tables F7 and F8 in the *Follow-up Report* as being implemented in their classrooms included: “use of inquiry” (32%), “group work” (26%), “the three levels of representation” (14%), and “new assessment tools” (12%) [1].

These selected quotes from the MCE *Follow-up Report* further illustrate the pedagogical learning experienced by teachers:

- “Professor A and Professor B used the Penn model for group instruction and discussion. The small group environment was beneficial because it allowed for several responses to the same question... The small group discussion, for me, reduced my misconceptions and improved my development of a concept.” [Teacher #16; Cohort II]
- “Many of the professors modeled pedagogy. Inorganic was low-tech in the demonstration examples. Organic showed me how to use concept maps critically and also elicit feedback from students. Incorporation of technology needed not only to be shown, but practiced, and I do this with my students as well.” [Teacher #38; Cohort V]
- “Inquiry has been the biggest influence. It is a heavy part of the way I teach—through labs... students almost always develop their own procedures and decide on appropriate data collection...” [Teacher #6; Cohort IV]

Findings—Timing of Change in Classroom Practice

The on-line survey also questioned the timeline during which teacher graduates implemented changes in their classrooms. Most teachers (30%) reported that they began to implement change in their classroom practices during the first school year after their initial summer of MCE coursework, some within the first semester (21%). Quotes from this survey provide additional insights into the implementation timeline:

- “I started to use more inquiry and group work after my first summer of the program.” [Teacher #35; Cohort III]
- “It started after the first summer of courses, but was most significant after the conclusion of the courses when there was more time for implementation.” [Teacher #60; Cohort II]

Findings—Student Achievement

Because MCE Cohorts I-V had not been asked to provide baseline data on student achievement in chemistry, proxy data from students of the first three cohorts of high school teachers in the Penn STI Program (MCEP) were used. These data were gathered from the students of MCEP teachers prior to the teachers starting the Penn STI, and they were drawn from responses to the Penn STI-developed chemistry concepts assessment. This assessment also was

administered to students of volunteer graduates of MCE teacher Cohorts I-V. The analysis of student achievement scores is shown in Table 1.

Table 1
Mean Percentage for Achievement: MCE and MCEP Students

Project	N	Mean	Std. Dev.	df	t-value	p-value
	32					
MCE	8	41.37	19.38	600	5.65	<0.001
MCEP Baseline	34					
Data	2	33.92	14.28			

* Table from the MCE *Follow-up Report*.

As the MCE *Follow-up Report* states: “It must be noted that the [student] groups may not be comparable. However, there is a significant difference in favor of the MCE [graduates] group, suggesting that participation in the MCE program can enhance the chemistry achievement of students of participating teachers” [1].

Teacher Content Knowledge

Teacher participants in MCE Cohorts I-V were not administered a pre-/post-program chemistry content knowledge examination, as is now done in the MCE Program (MCEP) of the Penn STI. As a result, no quantitative data were available on teacher chemistry content knowledge for the follow-up study. However, teachers were queried through the on-line survey on what they perceived as the benefits of their new content knowledge and how they utilized it in their classrooms.

Both “Greater in-depth knowledge of concepts” and “Broader understanding of concepts” were listed by 21% of respondents as shown in Table F3 of the *Follow-up Report*; this was followed by “Expanded general knowledge of concepts” (12%) as benefits of their MCE participation [1]. Teacher classroom use of specific knowledge gained in MCE included “light concepts using spectroscopy” (21%), “environmental science concepts, including global warming” (18%), “periodic table concepts” (14%), and both “orbitals” and “Lewis structures” (12%). Again, quotes from teacher respondents like the following support the finding of enhanced content knowledge by graduates of the MCE program:

- “I feel like I have a better appreciation of how all of it fits together. I also have a better understanding of chemical research that I can convey to my students.” [Teacher #60; Cohort II]

- “Being able to understand the background of many of the chemical concepts that I teach has enabled me to have a sense of a ‘bigger’ picture. This helps me to frame responses to students’ questions.” [Teacher #50; Cohort IV]
- “I was able to give my advanced students a more detailed description of orbital/quantum theory and my average students more accurate analogies of the theory. I used biochem applications in a food chem. unit with my lower students.” [Teacher #9; Cohort III]

Leadership and Collegial Collaboration

One expected outcome of the MCE program, as well as the current Penn STI programs, is that graduates will become Teacher Leaders in their schools and/or districts, working collaboratively with their colleagues to share their new pedagogical and content learning. The on-line survey included questions on leadership activities and such collegial collaborations.

Twenty-one percent of the MCE graduate respondents reported that they were “involved in curriculum discussions/revisions in order to meet state standards,” with 12% reporting that they “mentored new teachers or student teachers” and 9% reporting that they “shared teaching, writing, and reading strategies with faculty.” Additionally, 33% reported the “sharing of content, curriculum, and/or activities with other teachers” (see Tables F10 and F11 in the *Follow-up Report*) [1]. Examples of leadership activities are described in the following quotations from the *Follow-up Report*:

- “I was asked to chair the Professional Development Committee during 2004-5... to co-teach and model lessons... [and] prepare workshops for non-tenured teachers...” [Teacher #5; Cohort I]
- “I was asked to help rewrite the biology and chemistry curriculums for the high school.” [Teacher #37; Cohort III]
- “I find other teachers are willing to try new strategies like POGIL and PIM because of the MCE program and my involvement.” [Teacher #59; Cohort V]
- “The members of my department who know that I completed MCE will often ask me content-based questions that they think I will be able to answer with more insight than they have into certain areas of chemistry. I also let members of my department know that I can be used as a resource for developing their curriculum as well. Younger teachers in my department will often come to me with questions about curriculum and classroom management.” [Teacher #32; Cohort II]

Conclusion

Data gathered for the *Follow-up Report* provide strong indications that the Penn STI program model is effective in changing classroom practices toward more frequent use of research-based strategies and that those changes begin *during* a teacher's involvement in the program. The program structure places pedagogical courses during the school year, following a summer in which teacher participants have experienced inquiry strategies as *students*, often discovering that those strategies enhance their own learning. In all, the Penn STI and its precursor provide an effective model of initiating timely change in classroom practice. Further data from the *Follow-up Report* provide initial evidence that student learning may be increased as a result of a teacher's participation in sustained, rigorous, content-based professional development, the model used in the MCE and STI programs at the University of Pennsylvania.

Changes in teacher content knowledge in the *Follow-up Report* are self-reported and largely qualitative. However, the evaluation report (*University of Pennsylvania Science Teacher Institutes—Year 4*) provides quantitative data of pre-/post-program increase in teacher chemistry content knowledge [5]. These data confirm significant content gains by teacher participants over the twenty-six months of participation. In addition, the examples provided by on-line survey respondents on their level of leadership and collegial collaboration suggest that the Penn STI model meets its goal of graduating Teacher Leaders for schools and districts.

Lessons Learned—Future Plans

The Penn STI, which is based on the MCE program, has added several new structures as a result of “lessons learned” from its precursor, the MCE program. The extensive quantitative data included in the STI external evaluation are the most significant examples. The Penn STI Year 4 evaluation report contains substantial evidence that the Penn STI is successful in attaining positive outcomes, such as increasing teacher content knowledge, changing classroom practices to more research-based ones, and increasing student interest in and knowledge of science [5].

It is the intention of the Penn STI to make further use of the MCE *Follow-up Report* data, only part of which has been summarized here, as well as to seek further funding to continue the longitudinal study of both groups of teachers (chemistry and middle school science) in the Penn STI. Only through rigorous, multi-year studies that include both quantitative and qualitative data can we hope to understand adequately the wide range of teacher needs, teaching situations, and career trajectories. This will help determine appropriate and necessary program structures that

will enhance learning of science for all students. Certainly gaining this knowledge is also a goal of the National Science Foundation, and specifically, their Teacher Institutes for the 21st Century.

Acknowledgments

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OREGON MATHEMATICS LEADERSHIP INSTITUTE PROJECT: EVALUATION RESULTS ON TEACHER CONTENT KNOWLEDGE, IMPLEMENTATION FIDELITY, AND STUDENT ACHIEVEMENT

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Abstract

The Oregon Mathematics Leadership Institute (OMLI) National Science Foundation Mathematics and Science Partnership project partners are Oregon State University, Portland State University, Teachers Development Group, and ten Oregon school districts. The primary activities of the project were a sequence of three intensive three-week residential institutes emphasizing mathematics content knowledge for teaching, collegial leadership, and the building of Professional Learning Communities. Teachers at all levels of grades K-12 participated together in the mathematics content courses. By the conclusion of the third Summer Institute, teachers had shown significant improvements in mathematical content knowledge for teaching. Analysis of student achievement data in participating schools was initially inconclusive. However, once implementation fidelity traits were taken into account, a positive relationship between project participation and student achievement emerged. The degree to which schools implement the practices promoted by the OMLI project is a significant positive predictor of student performance above and beyond what can be explained by the socioeconomic factor as indicated by the percentage of students who qualify for the free and reduced lunch program. This relationship is particularly acute at secondary levels, but additional factors appear to be at play at elementary grade levels.

Introduction

The Oregon Mathematics Leadership Institute (OMLI) is a five-year project funded by the National Science Foundation under the Mathematics and Science Partnership program with additional federal funding provided through the Oregon Department of Education. The OMLI is a partnership between Oregon State University, Portland State University, Teachers Development Group, and ten Oregon school districts: Beaverton, Bend-LaPine, Crook County, Molalla River, North Clackamas, Redmond, Reynolds, Roseburg, South Lane, and Woodburn. These school districts include both rural and urban settings, a wide range of socio-economic student backgrounds, and one district with a majority of students classified as English Language Learners

(ELL). Some of the partner school districts themselves have provided additional funding to expand participation in the OMLI project.

The unit of participation in OMLI is a School Leadership Team, ideally consisting of two teachers and one school administrator, usually the principal of the school. The project has approximately 180 teachers (90 from grades K-5, 60 from middle school grades 6-8, and 30 from high school grades 9-12) and 95 administrators participating across the ten partner districts. The Oregon Mathematics Leadership Institute (OMLI) works to build collaborative Professional Learning Communities within the participating schools through a series of intensive summer institutes and academic year follow-up professional development activities for teams of teachers and administrators.

Participating teachers attended three, 3-week residential Summer Institutes during three consecutive summers (2005, 2006, and 2007). The participating administrators attended the third week of each of the three Summer Institutes. These Summer Institutes included mathematics content coursework across six strands: numbers and operations, algebraic structures, measure and change, geometry, data analysis and probability, and discrete mathematics. The mathematics content coursework was complemented by leadership development coursework.

Academic year activities facilitated the ongoing development of collaborative Professional Learning Communities (PLC's) within each participating school. These activities will continue at least through the 2008-09 academic year, and are intended to promote and sustain systemic mathematics reform to increase student achievement in mathematics.

Description of the OMLI Summer Institutes

Participants were housed on the Oregon State University campus and Institute classes were held in a middle school near the campus. The typical schedule for the Institute involved teachers attending two, 2-hour mathematics classes in the morning with a two-hour study session and a two-hour Collegial Leadership workshop in the afternoon. Approximately sixty teachers each were enrolled in a "triad" of courses consisting of a pair of mathematics courses and the Collegial Leadership workshop. Hence, all 180 teachers would have participated in all six mathematics content strands and three Collegial Leadership workshops by the conclusion of the third Summer Institute in Summer 2007. The six mathematics content strands are paired as follows: 1) *Numbers and Operations* and *Geometry*; 2) *Data and Chance* and *Discrete Mathematics*; 3) *Algebraic Structures* and *Measurement and Change*.

Using the Conference Board of the Mathematical Sciences recommendations for the preparation of teachers, OMLI mathematics instructors chose depth in a few “big idea” topics rather than attempting to address many topics [1]. In each content course, there was an explicit emphasis on student discourse and faculty were expected to model many of the pedagogical techniques used in K-12 classrooms that are the focus of the Collegial Leadership workshops in the afternoons.

During one of the afternoon periods, teachers participated in a facilitated “study hall” with mathematics content faculty available for assistance. During the other period, teachers participated in a Collegial Leadership workshop facilitated by staff from the Teachers Development Group. Approximately ninety teachers participated in study hall in the first afternoon session while the other ninety teachers participated in the Collegial Leadership workshops. During the second afternoon period, these two groups of teachers switched. In the third week of the Summer Institute, participating principals attended Collegial Leadership workshops in the morning while teachers were attending mathematics content classes. During the afternoons of the third week, principals had opportunities to work together in a team with the teachers from their schools to develop school action plans for professional development during the upcoming academic year.

A unique feature of the OMLI Institutes was that teachers from all K-12 grades participated together in the mathematics content courses. This was a conscious choice made to stimulate interaction among teachers from elementary, middle, and high schools in the same district and to give all teachers a better sense of the “trajectory” of a mathematical idea across the entire K-12 curriculum. To be sure, this choice placed unusual challenges on our mathematics content faculty. The OMLI mathematics content courses included explorations and tasks that could be approached at several levels of sophistication. This allowed all teachers in the course to initially engage together in an activity while still affording opportunities for teachers with *different backgrounds* to employ their existing knowledge bases. The use of new or unfamiliar mathematical settings also served to “level the playing field,” in the sense that tasks were provided that teachers at all levels could approach as fresh.

For example, *Geometry* focused on some non-Euclidean models for spherical geometry and the taxicab metric to foster insights into Euclidean geometrical properties. *Data and Chance* made extensive use of the software *TinkerPlots™*, something new to virtually all of the teachers. *Algebraic Structures* used a case study of a third grader’s conjecture to launch a far reaching investigation that ultimately involved elements of group theory. *Measure and Change* included extensive activities with non-standard units. The *Numbers and Operations* course examined

connections to harmonics in music. Not surprisingly, many of the topics of *Discrete Mathematics* were new to most of the teachers at all grade levels.

During Collegial Leadership workshop activities, the Collegial Leadership team draws heavily on the latest nationally recognized, evidence-based mathematics professional development and leadership development resources, such as: *Designing Professional Development for Teachers of Science and Mathematics*; *Learning and Teaching Linear Functions: Video Cases for Mathematics Professional Development, 6-10*; *Learning to Lead Mathematics Professional Development*; *Fostering Algebraic Thinking: A Guide for Teachers, Grades 6-10*; *Developing Mathematical Ideas*; *Children's Mathematics: Cognitively Guided Instruction*; and, *Lenses on Learning* [2-8]. Team members modeled and emphasized “best” instructional practices and curricula based on the NCTM’s *Professional Standards for Teaching Mathematics*, and provided extensive instruction and mentoring to School Leadership Teams for effective job-embedded, practice-based professional learning (e.g., lesson study, protocol-based collegial observations and examinations of student work, case discussions and development, book studies, etc.) [9].

Description of the OMLI Site Visits

Site visits to participating OMLI schools involved a minimum of a half-day site visit per school, with four site visits each year per school. These site visits are designed to meet the following goals:

- 1) Support School Leadership Teams for implementation of their Collegial Leadership Action Plans, which were crafted by the teams during the 2007 Summer Institute to initiate and sustain school-based collaborative Professional Learning Communities that center on mathematics content, learning, teaching, and leadership; and,
- 2) Support continued learning by the OMLI participants and their school colleagues through first-hand experiences with practice-based professional learning facilitated by OMLI faculty.

While a major focus of work in the schools centered around deepening the quality of mathematical discourse in classrooms through collaborative lesson planning, observation, and reflection about lessons, the following are other specific site visit activities designed to support learning for effective lesson design and implementation:

- Data snaps (classroom walk-throughs) to gather data as context for professional dialogue and making inferences regarding what typifies mathematical discourse across the school;
- Case discussions (video and print);
- Extended classroom observations and inference dialogue based on Teachers Development Group's Student Discourse Observation Protocol and Collaborative Lesson Planning Protocol (designed to support teachers in moving classroom discourse along a continuum from a focus on procedures and facts to a focus on justification and generalization);
- Consultation regarding implementation of school mathematics curriculum materials;
- Co-facilitation (with OMLI participants) of school-based professional development and district meetings;
- Coaching OMLI participants in leading the district site visit meetings; and,
- Facilitating and/or coaching the facilitation of the examination of student work by OMLI participants and/or their building colleagues.

In addition to site visits, OMLI site visit faculty members facilitate four half-day district meetings throughout the academic year in each district. During these meetings, all participating OMLI teachers and administrators from a district come together to share their successes and challenges, to plan for districtwide expansion of OMLI, and to continue learning together by examining student work, discussing professional readings, planning collaborative lessons, and analyzing and enhancing mathematical tasks, as well as other activities such as those in the list above.

District Leadership Teams worked with Collegial Leadership/Site Visit Support Teams to identify specific needs and to coordinate site visits. The District Leadership Teams conducted regular meetings during the academic year with the School Leadership Teams. School Leadership Teams (SLT) were expected to actively increase the quantity and quality of school-based collegial inquiry and discourse about mathematical and pedagogical content by planning and facilitating regular academic year meetings of building colleagues, and using and facilitating practice-based professional development activities, such as classroom observations and collaborative examinations of student work.

OMLI Project Evaluation Research Results

The figure below diagrams the Research Logic Model for the OMLI project.

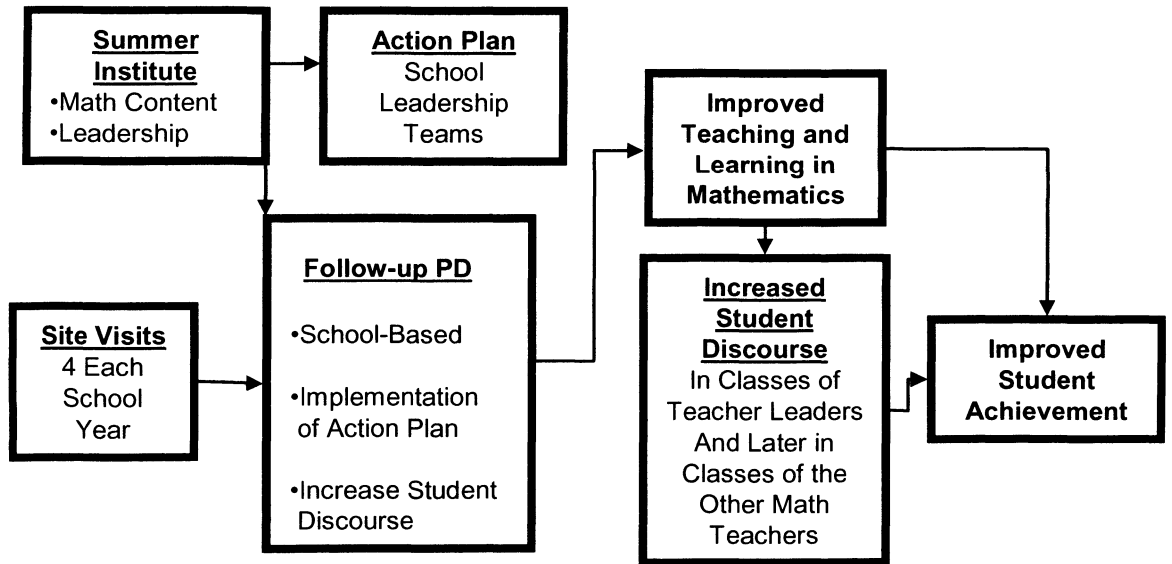


Figure 1. Oregon Mathematics Leadership Institute Partnership Research Logic Model.

The inputs to this Model are the activities and support provided by the project—namely, the series of intensive Summer Institutes followed up by the academic year site visits by project staff. The action plans developed by School Leadership Teams during the Institute were intended to shape the professional development activities in each school. The anticipated outcomes of the Model are the improved teaching and learning in mathematics in the participating schools with a direct emphasis on improving the quantity and quality of student mathematical discourse in classrooms. Ultimately, these intermediary outcomes were expected to result in improved student achievement.

Observation protocols were developed to provide measures of the quantity and quality of mathematical discourse. A report of this research, including the actual discourse observation protocol instruments can be found on the NSF-MSP website [10]. In this report, we wish to address the other two main evaluation research questions implied by the Research Logic Model:

- 1) Has the OMLI professional development prepared the Teacher Leaders for their leadership role in terms of mathematics content knowledge for teaching?
- 2) Has the OMLI project increased student achievement (as indicated by the percentage of students who demonstrate proficiency on the Oregon State Mathematics Assessments for Grades 3, 5, 8, and 10) in all participating K–12 schools?

Mathematical Content Knowledge for Teaching

At the conclusion of each Summer Institute, OMLI staff administered a post-survey of mathematics content knowledge to all SLT teachers. The pre-survey had been administered at the beginning of the 2005 Summer Institute or at the beginning of the first Summer Institute attended (in the case of new SLT teachers). The surveys comprised a series of mathematics problems developed and tested at The Study of Instructional Improvement and the “Learning Mathematics for Teaching Project” at the University of Michigan [11].

There were four versions of the surveys: two versions (A and B) for secondary teachers (middle school and high school teachers in grades 6-12) and two versions (A and B) for elementary teachers (grades K-5). Each group of teachers was randomly divided into two groups. One group completed version A for their respective grade level as the pre-survey and version B as the post-survey. The other group completed the surveys in the opposite order. Each survey included two to three standardized subscales. Raw scores on each subscale for each survey were converted to scale scores (z-scores) using lookup tables provided by University of Michigan staff. Tables 1 and 2 provide the mean scale score growth from pre-survey to post-survey for the overall group.

Both elementary and secondary SLT teachers demonstrated statistically significant gains from the pre-survey to the post-survey administered at the conclusion of the 2007 Summer Institute on the overall score and on all subscales.

Table 1
2007 Secondary SLT Teacher Content Knowledge Results

Scale	Survey	N	M	SD	M Diff	SE	<i>p</i>
Arithmetic and Algebra	Pre-	78	.767	.938	.397	.085	<.001
	Post-	78	1.164	.774			
Geometry	Pre-	78	.889	.554	.192	.063	.003
	Post-	78	1.081	.581			
Overall	Pre-	78	.761	.129	.055	.010	<.001
	Post-	78	.816	.107			

Table 2
Elementary SLT Teacher Content Knowledge Results

Scale	Survey	N	M	SD	M Diff	SE	<i>p</i>
Number Concepts and Operations	Pre-	84	-.100	.891	.343	.085	<.001
	Post-	84	.243	.799			
Geometry	Pre-	84	.228	.780	.479	.068	<.001
	Post-	84	.707	.802			
Patterns, Functions, and Algebra	Pre-	84	.101	.801	.372	.083	<.001
	Post-	84	.473	.807			
Overall	Pre-	84	.644	.155	.077	.010	<.001
	Post-	84	.720	.141			

Note. Statistically significant *p*-values ($p \leq 0.05$) appear in boldface type. Raw scores on each subscale for each survey were converted to scale scores (z-scores) using lookup tables provided by University of Michigan.

This growth in content knowledge can be attributed to the content courses offered at the Summer Institutes. Each Summer Institute participant took two of the six mathematics content courses each summer. The next summer, they rotated and took two more content courses. It wasn't until the 2007 Summer Institute that participants had completed all six courses.

After completing two content courses at the conclusion of the 2005 Summer Institute, teachers demonstrated some growth in their mathematics content knowledge, but the growth was limited to subscales of the assessment that correlated closely to the content of the courses completed by the participants (see Table 3). After completing four of the six courses at the conclusion of the 2006 Summer Institute, teachers demonstrated significant growth in some areas. The secondary teachers demonstrated significant positive growth on the arithmetic and algebra scale, but growth on the geometry scale was not statistically significant. The elementary teachers demonstrated significant growth on the number concepts and operations scale and the geometry scale, but not on the patterns, functions, and algebra scale (see Table 4).

Table 3
2005 Teacher Content Knowledge Results

Grade Level	Standardized Scale	2005 Summer Institute Course			
		Overall Growth	Algebra & Functions Measurement & Change	Data Analysis & Probability Discrete Mathematics	Geometry Number Syst. & Operations
Middle School and High School SLT Teachers					
	Arithmetic and Algebra Scale	0.110	0.382	-0.033	0.012
	Geometry Scale	0.191	0.260	0.112	0.185
	<i>N</i>	82	25	29	32
Elementary School SLT Teachers					
	Number Concepts and Operations Scale	0.138	0.282	-0.020	0.142
	Geometry Scale	0.258	0.338	0.075	0.340
	Patterns, Functions, and Algebra Scale	0.235	0.165	0.312	0.234
	<i>N</i>	90	30	28	33

Note. The data shown in the body of this table represents the change in the mean scale scores for each group of participants from the pre-survey to the post-survey.

Table 4
2006 Teacher Content Knowledge Results

Participant Group/Scale	Survey	N	M	SD	<i>p</i>	M Diff	SE
Secondary SLT Teachers							
Arithmetic and Algebra	Pre-	81	.757	.905	.003	.168	.056
	Post-	81	.924	.855			
Geometry	Pre-	81	.862	.570	.087	.091	.053
	Post-	81	.953	.606			
Overall	Pre-	81	.758	.127	.001	.025	.007
	Post-	81	.783	.122			
Elementary SLT Teachers							
Number Concepts and Operations	Pre-	92	-.010	.883	.003	.214	.071
	Post-	92	.119	.802			
Geometry	Pre-	93	.248	.784	.001	.200	.056
	Post-	93	.448	.742			
Patterns, Functions, and Algebra	Pre-	93	.150	.745	.069	.140	.076
	Post-	93	.290	.815			
Overall	Pre-	93	.647	.150	< .001	.037	.008
	Post-	93	.684	.144			

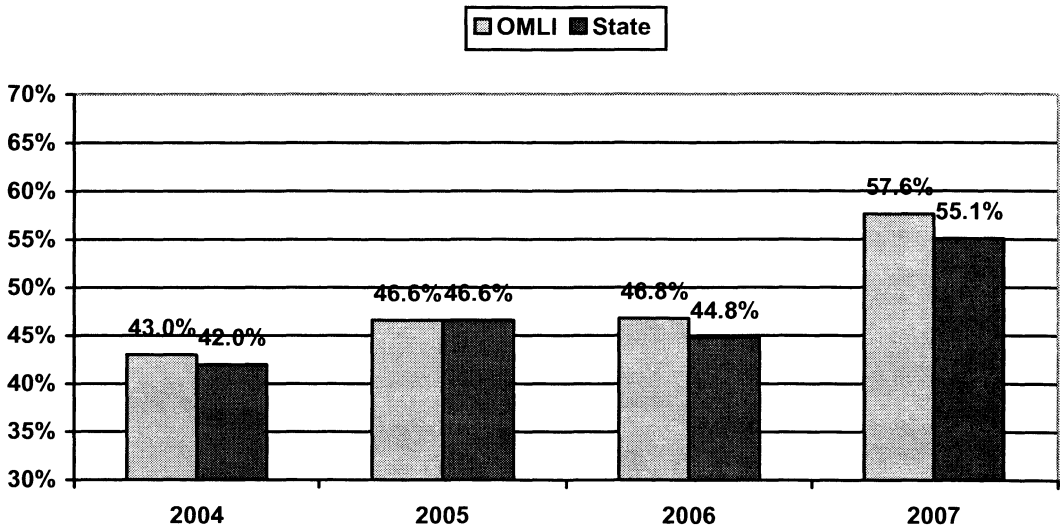
Note. Statistically significant *p*-values ($p \leq 0.05$) appear in boldface type. Raw scores on each subscale for each survey were converted to scale scores (z-scores) using lookup tables provided by University of Michigan.

After completing all six content courses at the conclusion of the 2007 Summer Institute, participants demonstrated significant content knowledge gains overall and on all subscales of the assessment (see Tables 1 and 2).

Analysis of Student Achievement

The school is the primary unit of change for the OMLI project. Thus, the evaluation examines trends in school-level student performance on the mathematics portion of the state assessment for the schools participating in the OMLI project compared to statewide averages. The following series of figures (Figures 2-5) show the percentage of students who met or exceeded the mathematics standard on the Oregon assessment of student performance for students in OMLI schools compared to the State average for each year from 2004 (2003–04 school year) through 2007 (2006–07 school year). All percentages represent the percentage of students who met or exceeded the mathematics standard weighted by the number of students assessed at each

grade level. The 2006 assessment was administered after the first OMLI Summer Institute in 2005 and the 2007 assessment was administered after the second Summer Institute in 2006. Complications with the on-line administration during the implementation of the 2007 assessment makes it difficult to compare the 2007 results with those of previous years. However, comparison of the OMLI schools to the State averages is valid for all years including 2007 because the complications were experienced by all schools in the State.



N = 12

Figure 2. Percentage of grade 10 students who met or exceeded the mathematics standard, 2004 through 2007.

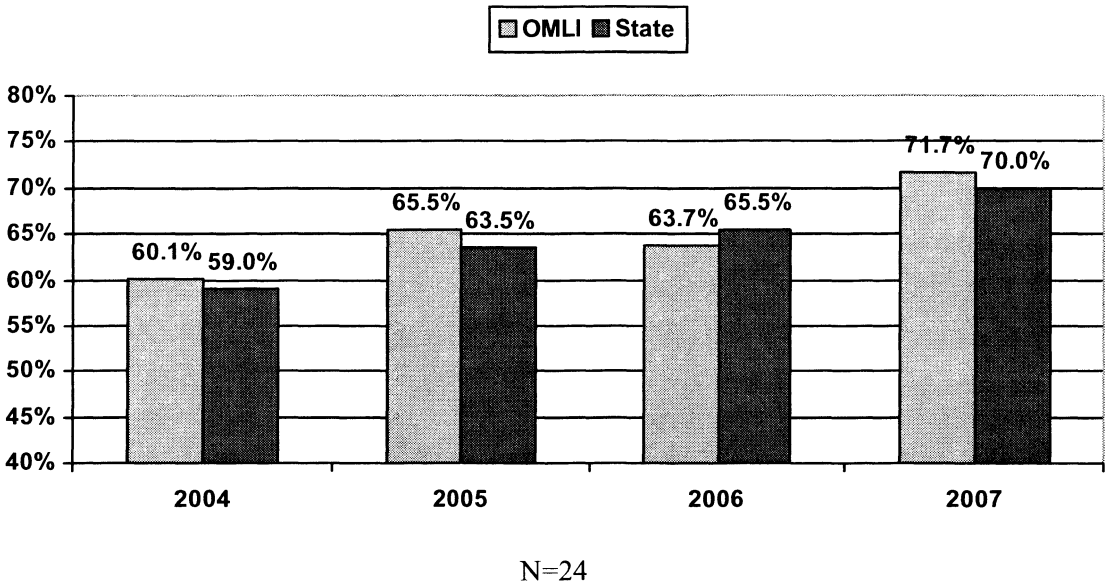


Figure 3. Percentage of grade 8 students who met or exceeded the mathematics standard, 2004 through 2007.

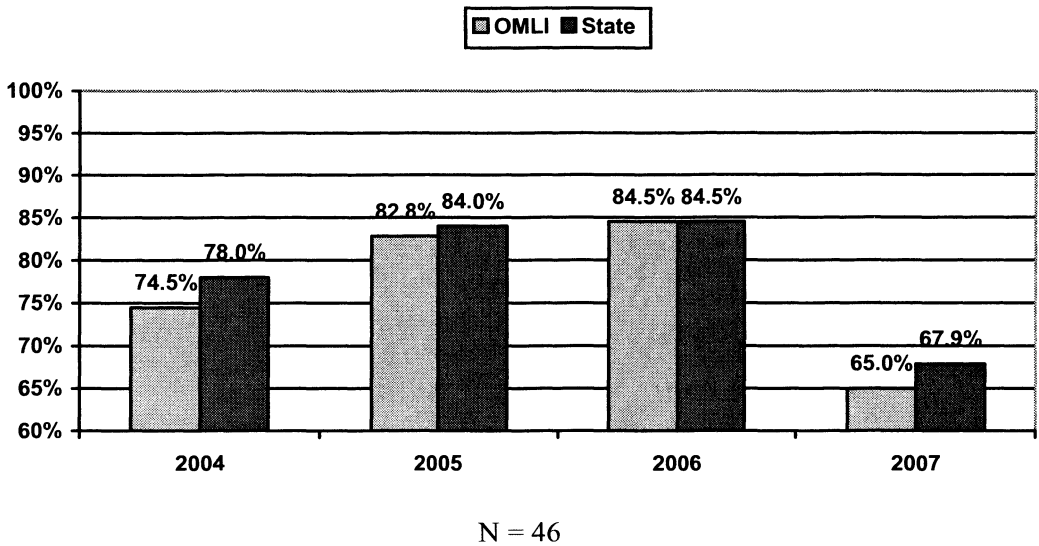


Figure 4. Percentage of grade 5 students who met or exceeded the mathematics standard, 2004 through 2007.

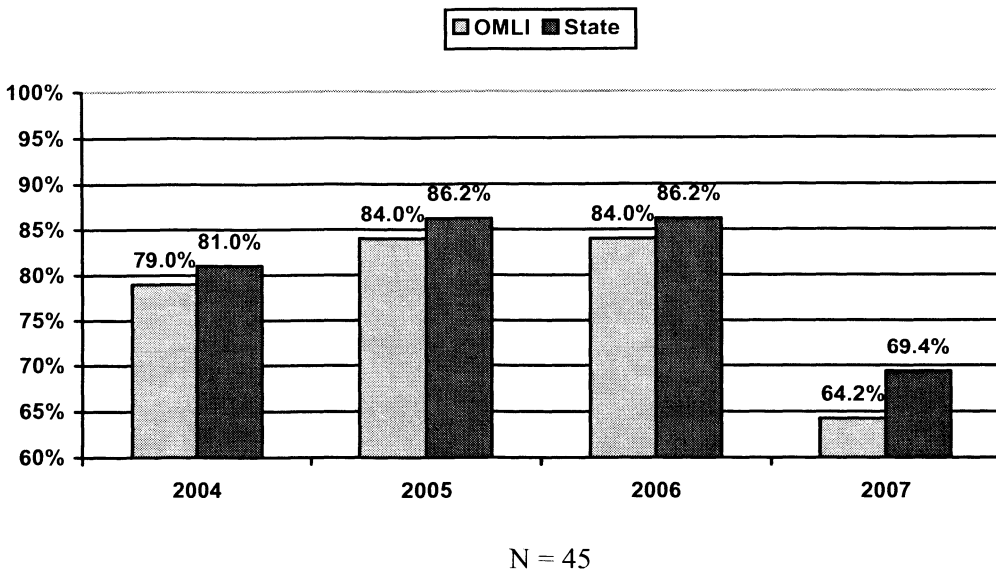


Figure 5. Percentage of grade 3 students who met or exceeded the mathematics standard, 2004 through 2007.

As shown in the graphs, results are inconclusive. The percentage of grades 3 and 5 students in OMLI schools who met or exceeded the standards was lower than the State average while the percentage of grades 8 and 10 students in OMLI schools was above the State average. This led us to revisit the logic model for the project (Figure 1) and note that simply using attendance at the Summer Institutes by participating teachers and administrators did not adequately reflect full participation in the project. This led us to collect information about the degree to which each school actually implemented practices promoted in the OMLI professional development. With input from the site visit staff, RMC Research developed a scoring rubric of thirteen traits for use by the site visit staff to rate the level of implementation of each school as of the end of the 2006–07 school year. The scoring rubric was composed of the following traits:

- 1) Quality of the School Leadership Team's action plan;
- 2) Implementation of the action plan;
- 3) Leadership exhibited by first teacher on School Leadership Team;
- 4) Leadership exhibited by second teacher on School Leadership Team;
- 5) Leadership and engagement exhibited by the school administrator on team;
- 6) Support of the district leadership team;
- 7) School policies/practices supported work of the School Leadership Team;
- 8) Stability of the School Leadership Team (in terms of turnover due to personnel moves);
- 9) School priority for mathematics;

- 10) Professional development responsibilities taken on by School Leadership Team;
- 11) Scope of professional development activities;
- 12) Use of professional learning tasks and protocols used in collegial leadership work;
and,
- 13) Evidence of impact of the professional development on other teachers in the school.

The RMC Research Corporation analyzed the data from each school and identified two sets of five of the thirteen traits that were highly correlated to student achievement on the 2007 state assessment. One set was correlated to student achievement at the elementary level and the other set was correlated to student achievement at the secondary level. The following traits make up the Secondary Implementation Scale (SIS) and are correlated to student achievement in secondary schools (grades 8 and 10):

- Quality of the school action plan for improving mathematics teaching and learning developed by the School Leadership Team during the Summer Institutes;
- How well the School Leadership Team implemented the action plan;
- The degree to which the School Leadership Team conducted regular, school-based professional development with the other mathematics teachers in their school;
- The degree to which the school-based professional development reached all or a critical mass of mathematics teachers in the school; and,
- The degree to which the professional development utilized well-defined professional learning tasks and protocols developed by project staff and modeled during the Summer Institutes.

The following traits make up the Elementary Implementation Scale (EIS) and were correlated to student achievement in elementary schools (grades 3 and 5):

- Leadership qualities of the teachers on the School Leadership Team;
- Whether the School Leadership Team had a second teacher participating;
- The degree to which the school and district policies and practices are supportive of the work of the School Leadership Team;
- The degree to which mathematics is a priority for the school; and,
- The degree to which the professional development utilized well-defined professional learning tasks and protocols developed by project staff and modeled during the Summer Institutes.

In order to calculate the elementary and secondary implementation scale score for each OMLI school, RMC Research used the ratings for each school. The implementation scale score was *calculated* so that “0” represented the lowest possible score on the five traits and “100” represented the highest possible score. The analysis of the data focused on relationships between

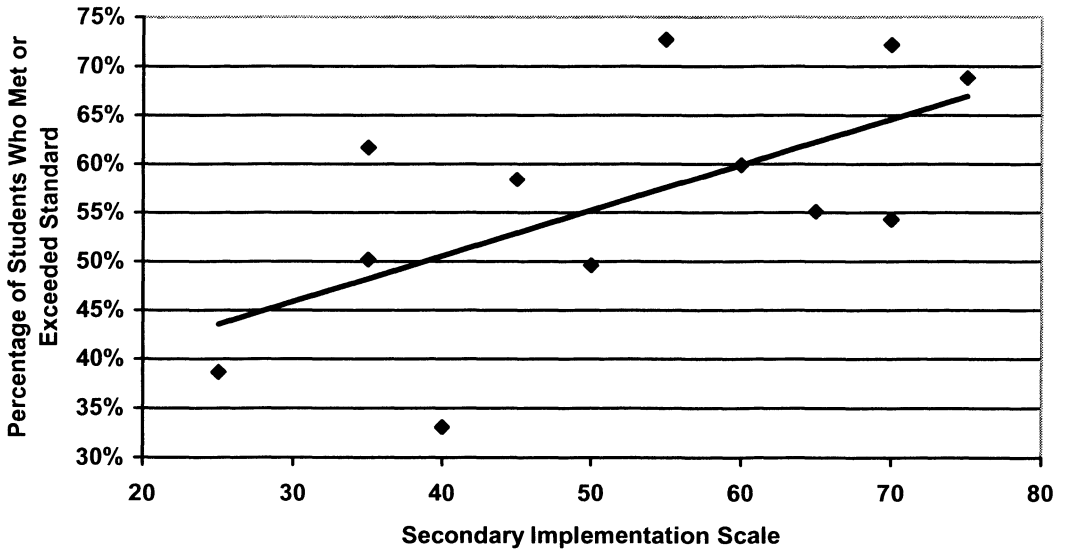
the implementation scale of the OMLI schools and the percentage of students in each school that met or exceeded the standard on the State mathematics assessments.

The RMC Research Corporation also took into account demographic factors such as the percentage of students who qualified for free or reduced price lunch (FRL) (proxy for socioeconomic level of the community), percentage of minority students, and the percentage of students with limited English proficiency (LEP). The percentage of students on FRL was the only demographic factor that had a significant relationship to student achievement. The FRL was used by RMC Research as a control variable in a regression analysis that used the OMLI implementation score as the independent variable and the percentage of students who met or exceeded the standard on the 2007 mathematics assessment as the dependent variable.

A series of graphics (Graphics 1-4) summarize the results of the analysis of student achievement at grades 10, 8, 5, and 3. Each graphic contains four components:

- 1) Scatter Plot—This graph shows the relationship between level of OMLI implementation as measured by either the elementary or secondary implementation scale and the percentage of students who met or exceeded the mathematics standard in 2007 for the respective grade level. Please note that this depicts school-level aggregates and is not weighted by the size of the school.
- 2) Implementation Level Group Bar Chart—Each school was assigned to an implementation level group based on their implementation scale. The RMC Research Corporation calculated the percentage of students who met or exceeded the mathematics standard for all the students in each group, weighted by the number of students who completed the assessment in each school. This bar graph shows the percentage of students who met or exceeded the mathematics standard for each implementation level group.
- 3) Implementation Level Group Data Table—This table contains the data used to plot the preceding bar graph.
- 4) Regression Analysis Results—This series of tables shows the results of the regression analysis of the data. Predictors considered in these models are the percentage of students who qualify for free or reduced price lunch and either the elementary or secondary implementation scale. The dependent variable is the percentage of students who met or exceeded the mathematics standard in 2007, weighted by the number of students in each school who completed the assessment. Noteworthy data is indicated with boldface type.

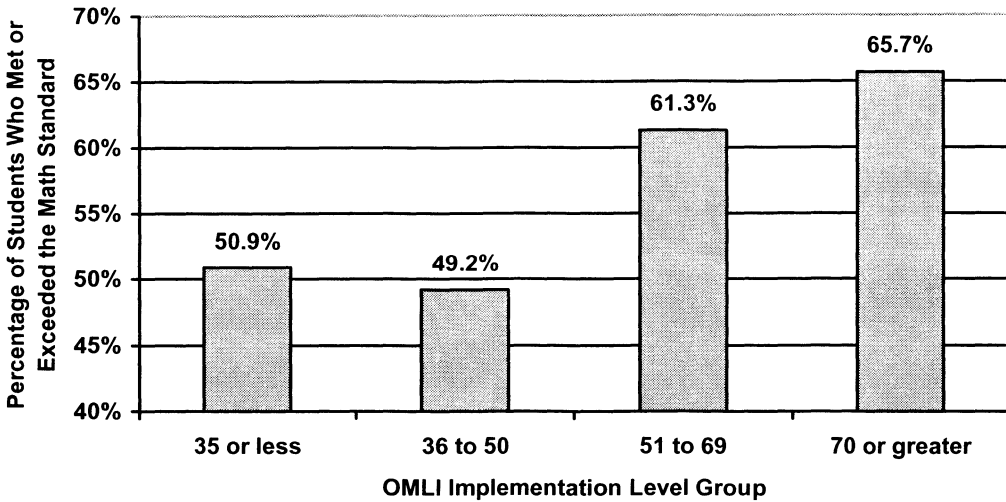
GRAPHIC 1—SCATTER PLOT, Grade 10



N = 12 Schools

Figure 6. Analysis of grade 10 student achievement.

GRAPHIC 1—IMPLEMENTATION LEVEL GROUP BAR CHART, Grade 10



GRAPHIC 1—IMPLEMENTATION LEVEL GROUP DATA TABLE, Grade 10

<i>Elementary Implementation Index Score</i>	<i>Number of Schools</i>	<i>Students Who Met/Exceeded Mathematics Standards</i>	<i>Students Assessed</i>	<i>Percentage of Students Who Met/Exceeded Standard</i>
35 or less	3	331	650	50.9%
36 to 50	3	722	1467	49.2%
51 to 69	3	691	1128	61.3%
70 or greater	3	1011	1539	65.7%

**GRAPHIC 1—REGRESSION ANALYSIS RESULTS, Grade 10
ANOVA Results (b)**

	Sum of Squares	df	Mean Square	F	Sig.
Regression	41.453	2	20.726	6718.445	.000(a)
Residual	14.749	4781	.003		
Total	56.202	4783			

a Predictors: (Constant), Secondary Implementation Scale (SIS), Free or Reduced Price Lunch Percent (FRLP)

b Dependent Variable: Percentage of grade 10 students who met or exceeded mathematics standard in 2007.

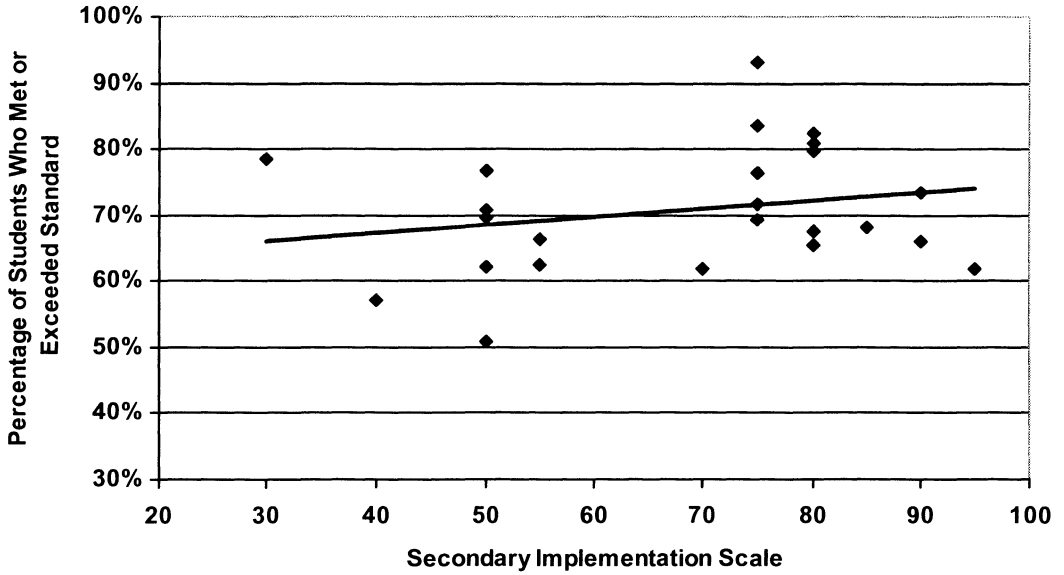
$R^2 = .738$ N = 12 Schools

Coefficients(a)

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.593	.005		123.888	.000
FRLP	-.612	.008	-.664	-79.646	.000
SIS	.002	.000	.320	38.455	.000

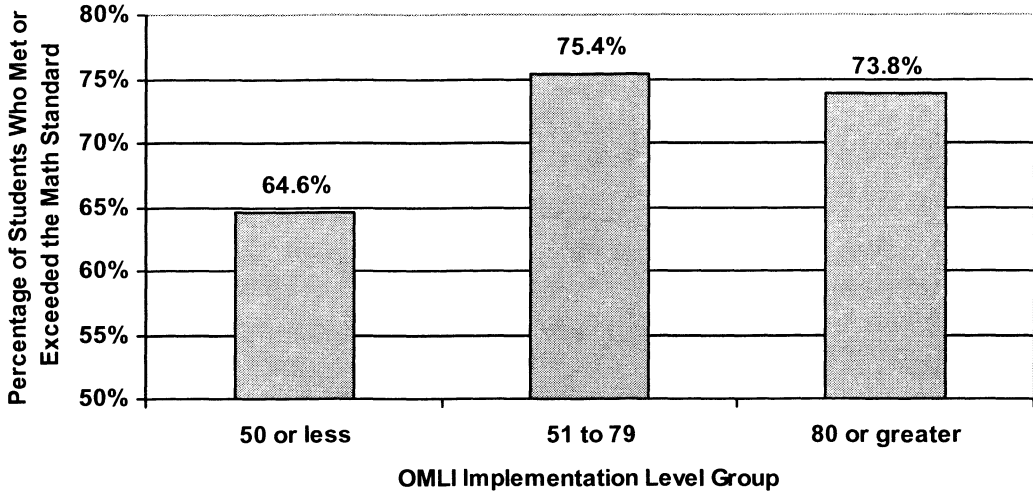
a Dependent Variable: Percentage of grade 10 students who met or exceeded mathematics standard in 2007.

GRAPHIC 2—SCATTER PLOT, Grade 8



N = 24 Schools

Figure 7. Analysis of grade 8 student achievement.

GRAPHIC 2—IMPLEMENTATION LEVEL GROUP BAR CHART, Grade 8**GRAPHIC 2—IMPLEMENTATION LEVEL GROUP DATA TABLE, Grade 8**

<i>Secondary Implementation Index Score</i>	<i>Number of Schools</i>	<i>Students Who Met/Exceeded Mathematics Standards</i>	<i>Students Assessed</i>	<i>Percentage of Students Who Met/Exceeded Standard</i>
50 or less	7	1020	1578	64.6%
51 to 79	8	1513	2007	75.4%
80 or greater	9	1434	1944	73.8%

**GRAPHIC 2—REGRESSION ANALYSIS RESULTS, Grade 8
ANOVA Results (b)**

	Sum of Squares	df	Mean Square	F	Sig.
Regression	30.901	2	15.450	3044.891	.000(a)
Residual	28.040	5526	.005		
Total	58.941	5528			

a Predictors: (Constant), Secondary Implementation Scale (SIS), Free or Reduced Price Lunch Percent (FRLP).

b Dependent Variable: Percentage of grade 8 students who met or exceeded mathematics standard in 2007.

$R^2 = .524$ N = 24 Schools

Coefficients(a)

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.777	.005		154.233	.000
FRLP	-.412	.006	-.652	-68401	.000
SIS	.001	.000	.197	20.651	.000

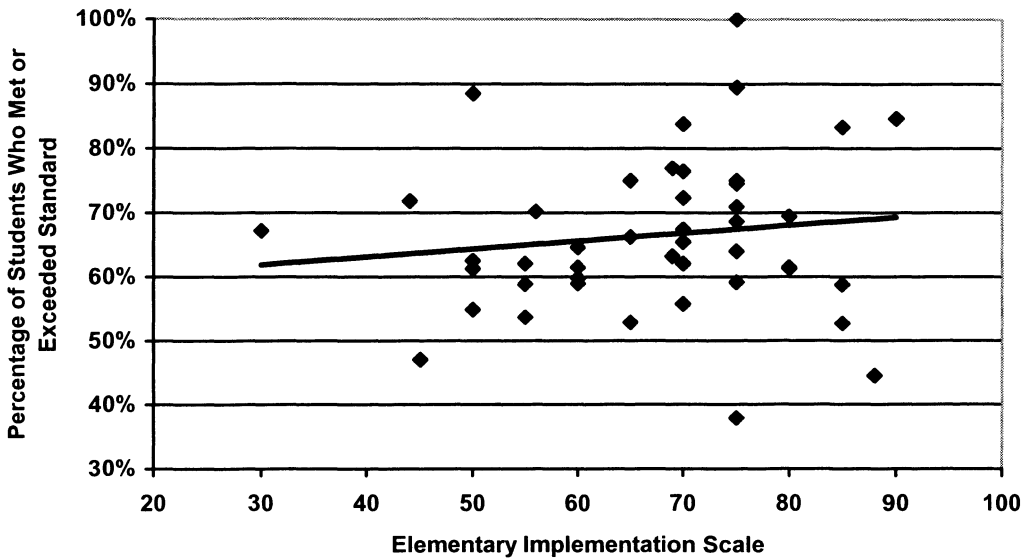
a Dependent Variable: Percentage of grade 8 students who met or exceeded mathematics standard in 2007.

The analysis of the data for grades 8 and 10 indicates that the degree to which schools implement the practices promoted by the OMLI project measured by the SIS was a significant positive predictor of student performance above and beyond what could be explained by the socioeconomic factor as indicated by the percentage of students who qualify for free and reduced lunch program (see Graphics 1 and 2). This relationship was particularly acute at grade 10 ($R^2=.738$, $Beta=.320$) and grade 8 ($R^2=.524$, $Beta=.197$). These predictors include the quality and implementation of the school action plan and regular, school-based, professional development that reaches the majority of the teaching staff. The use of well-defined professional learning tasks and protocols during school-based professional development are key elements.

Graphics 3 and 4 show the results of the analysis of the grades 3 and 5 data. The effect seen in grades 8 and 10 were evident to a lesser extent at grades 3 and 5 (Grade 3: $R^2=.224$, $Beta=.160$; Grade 5: $R^2=.110$, $Beta=.068$). Key factors accounted for by the EIS included the leadership qualities of the teachers on the School Leadership Team, whether the School

Leadership Team had more than one teacher participating, supportive school and district policies and practices, the degree to which mathematics is a priority for the school, and regular use of well-defined professional learning tasks and protocols during school-based professional development. Although there was a statistically significant relationship between these implementation factors and student achievement in mathematics, the model accounts for only a small portion of the variance in student achievement (note R^2 values). There are other factors at play beyond socioeconomics, demographics, and the traits measured using the OMLI implementation rubrics that influence student mathematics achievement at grades 3 and 5.

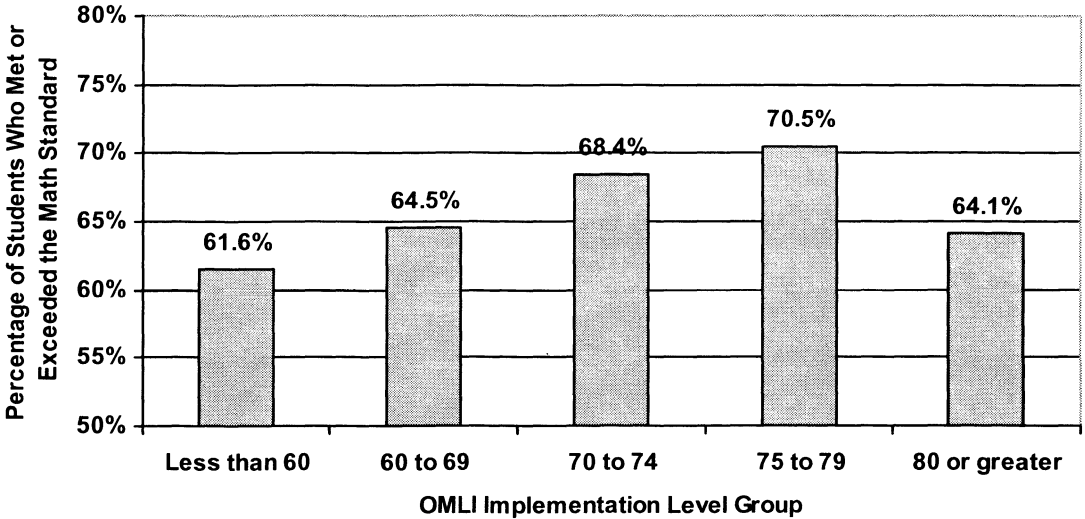
GRAPHIC 3—SCATTER PLOT, Grade 5



N = 45 Schools

Figure 8. Analysis of grade 5 student achievement.

GRAPHIC 3—IMPLEMENTATION LEVEL GROUP BAR CHART, Grade 5



GRAPHIC 3—IMPLEMENTATION LEVEL GROUP DATA TABLE, Grade 5

<i>Elementary Implementation Index Score</i>	<i>Number of Schools</i>	<i>Students Who Met/Exceeded Mathematics Standards</i>	<i>Students Assessed</i>	<i>Percentage of Students Who Met/Exceeded Standard</i>
Less than 60	11	435	706	61.6%
60 to 69	9	369	572	64.5%
70 to 74	7	359	525	68.4%
75 to 79	10	311	441	70.5%
80 or greater	8	412	643	64.1%

**GRAPHIC 3—REGRESSION ANALYSIS RESULTS, Grade 5
ANOVA Results (b)**

	Sum of Squares	df	Mean Square	F	Sig.
Regression	4.009	2	2.005	177.334	.000(a)
Residual	32.599	2884	.011		
Total	36.608	2886			

a Predictors: (Constant), Elementary Implementation Scale (EIS), Free or Reduced Price Lunch Percent (FRLP).

b Dependent Variable: Percentage of grade 5 students who met or exceeded mathematics standard in 2007.

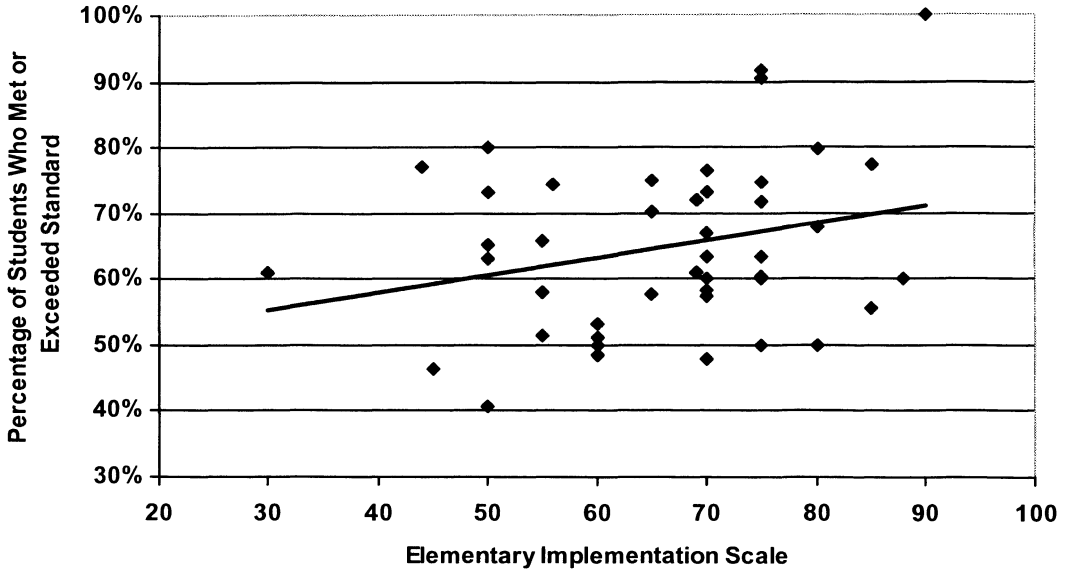
$R^2 = .110$ N = 45 Schools

Coefficients(a)

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.688	.013		54.486	.000
FRLP	-.172	.010	-.307	-16.917	.000
EIS	.001	.000	.068	3.747	.000

a Dependent Variable: Percentage of grade 5 students who met or exceeded mathematics standard in 2007.

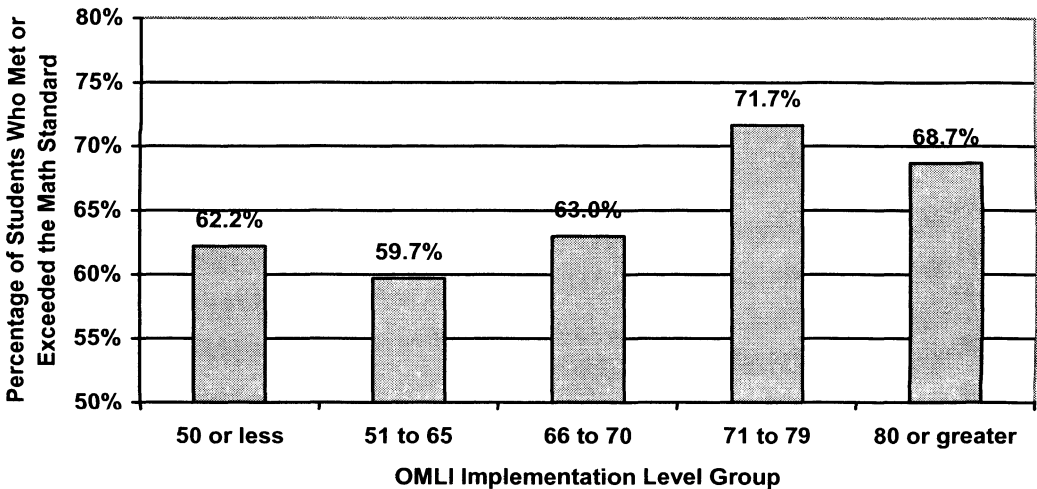
GRAPHIC 4—SCATTER PLOT, Grade 3



N = 44 Schools

Figure 9. Analysis of grade 3 student achievement.

GRAPHIC 4—IMPLEMENTATION LEVEL GROUP BAR CHART, Grade 3



GRAPHIC 4—IMPLEMENTATION LEVEL GROUP DATA TABLE, Grade 3

<i>Elementary Implementation Index Score</i>	<i>Number of Schools</i>	<i>Students Who Met/Exceeded Mathematics Standards</i>	<i>Students Assessed</i>	<i>Percentage of Students Who Met/Exceeded Standard</i>
50 or less	8	328	527	62.2%
51 to 65	11	490	821	59.7%
66 to 70	10	426	676	63.0%
71 to 79	8	289	403	71.7%
80 or greater	7	366	533	68.7%

**GRAPHIC 4—REGRESSION ANALYSIS RESULTS, Grade 3
ANOVA Results (b)**

	Sum of Squares	df	Mean Square	F	Sig.
Regression	8.934	2	4.474	425.702	.000(a)
Residual	31.079	2957	.011		
Total	40.028	2959			

a Predictors: (Constant), Elementary Implementation Scale (EIS), Free or Reduced Price Lunch Percent(FRLP).

b Dependent Variable: Percentage of grade 3 students who met or exceeded mathematics standard in 2007.

$R^2 = .224$ N = 44 Schools

Coefficients(a)

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.647	.012		52.950	.000
FRLP	-.232	.010	-.403	-23.924	.000
EIS	.001	.000	.160	9.484	.000

a Dependent Variable: Percentage of grade 3 students who met or exceeded mathematics standard in 2007.

Concluding Remarks

We conclude by revisiting the two specific evaluation research questions considered in this paper, the first of which is: “Has the OMLI professional development prepared the Teacher Leaders for their leadership role in terms of mathematics content knowledge for teaching?” Using the Learning Mathematics for Teaching measures, we found that after completing two of the six courses at the first OMLI Summer Institute, very little growth was evident [10]. After most completed four of the six courses after the second OMLI Summer Institute, significant growth was evident on some subscales of the measures. After most participating teachers had completed all six courses after the third OMLI Summer Institute, significant growth was evident on all subscales and overall. Based on these measures, we conclude that the answer to this questions is “yes.”

The other evaluation research question to be answered is: “Has the OMLI project increased student achievement (as indicated by the percentage of students who demonstrate proficiency on the Oregon State Mathematics Assessments for Grades 3, 5, 8, and 10) in all participating K–12 schools?” The degree to which schools implement the practices promoted by the OMLI project is a significant positive predictor of student performance above and beyond what can be explained by the socioeconomic factor as indicated by the percentage of students who qualify for free and reduced lunch program. This relationship is particularly acute at grades 10 and 8.

At grades 3 and 5, the degree to which schools implement the practices promoted by the OMLI project and socioeconomic factors are predictors of student performance. However, the regression model did not account for enough of the variance in student achievement. Evidently, there are other factors at play in elementary schools that are not accounted for by the traits measured by the implementation rubrics and socioeconomics, and a search for other possible factors is an ongoing effort in our evaluation plans.

Acknowledgments

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DEVELOPING LEADERSHIP IN A NATIONAL COHORT OF SECONDARY BIOLOGY TEACHERS: USES OF AN ON-LINE COURSE STRUCTURE TO DEVELOP A GEOGRAPHICALLY DISTANT PROFESSIONAL LEARNING COMMUNITY

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Abstract

This report is a descriptive study of the role that on-line courses might have on the development of Professional Learning Communities (PLC's) that support national leadership initiatives of participating high school biology teachers. The one hundred teachers involved in the Life Sciences for a Global Community (LSGC) Institute are expected not only to deepen their content knowledge, but also impact their district and state biology curricula. Additionally, the dispersion of Institute participants across the country presents a unique opportunity to develop, communicate, and implement a national coherent reform agenda. However, the geographic distance presents a barrier to collaborative design of leadership projects. Therefore, the LSGC Institute designed web-based, distance learning courses as a means for both the instruction and development of distant professional relationships.

This study is an initial investigation into the impact that three web-based courses had on the development of a national Professional Learning Community. We first report on themes and patterns that were derived from a conceptual analysis of the discourse generated in the first cohort of teachers during three on-line courses offered during the academic years 2007-2008. We then discuss the themes and patterns generated by this initial analysis as to the likelihood that they indicate movement toward a Professional Learning Community. Most of the comments across courses were characterized by individuals responding to instructional prompts. The second and third most common responses were interactions among the students, some related to teaching *biology while others covered matters of school context*. The emergent themes in the conceptual analysis were found to strongly align with three dimensions of Professional Learning Communities (PLC's) and weakly align with two dimensions. The results of this analysis will inform the Year Two on-line courses to include more structures to support the dimension of emerging leadership among the teachers.

Life Sciences for a Global Community: Description of Institute

Washington University in St. Louis, a leader in life sciences education and research, has developed the Life Sciences for a Global Community (LSGC) Institute, a high school biology teacher institute program leading to a master's degree in biology. The Institute offers an innovative approach to high school biology teaching and learning, centered around an interdisciplinary curriculum taught by world class researchers. Institute faculty are recognized leaders in all areas of biological research. They include sixteen faculty members, eight of whom are full professors. The program design includes two Summer Institutes at Washington University, work during the academic year with on-line support, and a leadership component. A mixed method research design will generate data regarding effectiveness, provide accountability, and inform dissemination.

Through the Institute, there is a commitment to preparing teachers to improve their students' biological content knowledge, and to help sustain change in teaching practice at their schools and districts. Project leaders envision a rigorous interdisciplinary approach, combining content knowledge and the broad implications for human impact. To this end, the project has the following goals:

- Develop a national cadre of master teachers of high school biology who demonstrate intellectual engagement with and mastery of global issues in life science, and who use related research-based pedagogy and challenging content in their courses;
- Improve interest, engagement, and achievement by affected students in secondary biology; and,
- Promote Institute partners' and participants' development as local and national educational leaders through participation in a national Professional Learning Community.

To assess teacher and student knowledge acquisition and achievement, the evaluation is built on a random-assignment control design of three cohorts of teachers who each begin the program in sequential years: 2007, 2008, and 2009. Of the teachers who applied and were accepted to the project, one hundred were assigned randomly to initial treatment and control groups. Teachers and students of Cohorts II and III serve as control groups for the programming presented to Cohort I. On-line administration of content pre-/post-tests and surveys of students' attitude toward learning biology were administered in Spring 2008. Results are currently being collected and analyzed.

Leadership Development: A National Professional Learning Community

Transfer of the content and enthusiasm for the discipline into the teachers' classrooms and the development of a national Professional Learning Community is another major component of the Institute program. However, the geographical dispersion of teachers within each of the three cohorts presented a unique challenge to the development of a leadership program that is based on collaborative models. Literature describing the dimensions of local Professional Learning Communities guided the design of the national model [1, 2]. The vehicle used to develop and maintain communication between teachers across the nation is a series of on-line courses during the academic year.

This study used the following courses: 1) *Chemistry for Biology Teachers*; 2) *Case Studies in Biology*; and, 3) *Program Capstone I*. It provides an initial look at the effectiveness of this tool in building and sustaining professional relationships that are likely to lead to collaborative leadership.

Methods of Analysis

The following is an analysis of the use of an on-line course structure as an instrument supporting the development of the national Professional Learning Community (PLC). We analyzed the written discourse of the teachers during the on-line courses by conducting a conceptual analysis [3]. The unit of transcript analysis for this study was the message level, which allowed multiple coders to agree on the total number of messages [4]. We then ranked the themes and patterns generated by this analysis according to those supported by the most evidence to those supported by the least. Evidence in this case was considered to be the quantity and quality of the statements made by each of the participants in the on-line system during each of the courses. The themes and patterns emerging from the analysis of the transcripts were then coded and discussed according to the alignment of each with the dimensions of a published framework characterizing Professional Learning Communities [1].

Results of Analysis

Each course had between 500 and 700 entries on the on-line discussion board over a fifteen-week period of time. The conceptual analysis identified five major themes and patterns evident across courses (see Table 1). For the purposes of this study, a theme/pattern is discussed if more than five participants indicated evidence, multiple times, within each course. The predominant theme, occurring on average in 48.3% of the messages, was derived from the

discussion among individuals sharing thoughts that were within the parameters of the course assignment. Two types of messages characterized these participant comments, one relating to instructors and the other to anyone in the cybercommunity.

Table 1
Percent of Total Themes and Patterns Generated by Analysis of On-Line Discourse among Teachers Participating in Distance Learning Courses in the Washington University LSGC Institute for High School Biology Teachers, 2007-08

Themes and Patterns	<i>Chemistry for Biology Teachers</i>	<i>Program Capstone I</i>	<i>Case Studies in Biology</i>
	N=510	N=513	N=648
Participant sharing of content within course parameters	60%	35%	50%
Participants interacting with other participants about course content	20%	25%	31%
Participants seeing selves and others as resources for participants	5%	20%	10%
Participants sharing the context of their teaching	10%	15%	5%
Participants sharing personal information about their professional and personal lives	5%	5%	4%

For example, in the course entitled, *Chemistry for Biology Teachers*, this comment was posted (11-21-07) by the course instructor in consultation with a research scientist, responding to several questions about the fate of the carbon dioxide that plants produce during respiration:

The carbon dioxide is released through the stomata like other gases and is then available for use during photosynthesis just as any other CO₂ in the atmosphere. However, some plants perform CAM photosynthesis where CO₂ is banked or stored for later use. In these plants, stomata open at night and remain closed during the day. The CO₂ is converted to an acid and stored during the night. During the day, the acid is broken down and the CO₂ is released to RUBISCO (an initial enzyme) for photosynthesis. The CAM plants include many succulents, such as cacti and agaves, and also some orchids and bromeliads.

The comment above shows an example of individual student-to-instructor interaction, as well as illustrating the depth of content that can be discussed in a distance learning environment. The following comments (posted on 9-22-07) show how several individuals respond to course design prompts in sequence without interacting with each other:

- The first post—“Animation on chemical bonding was excellent. It was very easy to understand, the explanations were clear. I am sure that my tenth grade biology and *Intro. to Chemistry in Anatomy* class would very easily understand the whole process of bonding.”
- The next post—“The enzyme connection is great. We just finished enzymes in *Anat[omy]*. For some reason it seems to be one of the topics that students struggle with the most. I’m going to use this with them as a review of enzymes and an intro into cellular respiration, which is our next topic.”
- Next post—“It was another good animation. The collection of short videos, animated and otherwise, will be helpful next week as I start the basic biochemistry stuff in biology class.”

These were prompted by the assignments and formed the fundamental structure of the interactions between members of the cohort and between individuals and the instructors.

The next strongest theme, evident in 25.3% of the responses, was that of *professional interactions* about the course content. These were initially prompted by the assignments, but were attempting a connection to other course participants, as well as the instructors. For example, in a posting on 1-28-08 from the *Case Studies in Biology* course, one participant wrote: “I agree with Jane, in that the Dilemma category is more effective for higher-level thinking. It requires the student to synthesize information from the case and then actually take action based on what they know.” Comments were placed in this category if they referenced a prior comment or asked a question of another teacher because of a prior position that he or she stated.

The third theme/pattern, occurring in 12 % of the total messages, contained comments in which teachers were sharing information about the context of their teaching. These were

sometimes about district politics, sometimes about school-based barriers to good teaching, and sometimes about environmental resources, such as those available for field trips.

One example of this type of comment was posted on 1-29-08 from the *Case Studies in Biology* course: “I’m so sorry that you consider twenty-six to be a small class. In our regular bio class, we limit it to twenty-four, and in the basic classes, they try to keep them to about twenty.” Or, as this teacher from an under-resourced district in the *Program Capstone I* course stated on 9-16-07, “My Commodore-644 won’t load these classroom pics, but I get some idea from your descriptions.”

The fourth theme/pattern was derived from comments that referenced each other as professional resources or experts and comprised 10% of the messages. These were sometimes aligned with course assignments and sometimes not. These comments were most often about matters of pedagogy or pedagogical content knowledge. An example of this type of interaction was posted on 2-09-08 and came from a student in *Case Studies in Biology*:

But to recap, I feel that class discussions in the form of the Socratic Seminar would be an effective method for underperforming students. I actually just went to a small seminar on the Socratic process. If anyone wants more information, here is a website...

This is an example of a comment that occurred on 10-21-07 during a discussion of course-related material in the *Chemistry for Biology Teachers*, but was more about sharing resources related generally to teaching:

Abby, thanks for the post. I too am a member of the *AP Biology* listserv and even though you get quite a bit of junk, there is a great deal that is very informative. I would suggest [that] anyone [teaching] AP or is considering teaching it in the future get on the list.

And finally, a fifth theme or pattern, occurring in 9.3 % of messages, encompassed comments that were made to share information about oneself. These appear to be attempts to relate to others on a more holistic level than course ideas alone would allow:

- “This past week, I was in charge of presenting a professional development [activity] for the entire staff on Monday, was out of town at a school improvement workshop on Monday night and all day Tuesday, had a swim meet out of town on Thursday, and still had to teach my classes, prepare two labs, and write a lab practical test. But, that is just me. As teachers, we are ‘living the dream!’” (*Case Studies in Biology*, 1-26-08)
- “[S]tay warm, it was a balmy -3°F here this past Saturday...wooooooeeeeee!!!”
- “I went for a 12-mile run right before the Super Bowl, had dinner, then fell asleep at kick-off only to wake with 45 seconds to go in the game. Saw all I needed to see.” (*Case Studies in Biology*, 1-05-08)

Discussion

The primary goal of the on-line courses was the delivery of content in a way that would help teachers integrate new content and instructional practices into their classrooms. The success of this goal was assessed by a baseline of participation in the on-line discussion forum and the quality of student work produced in response to assignments. The secondary goal and the purpose of this study was to assess the ability of the on-line course environment to promote the establishment of a PLC comprised of teachers who are geographically dispersed across the country.

As we assess the Institute’s progress in the development of a national Professional Learning Community, we have drawn on the literature describing the dimensions of local PLC’s in school district organizations [1]. According to Hall and Hord, these PLC dimensions are:

- 1) Shared Values and Vision—Commitment to student learning;
- 2) Collective Learning and Application—Apply learning to better attend to students’ needs;
- 3) Supportive and Shared Leadership—Jointly held power and authority that involve teachers in decision-making processes;
- 4) Supportive Conditions—Physical and human capacities that promote collaborative organizational arrangements and relationships; and,
- 5) Shared Personal Practice—Feedback and assistance from peers that support individuals and community improvement.

The evidence from the teacher discourse during the on-line courses indicated that all three of the on-line courses, to varying degrees, were effective at supporting the development of all but one of the dimensions of these PLC indicators. The course structures provided supportive

conditions for the promotion of collaborative organizational arrangements (PLC#4). Teachers were given the time, space, and encouragement to share information about teaching. A reading of the discourse provides one with a picture of the similarities and differences in high school teachers' classrooms across the nation. The on-line discussion forum also provided a space for teachers to share values and vision for student learning (PLC#1). This was most often the result of a direct question or prompt, but was sometimes a conversation that resulted from a spontaneous question initiated by teachers.

The dimensions of PLC's supported by the strongest evidence from the cross-course conceptual analysis were those indicating the sharing of personal practices (PLC#5) and those that illustrate the teachers' collective learning and its application to better teach their students (PLC#2).

Not surprisingly, the dimension of PLC's not supported by the distance learning structure was that of supportive and shared leadership (PLC#3). Incorporating leadership goals into the distance learning environment will occur in the academic Year Two of the program, 2008-09.

Conclusion

In summary, the on-line courses, as taught during the first year, seemed to encourage participants to interact with each other around the specific content of the course and the more general context of teaching. There is also evidence, although less predominant, that they used the forum to begin to forge more personal relationships with one another. If electronic relationship formation in both professional and personal domains builds learning communities in the same way as local PLC's, then these findings would suggest that on-line coursework can support the development, at least initially, of collaborative leadership teams. These findings will inform the development and implementation of Year Two of the on-line courses, assuring that the designs reinforce the impact of the first year, and extend this into a peer leadership environment that would allow teachers to establish their work around shared values of educational reform.

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THE IMPACT OF EARLY POSITIVE RESULTS ON A MATHEMATICS AND SCIENCE PARTNERSHIP: THE EXPERIENCE OF THE INSTITUTE FOR CHEMISTRY LITERACY THROUGH COMPUTATIONAL SCIENCE

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Abstract

After one year of implementation, the Institute for Chemistry Literacy through Computational Science, an NSF Mathematics and Science Partnership Institute Project led by the University of Illinois at Urbana-Champaign's Department of Chemistry, College of Medicine, and National Center for Supercomputing Applications, experienced statistically significant gains in chemistry content knowledge among students of the rural high school teachers participating in its intensive, year-round professional development course, compared to a control group. The project utilizes a two-cohort, delayed-treatment, random control trial, quasi-experimental research design with the second cohort entering treatment one year following the first. The three-year treatment includes intensive two-week summer institutes, occasional school year workshops and year-round, on-line collaborative lesson development, resource sharing, and expert support. The means of student pre-test scores for Cohort I ($n=963$) and Cohort II ($n=862$) teachers were not significantly different. The mean gain (difference between pre-test and post-test scores) after seven months in the classroom for Cohort I was 9.8 percentage points, compared to 6.7 percentage points for Cohort II. This statistically significant difference ($p<.001$) represented an effect size of .25 standard deviation units, and indicated unusually early confirmation of treatment effects. When post-tests were compared, Cohort I students scored significantly higher than Cohort II and supported the gain score differences. The impact of these results on treatment and research plans is discussed, concentrating on the effect of lessening rural teachers' isolation and increasing access to tools to facilitate learning.

Introduction

When to expect outcome data sufficiently robust to assist research design and implementation refinement is a subject of general interest in the treatment of human subjects in education programming. The answer, at least in the authors' experience evaluating mathematics and science partnerships funded through the National Science Foundation or the Department of

Education and similar projects, has been later rather than sooner. Effects of teacher professional development programs on student achievement are often seen as long range outcomes beyond the three-to-five-year span of grant programs and their research components [1, 2]. The long-term course required to affect teacher performance measurably, with its attendant complexities, is accepted as a reasonable given [3, 4]. Additionally, study designs and research efforts can be constrained by resource availability, variable project staff and participant cooperation, extant data limitations, and the need for evaluative focus on formative and process concerns to ensure fidelity of implementation [5, 6].

Project leaders and evaluative researchers often must make do with the basics—pre-/post-tests framing relatively brief treatment phases, self-reported change in classroom practice, and limited classroom observation—which are perhaps the most commonly applied measures used to investigate achievement effects [7, 8]. However, if a sufficiently rigorous research and evaluation design is in place, if project cooperation is sufficiently supportive of research efforts, and if project activities are implemented with vigor, intensity and fidelity to plan, what may be expected? When can outcome data sufficiently robust to guide future implementation and research activities be developed? Put another way, what is the impact of such early analyses and results if they are available?

This paper addresses the case of the Institute for Chemistry Literacy through Computational Science (ICLCS), a National Science Foundation Mathematics and Science Partnership (MSP) Institute Project led by the University of Illinois at Urbana-Champaign's (UIUC) National Center for Supercomputing Applications (NCSA), School of Medicine, and Department of Chemistry. The ICLCS is a five-year research project investigating the effects of a statewide teacher professional development effort aimed at rural Illinois high school chemistry teachers. Thom Dunning, a professor in the Department of Chemistry and Director of NCSA, is the project's Principal Investigator. In addition to UIUC, other core partners for the project are the AC-Central School District and the Regional Office of Education #38, both rural educational entities in central Illinois.

The project includes the following goals:

- Improved teacher and student content acquisition in the context of present-day research;
- Increased teacher comfort with and use of computational and visualization tools in the classroom;

- Teacher-leadership development in STEM and computational science education; and,
- Related institutional change at the University and among the K-12 educational partners engaged in the project.

The project, funded in 2006, has just entered its second year of treatment for one cohort of teachers and its first year of treatment for the second cohort. This second cohort also serves as the control group for the first cohort. Treatment includes the following components: an intensive two-week summer institute conducted annually for three years for each cohort; ongoing virtual learning community activities through work group assignments, lesson planning, resource sharing, and rapid-response support to teachers' questions; twice annual workshops; provision of tools and technical support to teachers for use in their classrooms; and, individual leadership development planning. Central to project communications and activities is the use of a centralized, on-line system through which almost all ICLCS contacts, assignments, work products, resource information, etc. are shared. Teachers will be followed for two years after the formal treatment course. This article describes the research design and methods used for the project, reports early results, and discusses some of the effects of these early results on the project, evaluation, and research plans and activities.

Methods

Research and evaluation design and implementation for ICLCS is the responsibility of an external team from M.A. Henry Consulting, LLC, a St. Louis-based educational research and evaluation firm. External evaluation is a requirement of NSF Institute MSP projects.

Methods—Recruitment and Ascertainment

Teacher participants in the ICLCS were recruited through a broad-based effort that included information shared with Illinois state and local educational leaders and professional organizations, presented on various listservs, and communicated to more than 300 teachers who had expressed interest in an earlier needs assessment effort. A second focused recruitment aimed at areas of the state underrepresented in the first wave of results. Acceptance criteria included the requirement that teachers were currently teaching high school chemistry in an identified rural school district, an agreement by the principal and district to cooperate with project technical and teacher time requirements, and a personal statement of commitment by the teachers.

Methods—Random Assignment and Research Design

A quasi-experimental, two-cohort research design based on random assignment and delayed control group treatment was developed for the project. Versions of this design had been recommended at a joint Department of Education/National Science Foundation MSP conference as appropriately rigorous within the constraints usual in educational research [9]. Cohort I was to serve as the initial treatment group, with Cohort II serving as the control group with treatment delayed until the following year. As time passed, the second cohort would continue to be used as the control, as it always would be one year behind the first cohort's treatment. The research design is outlined in Table 1.

Once recruited, teachers were listed in order by their district's standardized mathematics scores, and randomly assigned by pairs into one of two cohorts. The first cohort was identified as the first treatment group. In the three cases where more than one teacher had applied from the same district, all teachers in that district were assigned to the same cohort, for purposes of resource sharing and avoiding cross-cohort contamination. Teachers recruited after cohort selection were included in project participation, but excluded from analyses focusing on the core treatment and control groups.

Table 1
ICLCS Research Design: Teacher and Student Chemistry Content Testing

Cohort	Year 1	Year 2	Year 3	Year 4	Year 5
Cohort I	Teacher Identification, Treatment Year 1	Treatment Year 2	Treatment Year 3	Re-test of content for retention	Re-test of content for retention
Cohort II	Teacher Identification, Control for Cohort I	Treatment Year 1, Control Cohort I	Treatment Year 2, Control Cohort I	Treatment Year 3	Re-test of content for retention
Teacher ACS testing and Student ACS testing, both cohorts, all years					

Methods—Teacher Cohort Characteristics

The initial research cohort contingent totaled 101 teachers. Early pre-treatment attrition, reassignment from the research cohort to non-research cadre participation in the other group

because of teacher issues, and subsequent attrition left $n=38$ for Cohort I and $n=39$ for Cohort II, for a total of 77 teachers available to participate in the first treatment year's research activities.

Table 2
ICLCS Project Teacher Participants: Research Cohorts and Total Participants

	Initial Research Cohort	Number in Research Cohort	Percent Research Cohort Retained	Total Teachers Recruited (Research Cohorts and Non-Research Participants)	Total Retained	Total Percent Retained
Treatment Group 1 (Treatment in Years 1-3)	51	38	75.5%	51	44	86.3%
Control Group 2 (Treatment in Years 2-4)	50	39	78.0%	69	60	87.0%
Total	101	77	76.2%	120	104	86.7%

Teachers in both cohorts had a broad mix of educational backgrounds and teaching assignments. While all teachers were engaged in chemistry teaching, many also taught physics, biology, general science, and other subjects. Some also had earth science responsibilities or worked with advanced chemistry courses. Eighty-one percent had undergraduate degrees in a science subject, with 36% having general science degrees, 19% having biology or biology education degrees, and 14% having chemistry degrees. Forty-seven percent of the teachers had graduate-level degrees. Of these graduate degrees, 78% were in the sciences or science education, but only 10% were specifically in chemistry or chemistry education.

Methods—Project Activities: Treatment

Treatment for the teachers in Cohort I has been described previously. The project has committed itself to design and implement its curriculum around the stated and demonstrated needs of the teachers, and to integrate computational and visualization tools into their real-world classroom work. The project team does not attempt to dictate new curriculum. Rather, its focus is on assisting teachers in integrating computational tools and content support into their existing

diverse chemistry curricula. The Summer Institute represents more than eighty hours of intensive work, with most day schedules including twelve hours of activities. Treatment comprises a combination of resource sharing, content refreshers, leadership workshops, open labs, and small group work engaged in lesson module development. Ample opportunity is given for teachers to address the concerns and challenges they face in their own classrooms. These and other project activities are organized into a graduate-level chemistry course for the participating teachers, which encompasses the academic-year workshops and project engagement with the virtual learning communication system that connects project participants, faculty, and staff throughout the year.

University faculty, drawn from computational chemistry, general chemistry, bioinformatics and computational biology, biochemistry and molecular and integrative physiology, and instructional development areas work closely with the teachers, aided by other staff and graduate and undergraduate students. Additional chemistry and medical school faculty serve as mentors assigned to each of the teacher groups engaged in lesson module development. The project also has provided and has been assisting in installing Personal Interfaces to the Access Grid (PIG's) at teachers' schools, with cameras and headsets provided. Technical limitations at the schools have presented a predictable challenge, but to date, twenty-eight of these PIG's have been installed to enable teachers to communicate with other teachers and participate in real-time technology and content refreshers during the academic year.

Methods—Chemistry Content Analysis Measures and Procedures

To establish chemistry content knowledge baselines, Cohort I teachers completed the American Chemical Society's *General Chemistry Brief Test for the Full-Year Course* at the start of their first Summer Institute [10]. To measure gains, this same test was given at the start of their second Summer Institute for post-test purposes. Analysis of these data are ongoing. Cohort II completed their comparable baseline pre-tests at an informational meeting in Spring 2008, three months prior to the start of their first Summer Institute, and will take post-tests at the start of their second Summer Institute in July 2009.

This teacher testing schedule is used in order to capture the effects of yearlong treatment, rather than merely the brief, intensive work in the Summer Institute. The project asserts that its sustained engagement with teachers during the school year via the on-line system, workshops, and teacher group work will enhance gains in content knowledge, as well as classroom practice

and incorporation of computational tools in chemistry lessons. Post-tests, therefore, are timed to capture the effects of a full year's engagement in the project.

Student chemistry concept testing is performed using the American Chemical Society's *High School Chemistry Test* [11]. Pre-tests are to be delivered at the start of the school year to students of both Cohort I and Cohort II teachers, with post-tests delivered by the beginning of April to accommodate timing of Illinois state standardized testing.

American Chemical Society (ACS) tests were selected because of their long established status, broad acceptance, and coverage of appropriate chemistry concepts. Teachers in ICLCS noted that they did not teach all concepts on the ACS tests to their students. However, as chemistry content domains on the tests represent the full spectrum of Illinois chemistry high school standards, measures for all domains were included in testing.

Content tests also are delivered to non-research teacher participants in both groups and pre-tests and post-tests are delivered to their students. Parallel analyses are performed for the full cadres at the same time as research cohort analyses are done. Teachers themselves are not informed whether they are part of the research cohorts, although the circumstances of their entry into the project could inform them of their status.

Student ACS tests are delivered to students by their teachers at their schools. Teachers score their own student tests and report results using individualized student codes. Scores and answer sheets for pre-tests and post-tests are returned upon completion to the research and evaluation team for data entry and quality control checks. The test copies are returned with post-test materials for redistribution at the start of the next year's school year.

Other data are collected from teachers in numerous ways. Surveys track confidence with chemistry content domains, access to and use of technical resources, support networks and teaching workload. Interviews, classroom observations, module plan analysis, and analysis of communications on the on-line system are among the other data collection methods being applied to the project. In the case of this article, however, ACS content tests serve as the item of focus.

Results

Matched pre-/post-tests were returned by fifty-four of the seventy-seven research cohort teachers, for a 70% response rate. By cohort, twenty-nine of thirty-eight Cohort I teachers (76%) and

twenty-five of thirty-nine Cohort II teachers (64%) contributed matched pre-/post-tests. The total number of students for whom matched pre-/post-tests were returned was 1,825, of whom 963 were students of Cohort I teachers and 862 were students of Cohort II teachers. The mean number of student tests returned by teachers was thirty-four. The results of these tests provide the first evidence of whether or not ICLCS teacher participants are contributing to an effect in student achievement in chemistry content areas.

The results are reported in Table 3. The mean pre-test scores were not statistically different for students of Cohort I teachers and students of teachers in Cohort II ($t = -0.016$, $df = 1,823$, *ns*). The mean pre-test score was 27.4% correct for both Cohort I and Cohort II students. This result supports the comparability of students' chemistry knowledge between the two cohorts and appears to indicate the soundness of the random assignment process used. Student pre-test scores ranged from 0 to 65.0% correct for the Cohort I treatment group and 0 to 67.5% for the Cohort II control group.

Table 3
Pre-Test, Post-Test, and Gain Score Mean Differences:
Research Cohort I versus Research Cohort II

	Group	N	Mean	Standard Deviation	Mean Difference	t-test
Pre-Test	Cohort I	963	27.407	8.106	-0.0065	$t = -0.016$
	Cohort II	862	27.413	9.065		Not significant
Post-Test	Cohort I	963	37.17	12.823	2.996	$t = 5.32$
	Cohort II	862	34.18	11.219		$p < .001$
Gain Score	Cohort I	963	9.765	13.106	3.042	$t = 5.13$
	Cohort II	862	6.723	12.098		$p < .001$

Comparison of post-tests between research cohorts and total cadres presents a very different picture. Cohort I students scored significantly higher ($t = 5.32$, $df = 1,821$, $p < .001$) on their post-tests than did Cohort II students (mean difference of 2.996), with a Glass's effect size of .27 of a standard deviation. The range of post-test scores was 0 to 80.0% correct for the treatment group and 0 to 78% for the control group. Running this analysis with pre-test scores as a covariate to increase the power of the analysis yielded similar results.

Finally, when pre-test and post-test results are considered in the context of comparative gains, additional differences between the Cohort I treatment group and Cohort II control group are evident. Results for gain score differences are similar to those for post-test differences. Cohort I students scored significantly higher gains on their post-test than did Cohort II students with a mean difference in gains of 3.0419 ($t = 5.132$, $df = 1,823$, $p < .001$) and effect size of .25 standard deviation units.

To summarize, given the basis of research cohorts in a quasi-experimental, randomized assignment design and the lack of pre-test differences between the two cohorts, a significant difference can be seen in measures of treatment effects of the ICLCS project on Cohort I teachers over the control group (Cohort II) in terms of content acquisition by their students, as evidenced by differences in ACS chemistry test scores among students.

Discussion—Caveats

The finding of statistically significant greater gains in chemistry content knowledge among students of treatment teachers versus students of control teachers following at most ten months of teacher treatment is unusual. Before considering the impact of these results, discussion of some caveats is useful.

The possible effects of the teacher response rates in returning student tests must be taken into account. As described, an overall 70% response rate was experienced, based on returns of matched pre-tests and post-tests. By cohort, the rates were 76% returns by treatment teachers and 64% by control teachers. It is conceivable that differences in responder and non-responder characteristics among teachers in the two cohorts could have contributed at least some of the apparent differences in gains seen. A lower response rate among control teachers could indicate less motivation generally, as one may expect active participants to respond at higher rates.

Non-responding teachers in both cohorts reported uniformly to evaluators that their reasons for not returning student tests were either confusion about procedures, or workload issues at school and at home that prevented undertaking this extra work. To counter the explanation of confusion, it can be noted that non-responding teachers received no fewer than six reminders from evaluators and project staff during the course of the school year. No obvious difference in non-responding teacher characteristics between cohorts was seen when teaching experience or length of time at their schools was compared. Finally, the actual difference in the number of

teachers returning student tests between treatment teachers and control teachers was only four teachers, with twenty-nine treatment and twenty-five control teachers responding.

Despite the possibility of some differential response effect on gains, the non-equivocal strength of the statistically significant differences, the relatively large numbers of student scores included in the analyses in both cohorts, and the lack of a discernible pattern in cohort non-response characteristics indicate to the authors that a positive treatment effect in students at an early stage in the teachers' involvement in ICLCS is evidenced by analysis results.

Discussion—Impact of Early Positive Results on Student Chemistry Content Knowledge

First, the availability of such results is a direct consequence of the quasi-experimental design in place for the project. With a less rigorous design, confidence would be reduced and a greater chance would exist that positive, negative, or inconclusive results could be missed.

Of course, in simplistic terms a persuasive indication of positive student effects from a short-term teacher professional development treatment represents a welcome scenario. The results have served to informally validate both the project plan and the research design developed to investigate it. Based on observation and informal interviews, some stakeholders engaged in the project with a layperson's view of evaluation, acquired a greater understanding of the usefulness of the design. For example, this understanding has reduced requests for cross-cohort mingling in the interest of sharing helpful information more broadly. Such enhanced cooperation is not trivial. In educational research, it can be challenging to communicate about design protocols convincingly so that participants who are unfamiliar with such work do not view these procedural requirements as counterproductive or unnecessarily draconian.

In a similar vein, evaluators were asked by project leaders to share selected results with the treatment group, partly in response to teacher requests for information and partly to see if such information could assist in strengthening cooperation with evaluation procedures. Cohort I treatment teachers were briefly told of student content gains results in a group session during which their own ACS post-tests were delivered. The response was overwhelmingly supportive, with numerous questions posed for the first time about research plan rationales. This response and the stated commitment of several teachers to conform more closely to the research model resonates with literature on the benefits of teachers' active participation in research [12].

When asked in this session what the teachers themselves thought about the gains seen in their teaching, an overwhelming majority agreed that the project was providing them with a network of content support and engagement previously lacking in their work. Furthermore, it was also providing them with tools that they could apply in their existing curricula to better stimulate their students' interest and enhance their classroom delivery.

The limited availability of other teachers or content experts to consult when questions or challenges arise has been documented by the authors among these rural teachers. As discussed, they often are teaching multiple subjects and may be the only high school science teachers in their districts. The capacity of the ICLCS project to meaningfully connect them with other teachers and with content authorities, as represented by university faculty, confirms its relevance to the teachers' actual teaching practices.

Additionally, technical resources and support often are lacking in rural schools and districts. At times, the issue is not just equipment, but installation and troubleshooting. The project has connected teachers not only with various tools, but when challenges arise, the project has provided technical assistance, directly to them or to the technical staff at their school or district. Despite continued difficulties in some schools concerning computer and Internet access, including bandwidth concerns, teachers stated that they felt better equipped for chemistry to engage students more actively and meaningfully. Another potential benefit from sharing results with teachers and thereby increasing their understanding and motivation about the research component is the possibility that response rates could improve when next year's student ACS tests are to be delivered.

The impact of the early positive results on the project implementation team has been to support the curricular choices made for the Summer Institute and other project activities. Allowing much of the chemistry content choices to emerge from teacher needs appears defensible. The project has recognized the difficulty of strongly prescribing curriculum in a treatment setting including teachers from eighty different school districts. Teachers with varying degrees of experience and understanding have shown themselves to be reliable arbiters of what they need to improve their chemistry teaching. The project team also agree from their own perspectives that the reduction of teacher isolation is largely explained by immersion in an ongoing learning community and through the provision of computational, visualization, and other chemistry tools to aid in lesson planning.

An added potential boon anticipated from early student outcomes related to the project is their effect on schools and school districts of the participating teachers. To date, school and district support for the project has been related more to teacher release time for the two workshops and the acceptance of some equipment and technical assistance related to PIG installation. It is expected that demonstrable positive project effects on their students will help lift the collaboration with schools and districts to the next level. This step will be useful as the project attempts to extend its beneficial influence through teacher leadership plan implementation and possible connections of the computational and visualization tools to other subject areas in the sciences.

The student results also have assisted the evaluators in expediting plans for more in-depth multivariate analyses to determine more specifically what causal chains may be at play between ICLCS participation, and teacher and student outcomes. Against the possibility that teachers in the treatment group and their students were in such uniformly dire straits concerning chemistry learning that any treatment was likely to produce an immediate, if short-term, effect, the evaluators note the range in student pre-test scores in both treatment and control groups. Of course, the next series of student test results will provide further indications of the longer-term pattern of student content acquisition post-teacher treatment.

An additional area of interest is in developing long-range plans to adapt the ICLCS model for replication in other circumstances. The availability of NCSA, a first-tier research organization in computational science, and other chemistry resources at UIUC makes for a project plan difficult to apply elsewhere. The indication that intensive and sustained engagement by many senior faculty members and active research scientists in high school teacher professional development can have a positive effect on teachers and their students could seem less noteworthy than the question of how such experience can be adopted elsewhere. The project team already has begun to address this issue, and is planning to refine virtual learning community tools and dissemination of computational and visualization tools usable in diverse educational contexts.

Future Directions

Further analyses contain the following variables of interest: depth and focus of teacher engagement in ICLCS; teacher formal education and degree concentration; teaching experience; school and district demographic characteristics; extent of school and district support—general to chemistry and science curriculum and project specific; content, pedagogy and technical support network changes; intellectual leadership growth; confidence with content domains; and, observed classroom practice. The interrelationships of these variables and their role in student content

gains and other student outcomes will be investigated. Another possible area to consider is the project effect on high school student interest in and pursuit of college enrollment, particularly with chemistry or other science majors in mind. While many of these analyses have been planned since the project's inception, the early and unexpected student gains seen have helped frame these analyses and contextualize them.

Case study methods will be applied to an in-depth study of nine teachers in Cohort I in order to better understand the work lives of teachers. Selected because of their middle range of teaching experience and their prior full participation in the project and its research components, these teachers will be visited and observed in the field for three days at a time by the research team. These observational and related teacher interview data will be augmented by interviews with school and district staff, including principals, superintendents, other teachers, and technical support staff members.

Conclusion

Finally, the availability of early positive student content gain data has assisted in further coalescing the partnerships contained within the ICLCS project. While partnership is inherent, as well as explicit, in the NSF Mathematics and Science Partnership program, the extension of partnership models for more in-depth exploration into the inter-organizational and interpersonal workings of implementation and research is facilitated by the first objective evidence of project success. Reaching students and being able to demonstrate this often reside at two different points on the educational research map. To have an early indication of project efficacy in affecting student content knowledge is both gratifying and a challenge to the project for continued rigorous and engaging work. Inclusion of outcome data analyses as early as possible in the implementation phase during research design development, regardless of the outcomes that emerge, helps ensure both the means to confirm efficacy and to indicate refinements called for in order to achieve the project's stated objectives.

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K-5 MATHEMATICS SPECIALISTS' TEACHING AND LEARNING ABOUT FRACTIONS

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Abstract

This paper describes the fraction-based mathematical activities of two teachers who are part of a Mathematics Specialist preparation program. Their work with fractions is traced from two perspectives: 1) their interactions with students as they struggle with fraction concepts; and, 2) their personal journeys to develop deeper understandings of fractions as participants in the *Rational Numbers* course that is part of their degree program. Through their stories, we gain a better understanding of the complex nature of their work with students and how their participation in the Mathematics Specialist program helps support their work in the school buildings.

Introduction

Our first cohort of graduate students has recently completed a master's degree program slated for Mathematics Specialists. Upon completing this degree program, these students are also eligible for a state licensure Mathematics Specialist endorsement. This endorsement is part of an effort to place one Mathematics Specialist in Virginia's K-8 schools for every 1,000 students—an initiative recommended by the State Board of Education. This initiative is not yet a funded recommendation. This move toward a K-8 Mathematics Specialist program is long awaited and is the result of over two decades of statewide efforts spearheaded by the Virginia Mathematics and Science Coalition (VMSC), a collaborative venture among district, university, and K-16 education stakeholders.

What is the Mathematics Specialists' role in the elementary school building? The list of responsibilities is long and appears to be growing as we consider recent proposals by mathematicians, mathematics educators, and organizations like the Virginia Mathematics and Science Coalition [1-4]. Reys and Fennell, for instance, describe the Mathematics Specialists' role using two models: lead-teacher model or the specialist-teaching-assignment model [3]. When the Mathematics Specialist serves in a teacher leader role, he or she is "released from classroom instruction to assume mentoring and leadership responsibilities at the building or district level" [3, 5]. One might expect a Mathematics Specialist to plan, co-teach, make observations, model lessons, and so on [3]. By way of contrast, Mathematics Specialists that serve in the specialist-teaching-assignment role assume, for instance, the primary responsibility

for teaching mathematics at a particular grade level [3]. A fifth grade Mathematics Specialist might teach math to all of the fifth graders, as well as provide professional development for the vertical math team (i.e., third, fourth, and fifth grade teachers of mathematics). Reys and Fennell suggest that in the latter case, the classroom teacher develops a more narrow set of competencies and responsibilities [3].

The Virginia Mathematics and Science Coalition (VSMC), too, offers their own vision of the Mathematics Specialist's role:

[K-8] Mathematics Specialists are teacher leaders with strong preparation and background in mathematics content, instructional strategies, and school leadership. Based in elementary and middle schools, Mathematics Specialists are former classroom teachers who are responsible for supporting the professional growth of their colleagues and promoting enhanced mathematics instruction and student learning throughout their schools. They are responsible for strengthening classroom teachers' understanding of mathematics content, and helping teachers develop more effective mathematics teaching practices that allow all students to reach high standards, as well as sharing research addressing how students learn mathematics [6].

As the VSMC suggests, the Mathematics Specialist assumes responsibility for promoting and supporting professional growth for their colleagues that lead to supporting or enhancing student learning.

The characteristics outlined in these definitions of a Mathematics Specialist have informed our work with teachers. The program has as its goal to support the transition of Mathematics Specialists into roles that parallel the description offered by VSMC. In addition to following Reys and Fennell, we hope that, ideally, graduates from the program would acquire positions that fit with the lead-teacher model [3].

For the last few years, we have made a concerted effort to understand the Mathematics Specialists' roles in different school settings as they become or continue to serve as Mathematics Specialists. As part of this process, we have followed six of the twenty-six participants in the first cohort in this degree program. To document their activities, we videotaped all of the class meetings for three of the five mathematics courses and two of the three education leadership

courses that are part of the graduate degree program. In addition, we made visits to their school buildings each of the three years that they participated in the program. During our school-site visits, we also conducted audio taped interviews to address aspects of their daily work. By collecting these different types of information, we have attempted to understand how their participation in this graduate program has supported, in part, their work with teachers and their students. This article is our first attempt to develop a report that coordinates their experiences in the degree program with their work in the school buildings.

Ms. Smith and Ms. Sneider

To better understand how their experiences in the degree program might support the participants' daily work in schools, we use examples taken from both sets of data: their school-based activities and their participation in course activities. In our discussion, we use examples taken from our school-site visits at two of the participants' school buildings to illustrate how they use mathematics in their daily work. We then highlight an example from one of their class discussions in the course entitled, *Rational Numbers and Proportional Reasoning*, one of the mathematics courses in their degree program. Here, we tell the story of two of our recent graduates, "Ms. Smith" and "Ms. Sneider." Ms. Sneider's responsibilities are similar to those described by the leader-teacher model. She serves as a Mathematics Specialist in her school building. By way of contrast, Ms. Smith's responsibilities align more with the specialist-teaching-assignment model—she is a regular classroom teacher. As we tell parts of their stories, we attempt to understand what their roles might entail and how their roles are supported through their participation in the Mathematics Specialist program.

In both of our school-based examples, Ms. Smith and Ms. Sneider worked with similar concepts related to students' beginning understanding of fractions. Ms. Smith's example is taken from an introductory fraction lesson that she co-taught with another teacher while Ms. Sneider's example is taken from a lesson that she taught to a small group of fifth graders. We first provide examples of their daily work and then we make connections between Ms. Smith's and Ms. Sneider's graduate course experiences with fractions and their leadership roles in their respective school buildings. We begin our discussion by telling part of Ms. Smith's story.

Background—"What Fractional Part of the Two Pizzas is Left?"

Ms. Smith currently teaches fourth grade and is responsible for all instruction in all subject areas. Prior to the 2006-07 school year, Ms. Smith taught at a school where she had been

a primary grade teacher for six years. Ms. Smith was one of the Lead Teachers for mathematics and science instruction in her building. She also worked closely with the building math coach (i.e., Mathematics Specialist). She, in fact, hoped to serve in a similar role once she completed the Mathematics Specialist program. After completing her first year in the program, Ms. Smith was reassigned to a different school building for the 2006-07 school year. In addition to teaching in a different school building, she was assigned to a new grade level—fourth grade. Ms. Smith had never taught fourth grade before.

One of the ways that Ms. Smith capitalized on leadership opportunities as a fourth grade teacher was through co-teaching mathematics with “Ms. Applebee,” a special education teacher. To our surprise, these two teachers did not know each other before they began working together. As Ms. Smith commented once during an interview, “We did not know each other from a hill of beans.” One would not have suspected that they had never worked together. During our first visit to their classroom, we realized they had developed a rich, collaborative, professional relationship.

Ms. Smith and Ms. Applebee often met before or after school to plan mathematics lessons. They frequently exchanged ideas about how they would introduce the lesson, which students might need additional support, what activities they would use, etc. Both teachers stood in the front of the room during whole class discussions, and moved from group to group during independent or small group work. Usually, Ms. Smith introduced lessons and orchestrated whole class discussions although Ms. Applebee, too, helped lead discussions.

The Lesson—“What Fractional Part of the Two Pizzas Is Left?”

Our example is taken from an introductory lesson we observed about adding fractions. For this lesson, students solved the following problem independently: “Patrick ate $\frac{1}{8}$ of a pepperoni pizza and $\frac{3}{8}$ of a cheese pizza. How much pizza did he eat?”

After the students solved this and several other problems, Ms. Smith led a whole class discussion about the above problem. She began the discussion by asking the students what equation they had written to represent this problem. She then asked the students why they decided to combine the two fractional parts to determine what Patrick had eaten.

After students agreed that Patrick had eaten $\frac{4}{8}$ of a pizza, Ms. Applebee asked the students why the answer was not $\frac{4}{16}$ instead of $\frac{4}{8}$ of a pizza. When Ms. Applebee asked this

question, the students became very quiet. Previously, the students had engaged in a lively discussion about why the answer was $\frac{4}{8}$ (see Figure 1).

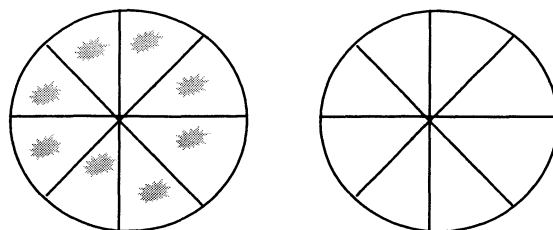


Figure 1. Ms. Smith draws one pepperoni and one cheese pizza.

When Ms. Applebee asked why the answer was not $\frac{4}{16}$, the students seemed puzzled. When none of the students attempted to answer Ms. Applebee's question, Ms. Smith referred to the pictures of pizzas on the board and asked a different question. She asked the students if they could make one whole pizza with the remaining pieces of pepperoni and cheese slices (see Figure 2).

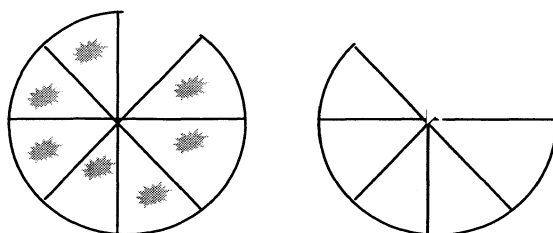


Figure 2. One slice of pepperoni and three slices of cheese pizza are missing.

In response to Ms. Smith's question, students explained how they would move three of the leftover pepperoni slices to the cheese pizza to make a whole pizza. Using both pepperoni and cheese slices, they would then have one whole pizza and one-half of a second pizza remaining. Ms. Smith recorded the students' ideas using arrows and drawing three slices to fill up the cheese pizza (see Figure 3). She also wrote the fractional amounts under each pizza (see Figure 4).

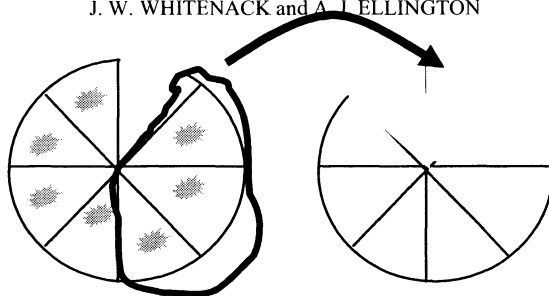


Figure 3. Ms. Smith represents moving three pepperoni slices to make one whole pizza.

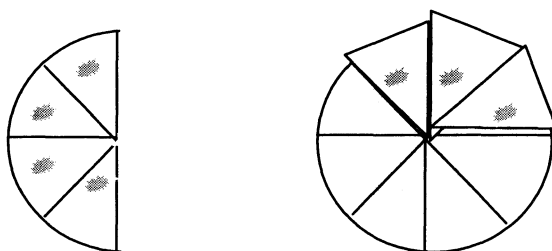


Figure 4. Ms. Smith represents one whole pizza and one-half of a pizza to illustrate the number of slices that remained.

Discussion—“What Fractional Part of the Two Pizzas Is Left?”

As the lesson unfolded, we wondered why Ms. Applebee asked this question at this juncture. Had she spoken with students who had derived this answer of $\frac{4}{16}$ instead of $\frac{4}{8}$ for the answer? Or did she hope to engage the students in a discussion about a common error that she has seen other students make when they combine fractions? We also wondered how Ms. Smith might orchestrate the discussion following Ms. Applebee’s question. From above, we know that Ms. Smith chose not to address Ms. Applebee’s question during this lesson. Instead, she asked the students a different question that refocused the discussion around combining fractions with like denominators. Her question proved to be an important one. By asking this question, students had an opportunity to explore ideas related to making whole pizzas (units) with the remaining slices (eighths).

As she initiated this teacher move, she also indirectly supported Ms. Applebee’s teacher moves during this part of the lesson. Although Ms. Applebee’s question is an important one for the students to consider (at some point during this fractions unit), Ms. Smith’s decision to redirect the discussion was an important teacher and coaching move. As Ms. Smith asked this question,

she was also in the position to support Ms. Applebee as she made contributions during the lesson. When Ms. Applebee asked a question that did not appear to move the students' thinking forward, Ms. Smith could offer a different question so that students could consider some related, important ideas about combining fractions. As such, this situation was a possible learning opportunity for the students, as well as for Ms. Smith and Ms. Applebee. By redirecting the question, students had the opportunity to use ideas to explore another problem involving addition with fractions. Ms. Applebee had the opportunity to "see" a possible teaching move that might be more appropriate at this point in the unit about fractions. In order to facilitate this shift in the discussion, Ms. Smith drew on those mathematical ideas that she understood about fractions to address a situation that she had not anticipated prior to this lesson.

During our taped debriefing session following the lesson, we asked Ms. Smith why she decided to ask the question about combining the leftover pieces of pizza. Ms. Smith explained:

And so I think that is where I was trying to bring them back to. "So if you have pepperoni pizza...Can you re-form that whole? Does it change how many pieces that whole is cut into?"

Ms. Smith chose to move the discussion forward by relating the problem to ideas that the students had previously explored. Two ideas that she hoped to address were reforming the whole and conserving the whole or what she referred to as "chang[ing] how many pieces."

Without prompting, she then related her students' thinking to ideas that she had encountered in the *Rational Numbers* course that she had successfully completed the previous summer:

The students' thinking is amazing to me. It is amazing to me—the idea of the parts and what makes up the whole... Some of the same things we were dealing with this past summer in our own [*Rational Numbers*] class.

As we pursued the influence of the course on her teaching, she offered additional insight into how her instructional approach had changed:

Oh, yeah [laughing]. I would be there right with them. "Okay, let's multiply by two and get a common denominator..." I wouldn't have had a clue as to how to teach this math topic. I would have had the textbook out, and I would have used a little bit of *Innovative Mathematics* and I would have said, "I don't know how I am going to

get from here to here.” ...And I see a little bit as to how we will get to those places...

She viewed her experiences in the course as important because she could “see a little bit as to how we will get to those places”—places they needed to reach as she supported her students’ understanding of fractions. Rather than simply following the curriculum as presented in her teacher’s guide, she could initiate discussions around some of the important ideas about fractions. So, Ms. Smith’s work in the course contributed, in part, to how she could better teach ideas around fractions. We also suspect that her experiences in the course made it possible for her to offer potential situations for coaching Ms. Applebee about teaching their ideas more effectively.

We now turn our attention to Ms. Sneider’s work as a Mathematics Specialist.

Background—“What Fractional Part Is the Yellow Pattern Block?”

Ms. Sneider is a full-time Mathematics Specialist in her school building. She, too, had successfully completed *Rational Numbers* during the previous summer. As a Mathematics Specialist, one of the challenges she faced was scheduling time to visit with teachers at each grade level throughout the school year. As part of her plan, she worked with teachers in a particular grade level for several weeks, and then moved to another grade level to work with a different group of teachers. As she worked with teachers, she sometimes co-taught lessons or made drop-in visits to classrooms while teachers were teaching mathematics lessons. When she made drop-in visits, it was not uncommon for her to interject comments during the lesson. When students completed assigned problems as they worked independently or in small groups, she typically walked around the room, stopping at an individual student’s desk to ask clarifying questions, listening to the student’s explanation or, in some cases, providing additional instruction.

During her second year as a Mathematics Specialist, she also worked with small groups of students who were pulled out of their classrooms to receive additional support. Our example is taken from one of these pullout sessions. In this particular pullout session, Ms. Sneider worked with a small group of fifth graders who continued to struggle with understanding fractions. The fifth grade teachers asked her to work with these students to prepare them for the upcoming school building quarterly assessment—a benchmark assessment in preparation for the statewide mathematics test.

The Lesson—"What Fractional Part Is the Yellow Pattern Block?"

Ms. Sneider began this session by asking students to make a yellow hexagon shape (the unit) using other pattern blocks. Pattern blocks are six geometric shapes: green equilateral triangles, blue rhombuses, tan rhombuses, orange squares, red trapezoids, and yellow hexagons (see Figure 5). Red, green, and blue blocks can be used to make yellow blocks. The green blocks can be used to make blue blocks or the red blocks, etc. As each of the students explained their pattern block configurations, they seemed confused about what fractional part each of the six green triangles represented. Although some of the students stated correctly that one green triangle represented $1/6$ (e.g., because six green triangles made one hexagon), it was not clear if students understood that these six triangle pieces needed to be the same size. To address this misconception, Ms. Sneider made a different shape using all 6 shapes (see Figure 5). She referred to this configuration as a "funky cookie."

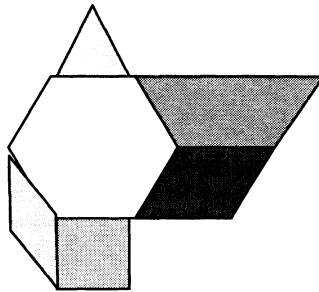


Figure 5. Ms. Sneider makes a "funky cookie" using all six pattern blocks.

After Ms. Sneider made this funky cookie, she asked the students what fraction the yellow hexagon block represented. Not surprisingly, students were not sure what this fractional part was. She then asked if she could share the cookie fairly by giving each student one of these six pieces. Following her questions, the students stated that if she shared her funky cookie, she would not share her cookie fairly. After some discussion, several students made different shapes using the blue and green blocks and correctly explained how they could share their pieces fairly by divvying out blocks so that each person could receive the same amount.

Discussion—"What Fractional Part Is the Yellow Pattern Block?"

As we observed this session, we were not aware that Ms. Sneider had decided to change her lesson plan. As she explained later during our debriefing session, she realized that the students did not necessarily understand that each of the $1/6$ needed to be the same size. The students understood that they needed six pieces to make the whole, but that they did not

understand that those pieces needed to be the same size. Once she realized that they did not have a solid understanding of what constitutes fractional parts, she decided to scrap her original lesson plan—helping students change improper fractions to mixed fractions (e.g., $5/3 = 1\frac{2}{3}$) using pattern blocks. Instead of introducing a new activity, she posed several tasks in which students used pattern blocks to make the whole.

Her decision to pose the “funky cookie problem” was a critical point in her revised lesson. Her decision to make a pattern block configuration that involved *unequal* pieces was a particularly important one because it explicitly highlighted the misconception that the students had about fractional parts.

Observations

Both of our examples illustrate how Ms. Smith and Ms. Sneider used their understanding of key mathematical ideas to support their students’ reasoning about fractional parts. Interestingly, although they had not planned to pose these particular problems, they both made important, on-the-fly decisions that advanced their instructional goals. They used their understanding of the mathematical ideas related to fractions in unique ways as they worked with their students.

One of the reasons that they were able to do so was because of their experiences in *Rational Numbers*, a course that they had completed during the previous summer. Recall that Ms. Smith actually referred to the importance of *Rational Numbers* in the debriefing session. Ms. Sneider, too, mentioned during debriefing sessions that her experiences in *Rational Numbers* were part of the reason she could pose these types of tasks, tasks that challenged students to think about important ideas about fractions. So what opportunities did participants have to explore and build new ideas about fractions? To answer this question, we turn to our example from the course.

Exploring Rational Numbers—“Can You Find a Fraction between 1/11 and 1/10?”

To illustrate the types of experiences that they had during *Rational Numbers*, we highlight part of one of the lessons that occurred during the second week of the course. For this lesson, participants explored an activity from “Bits and Pieces: Part I,” one of the fraction modules from the *Connected Mathematics* curricular series [7]. To begin this lesson, the course instructor asked participants, in small groups, to find a fraction between 1/11 and 1/10.

Participants had solved a similar problem for homework (i.e., “Can you find a fraction between $1/10$ and $1/9$?”).

Exploring Rational Numbers—The Lesson

To introduce this problem, the course instructor drew a fraction strip and as the discussion ensued, he explained how he could use the fraction strip to represent these different fractions (see Figure 6):

And remember that we were working with these strips—fraction strips. We were looking at those fraction strips [draws a picture of a unmarked fraction strip on the white board] and marking them so that by folding first here, we have a $1/2$ [makes a mark and writes $1/2$, and divides it into fourths]. And this of course would be $2/4$ [writes these numbers on the fraction strip]... The rational numbers there are representing distances from 0. So that’s one way—a very, very natural way that rational numbers appear as distances. Remember that we extend them so that it went beyond 1 [extends the fraction strip and writes 1 at the hash mark that represents $4/4$].

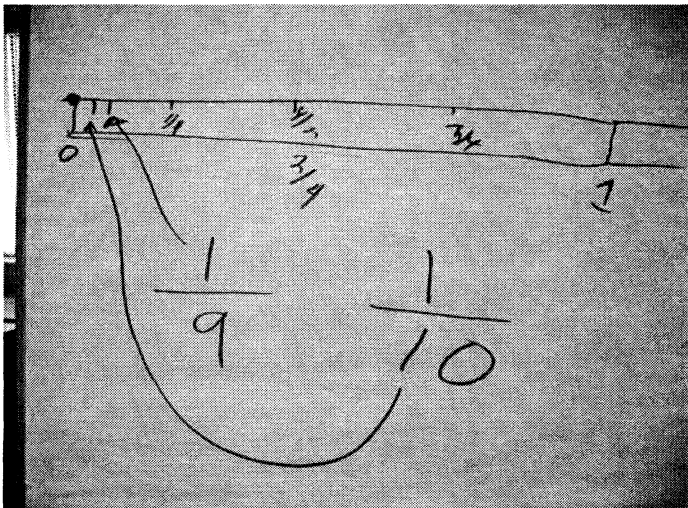


Figure 6. The instructor used the fraction strip to represent $1/4$, $1/2$, $3/4$, and 1.

As the discussion continued, the course instructor marked approximately where $1/10$ and $1/9$ were located on this strip (see Figure 7). After marking these numbers on the number strip,

he asked the participants if they could think of a fraction that was smaller than $1/10$. Several participants, in unison, said that $1/11$ was a fraction that was smaller than $1/10$.

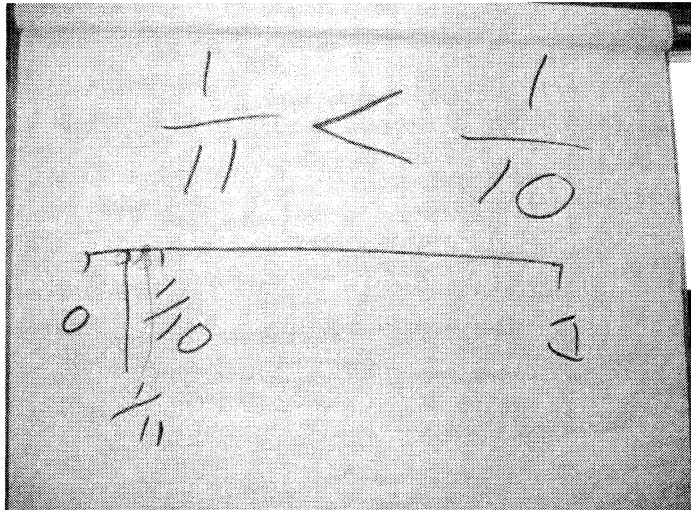


Figure 7. The instructor used the fraction strip to represent $1/11$ and $1/10$.

As the discussion continued, he posed the problem that they would explore in their small groups:

There are lots of numbers that are less than $1/10$, but one that is nice, that is less than $1/10$ is $1/11$. Just to get ourselves going again, at each of the tables, figure out a way to find a rational number between $1/10$ and $1/11$...Then I'll ask you to come up and share with us.

Participants began to work with others sitting at their tables to devise or refine their methods for finding fractions between $1/11$ and $1/10$.

Ms. Smith and Ms. Sneider worked with two other participants at their table. Ms. Sneider talked at some length about one participant's method. Ms. Smith used Ms. Sneider's approach to find other fractions. As we asked questions about their solution methods, Ms. Sneider explained her ideas about finding a fraction between $1/10$ and $1/9$, the homework problem:

[T]he other night when I figured out this problem. I thought, oh, I finally found a fraction between these two [fractions]. And then I let it rest. And then we come here; we talked about it and everything. Well, I couldn't get that problem off my

mind, so I was thinking about it more over the weekend, and I finally thought to myself, “What if I didn’t [multiply by] 2, what if I multiplied by 3?” Then I’d have $\frac{3}{30}$, and $\frac{3}{33}$. And there’d be two fractions... 31sts and 32nds that could go. Then I thought, “What if I multiplied it by 4?” And so you can multiply it by anything. So it gets you close to—if you kept on going—that there are an infinite number [of fractions]. But that was an “aha” moment when I realized that you can do it with more than just [multiplying by] 2!

As her comment suggests, Ms. Sneider figured out that she could generate equivalent fractions by multiplying the numerator and the denominator by the same number. In fact, she claimed that she could find an infinite number of these fractions between $\frac{1}{10}$ and $\frac{1}{11}$. When Ms. Sneider made this comment, Ms. Smith nodded her head in agreement.

We also talked with Ms. Smith about her method for finding fractions. Ms. Smith explained that she multiplied both $\frac{1}{10}$ and $\frac{1}{11}$ by $\frac{4}{4}$ to rename them as $\frac{4}{40}$ and $\frac{4}{44}$. As she explained her answer, she pointed to Ms. Sneider as if to indicate that she had decided to use Ms. Sneider’s method to find this fraction:

I just wanted to see if I could do this a different way [points to Ms. Sneider]. So I tried 4 over 42; that is what I did... So I just split 4 and 42 and it still reduced down to $\frac{2}{21}$.

So Ms. Smith used a method similar to the one that Ms. Sneider had used to find fractions between $\frac{1}{10}$ and $\frac{1}{9}$. The first part of her comment, “I just wanted to see if I could do this a different way” is curious. Had she initially solved the problem differently? As it turns out, she had. For her first attempt at this problem, she had used a calculator to rename each fraction as its decimal equivalent, and then had found a decimal that was larger than $\overline{.0909}$ and smaller than $.1000$. She used Ms. Sneider’s method to find the result after she had used the decimal method. So she used Ms. Sneider’s method to experiment with a different method.

To begin the whole class discussion, the course instructor asked one of the participants to share her method with the class. Like Ms. Smith, this participant shared that her group converted $\frac{1}{10}$ and $\frac{1}{11}$ to their decimal equivalents. She explained that $\frac{1}{10}$ was equivalent to 0.1000 and

$1/11$ was equivalent to the repeating decimal $.09090\dots$. So, $.095$ (or $95/1000$) was one of the fractions between $1/11$ and $1/10$. After this participant shared this idea, Ms. Sneider suggested, without prompting, that she could have also chosen $.091$, $.092$, $.093$,...or $.099$. She then argued that to find a decimal (and its fraction equivalent), one merely needed to increment the digits, in this case, in the thousandths place. She then related this strategy to how one incremented the digits to manipulate whole numbers— 92 is one more than 91 , 93 is one more than 92 , etc.

As the discussion continued, another participant shared her group's method for finding other fractions. She explained that she first converted $1/11$ to $10/110$ and $1/10$ to $11/110$. Then, she stated that $10\frac{1}{2}/110$ was halfway between $10/110$ and $11/110$. She demonstrated this fact by drawing an open number line and marking $1/11$ and $1/10$ on this number line. She then drew a line halfway between these two fractions and indicated that this mark on the number line was the position of the fraction that they had found. At this point in the discussion, the course instructor turned to the whole class and asked a question about this group's method. As he did so, he again referred to the fraction strips:

Instructor: Before you go any further there, if you have one of these fraction strips, how many pieces would it fold up into now?

Participants: [In unison] 110.

Instructor: 110 pieces. Can you go from actually folding 8 or folding 12, to actually thinking in your mind 110 folds? I couldn't do 110 folds; I'm not that good. But I kind of think it's as if I had folded 12 times. It's the same idea. So it's folded into 110 little pieces.

As the discussion continued, the participant explained that her group struggled with how to represent $10\frac{1}{2}/110$. Because they did not like how their new fraction was written (i.e., it was an improper fraction), they split each $1/110$ and created smaller pieces that were one-half of $1/110$, $1/220$.

Again, the instructor asked clarifying questions about how this group generated these smaller pieces. He first asked if her group had folded (or imagined folding) each piece in half. After responding again that they would have 220 pieces, the participant then explained that after splitting each piece in half, they could rename $10/110$ as $20/220$ and $11/110$ as $22/220$. By renaming $10\frac{1}{2}/110$ as $21/220$, they took care of their "problem" of working with improper fractions. So $21/220$ was one proper fraction that they found that was between $1/11$ and $1/10$.

As the whole class discussion continued, several other participants explained how they used different methods to find fractions between $1/11$ and $1/10$. Another group, for instance, renamed $1/11$ and $1/10$ as $3/33$ and $3/30$. They then explained that they could find two fractions between these two fractions, $3/32$ and $3/31$. To justify their answer, they explained that their strategy was similar to when one orders the unit fractions, $1/2$, $1/3$, $1/4$, $1/5$... To find a small fraction, they simply needed to increment the denominator as long as each of these fractions had the same numerator.

As the discussion ensued, the course instructor clarified participants' explanations and asked questions to check for the participants' understandings. Throughout the lesson, participants had opportunities to understand others' methods for finding fractions between two given fractions. As they did so, they began to explore the density property, one of the important properties that is unique to the set of Rational Numbers (and Real Numbers).

Exploring Rational Numbers—Discussion

At the outset of this lesson, we see that the course instructor used a different approach to introduce ideas—an approach that seems quite different from a more traditional lesson about ordering fractions. The course instructor, for instance, referred to different fractions as quantities that represented distances that he could mark on an “open” fraction strip.

His role during the lesson seems different as well. After setting up the problem, participants worked with their partners to solve the task. When they had had time to work on the problem, the course instructor reconvened the class and asked different groups to explain their methods for finding fractions between two fractions. He offered support, asked clarifying questions, and highlighted aspects of their methods during whole class discussion. As such, he and the participants co-constructed an environment in which it was normative to explain and justify their ideas, and to represent their ideas. Interestingly, this characterization of the learning environment fits with what is commonly referred to as an *inquiry mathematics tradition* [8].

One of the earmarks of inquiry mathematics is that participants are thought to work with ideas and representations that are experientially real mathematical objects [8]. In our example, there are several instances of the instructor and the participants doing so. The instructor, for his part, often referred to the participants' ideas using the fraction strip to model ideas. As he did so, he spoke of fractions as values or as having distance. He also referred to this model as he elaborated the participants' explanations. As a result, he provided others the opportunity to

understand a group's reasoning. Further, if participants were confused, they too might imagine using the fraction strip to generate equivalent fractions. So as he facilitated the whole class discussion, he implicitly communicated that he valued these types of explanations, ones in which participants reasoned sensibly with fractions.

For their part, the participants were obliged to give explanations that were couched in their understanding about fractions. Recall, for instance, that when explaining how her group renamed $10\frac{1}{2}/110$, one of the participants drew a number line to demonstrate where this fraction was located on it. She also explained that her group imagined using the fraction strip (suggested first by one of the other course instructors) to split each of the 110 pieces to find an equivalent fraction for $10\frac{1}{2}/110$. Rather than simply applying a procedure for multiplying the numerator and denominator by 2, the participant essentially explained the rationale behind this procedure.

Additionally, as participants worked in small groups, they continued to hold themselves to this same standard. Ms. Smith's attempt to try Ms. Sneider's method is a case in point. As she used Ms. Sneider's method, she also had an opportunity to build some new understandings. Ms. Sneider, too, continued to pursue ideas that eventually led her to develop an argument for the density property for the Real Numbers.

Final Comments

In our discussion, we have addressed how the ideas that participants explored in the course might take on a life of their own as they worked with teachers and their students. In Ms. Smith's case, she had the opportunity not only to facilitate her students' understanding, but also to create an opportunity for Ms. Applebee to reflect on how she might facilitate students' understanding more effectively. Although we do not know if Ms. Smith capitalized on this instance, we could imagine the rich discussion that she and Ms. Applebee might have as they debriefed about this lesson. Similarly, if Ms. Sneider had the opportunity to share with the fifth grade teachers, she and her teachers could have a rich conversation about the important ideas that underpin the "funky cookie" task. Ms. Sneider, however, would need to work hard to make her instructional practices explicit to her teachers because they were not present during the pullout sessions. This said, it would be unfortunate if she did not have the opportunity to share what happened during this pullout session. Although her students might benefit from this experience, their teachers might not have the opportunity to think carefully and deeply about the nature of their students' misconceptions about fractions. Interestingly, Ms. Smith was in a much better position to positively affect her colleague's teaching practice. Although Ms. Smith was a regular

classroom teacher and Ms. Sneider was a Mathematics Specialist, in our two examples they seemed to have (temporarily) switched roles.

We have also addressed the important role that that the course *Rational Numbers* might have played in supporting the participants' mathematical learning. The instructor's role was particularly important here. He required participants to make sense of one another's methods. He also supported them as they gave explanations by asking clarifying questions and elaborating the important ideas that they addressed.

We suspect that the course experiences provided Ms. Smith and Ms. Sneider opportunities to reason deeply about fractions. We also have evidence that they drew on these ideas somehow as they made instructional decisions in order to support their students' learning. In fact, they appeared to have continued to think about ideas, even after the course had ended. As our examples illustrate, they found important ways to use their understanding of these ideas in novel, but different ways.

As we continue to explore the vast amount of data that we have gathered over the last few years, we may gain new insights into how different course experiences support the participants' daily work in schools. Perhaps we will also uncover some of the ways that the program might better serve Mathematics Specialists as they transition into their leadership roles. Can we improve on the courses that we offer? Are there other course experiences that might better support their daily work? As we traverse the data, we hope to answer these as well as other questions. At this juncture, however, we simply marvel at the extent to which the participant's work has begun to truly take on a life of its own.

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VIRGINIA'S MATHEMATICS SPECIALIST INSTITUTE PROJECT: A SUMMARY OF EVALUATION FINDINGS

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Introduction

Horizon Research, Inc. (HRI) serves as the external evaluator for the NSF Institute's "Preparing Virginia's Mathematics Specialists" project, described in a previous article. Participants in this project do coursework at each of three Summer Institutes. These five-week residential experiences have been held on the campuses of Norfolk State, Virginia Commonwealth University, and George Mason University. During each Institute, participants complete two of the five required mathematics courses and the first half of an Educational Leadership course. Participants complete the second half of each Leadership course by February of the following year. At the third Institute, participants complete the final mathematics course, as well as a course entitled, *Mathematics for Diverse Populations*. These nine courses—six mathematics and three leadership courses—are the major components of the Mathematics Specialist preparation program.

In our capacity as external evaluator, we have observed several days of each Summer Institute. In addition, we have surveyed Institute participants and interviewed them on several occasions. Data from these activities point to specific impacts resulting from the Institutes. In this article, we discuss three kinds of outcomes:

- 1) Impacts on Mathematics Content Knowledge;
- 2) Impacts on Participants' Perception of their Pedagogical Content Knowledge; and,
- 3) Impacts on Participants' Perceptions of their Leadership Skills.

We devote one section of the article to each impact, ending with a discussion of participants' thoughts about the residential aspect of the Institute.

Impacts on Participants' Mathematics Content Knowledge

Each summer, HRI conducts several different evaluation activities to assess the impact of Institute courses on participants' mathematics content knowledge. Data from pre- and post-course content assessments, a post-Institute questionnaire, on-site observations, and post-Institute interviews indicate that the courses have affected the participants' mathematics content knowledge substantially.

Over three Summer Institutes, participants complete five mathematics courses. During the first Institute, participants take the *Numbers and Operations* and *Geometry and Measurement* courses. *Rational Numbers and Proportional Reasoning* and *Probability and Statistics* are offered at the second Institute, and participants complete *Algebra and Functions* at the third Institute.

The evaluation primarily uses project-developed assessments to gauge impacts on content knowledge. While some rigorous, externally developed content assessments for teachers exist, only a geometry instrument was aligned well enough with the Institute courses to be considered a fair measure. This assessment was developed by the Learning Mathematics for Teaching project at the University of Michigan, as described by Hill, Schilling, and Ball [1]. Horizon Research scored the *Geometry and Measurement* assessment with a key provided by the instrument developers. In addition, Horizon Research developed scoring guides for all the project-developed assessments. Two staff members, trained to 90% inter-rater agreement, scored the papers.

The data in Table 1 show the pre- and post-course means of participant content knowledge across all five courses. The increase in mean scores is significant, and all the courses appear to have had a large positive effect on participants' mathematics content knowledge. Each effect size is based on a different measure. Therefore, it is inappropriate to make comparisons among courses. For instance, these data cannot be used to argue that one course is more effective than another. This caveat applies to each data table in this article; i.e., effect sizes should not be used to compare courses.

Table 1
Mean Scores for Content Assessments Administered in Institute Courses

Courses (in the order participants completed them)	N	Pre-Course		Post-Course		Effect Size
		Mean	S.D.	Mean	S.D.	
<i>Numbers and Operations</i>	27	71.08	13.69	85.01*	10.03	0.83
<i>Geometry and Measurement</i>	27	55.25	21.58	73.77*	16.29	1.11
<i>Rational Numbers and Proportional Reasoning</i>	26	76.20	14.66	96.03*	6.10	1.44
<i>Probability and Statistics</i>	26	68.73	15.99	88.13*	9.65	1.44
<i>Algebra and Functions</i>	26	46.26	22.64	75.91*	23.66	0.90

*Post-Institute score is significantly different from pre-Institute score (two-tailed paired samples *t*-test, $p < 0.05$).

In addition to the content knowledge assessments, items on the post-Institute questionnaire asked participants to report their perceived preparedness in content knowledge before and following each course. A “retrospective baseline” (asking about prior preparedness *after* the Institute) was gathered because participants often do not recognize gaps in their understanding before taking a course. It is only after they engage with the content that they realize how much they initially did and did not know.

Items on the post-Institute questionnaire addressed specific content presented in each course. Horizon Research combined these items to create course-specific content knowledge composites. For example, on the *Numbers and Operations* questionnaire, participants rated their content preparedness on the following items:

- Mathematics of counting and the natural numbers;
- Place value system; and,
- Structures and concepts underlying the arithmetical operations.

For *Geometry and Measurement*, the following items were included:

- Understanding basic shapes, their properties, and the relationships between them;
- Measuring and understanding of angles; and,
- Solving problems involving right triangles and the Pythagorean Theorem.

Table 2 shows the composite mean scores for impacts on participant perceptions of their content preparedness. To capture the most recent versions of the course, it should be noted that the data for *Numbers and Operations* and *Geometry and Measurement* are from Cohort II participants.

Data for the remaining three courses are from Cohort I, the only group to have completed those courses at the time data were collected for this article. Large effect sizes are evident in all five courses, indicating that participants thought that their content knowledge increased substantially in each course.

Table 2
Composite Mean Scores for Impacts on
Participant Perceptions of Their Content Preparedness

Courses (in order participants completed them)	N	Pre-Course		Post-Course		Effect Size
		Mean	S.D.	Mean	S.D.	
<i>Numbers and Operations</i>	27	53.27	21.68	78.58*	15.22	1.52
<i>Geometry and Measurement</i>	27	37.48	19.33	69.07*	18.39	1.90
<i>Rational Numbers and Proportional Reasoning</i>	24	31.79	25.35	74.62*	16.81	1.92
<i>Probability and Statistics</i>	26	38.68	21.81	69.17*	12.71	1.91
<i>Algebra and Functions</i>	26	41.52	24.74	83.04*	16.89	1.94

*Post-Institute score is significantly different from pre-Institute score (two-tailed paired samples *t*-test, $p < 0.05$).

When asked on the post-Institute questionnaire what they gained from the courses, participants often commented on content knowledge impacts. For instance, in *Rational Numbers and Proportional Reasoning*, twenty-one of the twenty-six responses pointed to impacts on understanding of rational numbers and participants' ability to solve problems in multiple ways. Some of those comments are included here:

- “I gained more knowledge about how the basic aspects of rational numbers may be seen through illustrations as compared to how I was taught with formulas and/or computation.”
- “I feel I have a better understanding of rational numbers and have gained more background knowledge of the content. In *Proportional Reasoning*, I would have solved most situations with a proportion—and solved for the missing value. Now, I can find other ways to do it. It's a much clearer understanding.”
- “I gained a flexible way to look at percents and at fractions. I feel more comfortable using fractions in a variety of ways now.”

Impacts were similarly evident in responses to both closed- and open-ended questions about the *Algebra and Functions* course. An item on the post-Institute questionnaire asked

participants to rate the extent to which they had increased their knowledge of the course content. Two-thirds of participants gave a rating of 6 or 7 on a 7-point scale with 1 being “Not at all” to 7 being “To a great extent.” Similarly, in response to a question about effective aspects of the course, eighteen of the twenty-six responses described having a better understanding of algebra concepts. The following comments are two examples:

- “From this experience, I was able to relearn algebraic concepts with a contextual and conceptual understanding instead of only procedural understanding.”
- “I developed my own understanding of algebra by seeing and identifying patterns in ways I had not understood before. I developed various representations for algebra as well.”

The content courses are the central part of the Virginia Mathematics Specialist program. Offering these courses in an institute setting provides for a focused and intensive experience with mathematics content, and the data point to substantial positive impacts on participants' knowledge of content.

Impacts on Participants' Perceptions of Their Pedagogical Content Knowledge

The post-Institute questionnaire also asked participants about impacts on their pedagogical content knowledge. Shulman originally described pedagogical content knowledge as “the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction” [2]. Participants rated their preparedness to *teach* the mathematics content presented in each course, before and after taking the course. Participants responded to items targeted at pedagogical practices specific to each content course. For example, on the *Rational Numbers and Proportional Reasoning* questionnaire, participants rated their preparedness before and after taking the course on the following items:

- Use examples to show and illustrate the relationship between rates and ratios;
- Show how ratios can be used to represent a variety of relationships within a set and between two sets; and,
- Model and illustrate situations or problems where proportions are used to show patterns of change.

For *Probability and Statistics*, preparedness items included the following:

- Help students recognize the differences in representing categorical and numerical data;
- Have students formulate and solve problems that involve collecting, organizing, and analyzing data; and,
- Provide examples to help students explore concepts of fairness, uncertainty, and change.

At the third Institute, participants completed the *Mathematics for Diverse Populations* course, designed to develop participants' ability to recognize and respond to the needs of learners with a variety of backgrounds and abilities. Items on the post-course questionnaire assessing the increases in preparedness in this area include the following examples:

- Recognize and respond to students' cultural diversity;
- Recognize and respond to students' diverse learning needs; and,
- Encourage the participation of minorities in mathematics.

The items were combined to create "preparedness to teach" composites for each course. The data in Table 3 show pre- and post-Institute composite mean scores for each course. The effect sizes are large across all six courses, suggesting large impacts.

Table 3
Composite Mean Scores for Impacts on Participants'
Perceived Preparedness to Teach Mathematics

Courses (in order participants completed them)	N	Pre-Course		Post-Course		Effect Size
		Mean	S.D.	Mean	S.D.	
<i>Numbers and Operations</i>	27	55.31	20.36	88.64*	13.01	1.82
<i>Geometry and Measurement</i>	27	47.22	19.33	59.40*	18.11	0.96
<i>Rational Numbers and Proportional Reasoning</i>	24	54.21	21.97	73.26*	19.33	1.67
<i>Probability and Statistics</i>	26	46.89	23.78	73.08*	20.20	1.47
<i>Algebra and Functions</i>	26	41.96	20.60	78.90*	17.58	1.89
<i>Mathematics for Diverse Populations</i>	26	66.15	18.66	81.54*	13.51	1.67

*Post-Institute score is significantly different from pre-Institute score (two-tailed paired samples *t*-test, $p < 0.05$).

In responses to open-ended items on the post-Institute questionnaire, participants described both impacts on their ability to teach mathematics content and expected changes in their classroom practice. After completing the *Numbers and Operations* course, nineteen of the twenty-six participants mentioned their intent to provide extra time for students to explore their own ideas and develop algorithms rather than simply providing algorithms and asking students to apply them. Two participants commented:

- “I foresee myself giving my students more time to develop algorithms on their own. I also foresee allowing my students to share their way more and giving them time to explore and develop their own efficiency.”
- “I really want to focus more on developing number strategies with my students instead of the one old traditional method. This course helped me to understand how students can invent strategies. This was a huge breakthrough for me!”

In addition, ten of the participants mentioned their plan to incorporate the use of manipulatives in classroom instruction around number concepts more frequently. One offered this comment:

I will use many manipulatives. I am leaving this course with multiple strategies to offer my students instead of one method. I will provide more open-ended problem solving, rather than fact worksheets. I also want to provide more opportunities for students to use many different strategies and manipulatives to solve a problem.

Similar comments were made by interviewees:

- “Honestly, that class changed the way I do my job. I have so much more knowledge about the way students learn math.”
- “In that class, we always had manipulatives available to use. We worked in groups, sometimes in pairs, and we always took time to talk as a whole class about what we were learning. This is what I want my classroom to be like.”

Many of the participants indicated that the importance of “hands-on” activities and manipulatives was reinforced for them by taking the *Geometry and Measurement* course. Participants also noted the Van Hiele levels of geometric understanding were useful. One participant had this to say:

[The Van Hiele levels] helped me to understand why some kids get it and some don't. As a teacher, I knew some didn't seem to understand some geometry ideas, but I was never aware why, and these Van Hiele levels helped to explain why.

When making open-ended comments on the questionnaire, participants pointed to several examples of expected impacts on their teaching of geometry and measurement concepts:

- “I will give more time for my students to explore and work with shapes, not just waiting for the two weeks allotted in the spring for geometry.”
- “I plan to pay closer attention to how I design assessments. I want to spend more time discussing work, with less focus on covering material. This will help students with building connections and making meaning.”

Similar impacts were evident among participants in the course, *Mathematics for Diverse Populations*. Thirteen of the twenty-four respondents to the post-course questionnaire focused on planning lessons to meet the needs of individual students. The following are two sample comments:

- “I will be better prepared to make necessary modifications based on student needs. I will also be better equipped when planning lessons.”
- “I am going to be more aware of the learning preferences of my students as I plan classroom activities. I’d like to be more reflective in my practice to see if I’m addressing the needs of all learners.”

These comments, as well as the large composite score effect sizes across the six courses, suggest large impacts on the participants’ perceptions of their preparedness to teach mathematics. Such growth, coupled with their deepened content knowledge, will be a valuable asset as the participants assume leadership roles in their schools.

Impacts on Participants’ Perceptions of Their Leadership Skills

Strong mathematics content knowledge and pedagogical content knowledge are important aspects of the project’s vision for what makes an effective Mathematics Specialist. A third part of the vision is leadership skills that enable Specialists to work collaboratively with teachers. During each Summer Institute, participants take the first half of a leadership course. The balance of the course is completed in the fall as participants meet once a month for full-day sessions. Each of the three leadership courses focuses on different aspects of the knowledge and skills Specialists need. *Leadership I* provides participants with opportunities to develop their familiarity with the K–5 *Standards of Learning for Virginia Public Schools*, as well as the NCTM *Principles and Standards for School Mathematics* [3, 4]. *Leadership II* focuses on developing participants’ coaching skills. *Leadership III* continues a focus on coaching skills, includes work on formative assessment and the facilitation of Lesson Study.

At the end of each course, HRI administered a questionnaire to all participants and interviewed a sample of participants for more in-depth information about their experience. As with the other questionnaires, individual items were combined into composite variables reflecting the central themes of each course. For *Leadership I*, course participants indicated their familiarity (both before and at the end of the course) with the Virginia *Standards of Learning (SOL)* and the NCTM *Principles and Standards for School Mathematics* [3, 4]. For *Leadership II*, examples of items used to form a coaching composite included asking participants to rate their familiarity with the following:

- Coaching as a model for teacher professional development;
- The skills required to be an effective coach for mathematics professional development; and,
- The challenges of coaching experienced teachers.

For *Leadership III*, three composites were formed focusing on participants' familiarity with the following items:

- Formative Assessment
- Strategies for Coaching
- Lesson Study

Table 4 shows the pre- and post-course means for the composites in each of the three leadership courses. The data suggest that *Leadership I* participants' familiarity with standards documents increased substantially. Participants also showed large increases in their familiarity with coaching as a result of *Leadership II*; effect sizes associated with *Leadership III* are similarly large.

Table 4
Composite Mean Scores for Participants' Familiarity with Leadership Course Topics

Courses (in order they were offered)	N	Pre-Course		Post-Course		Effect Size
		Mean	S.D.	Mean	S.D.	
Leadership I Composites						
Virginia's <i>Standards of Learning</i>	27	46.30	24.28	67.49*	26.14	1.55
NCTM <i>Standards for School Mathematics</i>	26	20.51	22.81	68.80*	25.73	2.40
NCTM <i>Principles for School Mathematics</i>	26	13.08	23.13	73.85*	25.15	2.31
Leadership II Composites						
Peer Coaching	27	49.58	24.67	88.18*	13.47	1.86
Leadership III Composites						
Formative Assessment	25	55.67	25.43	91.33*	14.53	1.63
Strategies for Coaching	25	53.56	19.70	91.11*	12.21	1.88
Lesson Study	23	18.36	28.55	95.17*	10.50	2.52

*Post-Institute score is significantly different than pre-Institute score (two-tailed paired samples *t*-test, $p < 0.05$).

Data from open-ended questionnaire items about effective aspects of the courses provide evidence of the participants' positive views. For instance, one *Leadership I* participant wrote:

The course was helpful in understanding the NCTM *Standards* for each area—*Numbers and Operations, Geometry and Measurement*. I also think looking at the *Standards* and correlating them with activities and the tasks we give to students [was helpful]. As a Math Specialist, the coursework prepared me by giving me knowledge and skills to manage the standards and consider ways to effectively apply them in the classroom.

Participants highlighted coaching-related aspects of *Leadership II*. Of the twenty-seven participants responding to an open-ended item about effective aspects of the course, twenty-one commented on the coaching part. Participants were enthusiastic about the project, in which they videotaped themselves coaching another teacher in their school. Two examples of open-ended responses around coaching and the usefulness of the coaching project were:

- “The videotaping experience was extremely meaningful in reflecting on my own videotape and through watching the videos of my cohort members.”

- “I found the readings very helpful, as well as the class discussions. The process of the videotape assignment also furthered my understanding.”

There were large increases in participants' ratings of their familiarity with Lesson Study, and positive comments about Lesson Study featured prominently in open-ended questionnaire responses (eleven out of twenty-five responses). Some examples included the following:

- “The focus on Lesson Study taught me how to successfully plan with teachers to develop meaningful lessons.”
- “The opportunity to participate in a Lesson Study group was hugely rewarding.”

Data from the post-course questionnaires, and interviews, show the extent to which participants' perceptions of their leadership skills have grown. With a deepened understanding of mathematics and strong pedagogical content knowledge, these leadership skills position the Specialists to work successfully with teachers.

The Residential Aspect

The Summer Institutes are unique learning experiences that impact participants in substantial and meaningful ways. The Institute's residential setting likely heightens the learning experience beyond other professional development settings, such as workday, evening, or on-line classes, which fit more conveniently into the schedule of practicing teachers. Participants' comments show the value placed on living and working together. Included among them are the following examples:

- “I guess I'd say again everyone being together on campus gave us lots of opportunities to work together on the projects and share ideas and help out one another.”
- “The most helpful aspect was being able to talk, share, and ask questions in the evenings in the dorms. If I left class confused and frustrated, I was able to get help in the evenings from classmates.”
- “I think it was a great opportunity. I never imagined that I would grow so much in twenty days. The dinner panels and excursions made it a great experience. They provided a needed break and gave us the opportunity to leave the academics and build more relationships with one another.”
- “I think it was very good, very professional and respectful. I am very pleased. You work really hard, but you are learning a lot. The dinner panels and excursions were very

helpful. We learned more about the program and what was going on with Math Specialists.”

Obviously, the teachers who come to the Institutes are those whose schedules can accommodate a five-week residential experience. Still, all made sacrifices to attend, and they seem to feel that they received much more in return.

Summary

In the most general terms, the project’s theory of action is to work on three fronts simultaneously—developing participants’ mathematics knowledge, pedagogical content knowledge, and leadership skills—in a residential institute setting. The evaluation has produced a large body of evidence strongly suggesting that this model impacts the participants positively and substantially. Whether the outcome is content knowledge, pedagogical content knowledge, or leadership skills, participants report large positive changes. With regard to knowledge of mathematics, end-of-course content assessments provide more objective and similarly compelling evidence of impact. Comments from teachers suggest the residential aspect led to deeper impacts than they might have experienced in more traditional professional development settings.

At the end of July 2008, the project had completed its fifth Institute, each one an immense investment of time for the project and the participants. Impact data indicate that the return is well worth the investment.

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THE IMPACT OF THE LEAD TEACHER PROFESSIONAL LEARNING COMMUNITY WITHIN THE RICE UNIVERSITY MATHEMATICS LEADERSHIP INSTITUTE

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Abstract

Now in its fourth year, Rice University's Mathematics Leadership Institute (MLI) has developed over sixty high school mathematics Lead Teachers. We focus on how membership in MLI has impacted participant teachers' professional lives. The Lead Teacher community that emerged during MLI's first Summer Leadership Institute embodies the characteristics of a sustaining and coherent *knowledge* community where teachers are able to share their secret "stories of practice in safe places . . . in order to make their personal practical knowledge explicit to themselves and to others" [1]. This article includes stories of individual teachers who refused to sacrifice hours of instructional time for mandated curriculum testing, who encouraged and supported a large group of MLI teachers to participate in a grueling advanced certification program, and who challenged the local administration's expectation to compromise personal professional standards. These stories may not have emerged in their particular ways had these teachers and their supporting co-manager not been members of this coherent and sustained knowledge community. This knowledge community has enabled the achievement of MLI goals with respect to teachers' increased mathematics content knowledge, leadership development, and student achievement. We also include focus group comments and quantitative data.

Introduction

In 2004, the Mathematics Leadership Institute (MLI), a National Science Foundation-funded Mathematics and Science Partnership (MSP), was established as a partnership among Rice University and Houston Independent School District (HISD) and Aldine Independent School District (AISD). During its longstanding relationship with these two districts, Rice University advised and collaborated with district-level mathematics directors on districtwide initiatives, and in individual schools and with mathematics teachers of all grade levels. The MLI was conceptualized when the University, unable to meet the huge demand for mathematics support for many of the schools in the two districts, identified the need for on-site mathematics leadership and support in their high schools. The districts' traditional professional development workshops

and centralized support may have inspired teachers, but follow-up enactment in classrooms did not occur to any noticeable extent. This phenomenon has been documented widely [2-4].

A major goal of MLI is to develop two cohorts of high school mathematics Lead Teachers to serve as intellectual leaders and mathematics advocates on their campuses. In this capacity, Lead Teachers may act as change agents responsible for catalyzing reform in mathematics instruction at their schools. They may lead course-level planning meetings, mentor new teachers, critique and advise on programs that affect mathematics in the school, and present at teacher conferences. Each MLI cohort attends two Summer Leadership Institutes, each for a four-week period for two consecutive summers. The focus of these Institutes is to develop teachers' mathematical pedagogical content knowledge, leadership skills to interface with administrators and mentor peers, and to think about school and classroom diversity in new ways, ultimately to increase student achievement in participating schools. The MLI teachers also meet regularly during the academic years over the five-year life of the grant.

The Context

The MLI initially intended to support eighty Lead Teachers in forty high schools in two teacher cohorts (beginning June 2005 and June 2007, respectively) across HISD and AISD. Although HISD is approximately three times larger than AISD and varies with respect to some important administrative features (see Appendix A), the student and teacher demographics between the districts are comparable in terms of ethnic and socioeconomic diversity (see Appendix B and Appendix C). Currently, HISD supports thirty-five MLI teachers while AISD supports nine. Due, in part, to decentralization and conflicting philosophies about teacher leadership, Lead Teacher participation did not occur to the extent of the goal. The Institute has suffered some attrition due to retirement, transfer to non-participating districts, promotion to central office mentoring positions, departure from the profession, and death. To increase the number of Lead Teachers in the Institute, schools were invited to send more than one Lead Teacher to each cohort, resulting in more than two Lead Teachers in some schools from the start. Over time, some Lead Teachers moved to other schools that were already participating in MLI so that one school had four Lead Teachers after the second cohort joined the Institute. Appendix D shows Lead Teacher enrollment numbers and attrition from the onset of MLI in June 2005 through academic year 2007-2008. Appendix E shows MLI school participation and the number of Lead Teachers on AISD and HISD campuses.

Theoretical Foundation

Clandinin and Connelly adopted the metaphor of teachers' professional knowledge landscapes to capture the complexity of teacher knowledge expressed through the contexts in which teachers live [5]. Teachers' professional knowledge landscapes are composed of relationships among people, places, and things. In particular, the landscape comprises two "fundamentally different places, the in-classroom place and the out-of-classroom place" [5]. Generally, the out-of-classroom place is "littered with imposed prescriptions . . . filled with other people's visions of what is right for children" [6]. These impositions, designated *sacred stories*, to which teachers are obliged to respond, reach teachers through communication channels metaphorically denoted as the *conduit* [7]. Teachers' responses to these sacred stories are designated *cover stories*, but these may take on a very different appearance to teachers' actual practices within the closed confines of their classrooms [8]. In-classroom practices are designated *secret stories* which are essentially free from scrutiny [6]. Furthermore, Olson and Craig define a *knowledge community* as a safe communal place in which teachers can share their secret stories in ways that engender intellectual and professional growth [9]. Knowledge communities may evolve in formal or informal settings. They may exist between only two members or among larger groups. Knowledge communities evolve, expand, or sometimes dissolve, temporarily or permanently depending on the nature of the relationships among those who are present at any given time. For this study, the MLI community of Lead Teachers represents a knowledge community that arose from formal roots [10].

The Emergence of the MLI Knowledge Community

The MLI Lead Teachers participate in two consecutive Summer Leadership Institutes. These summer professional development Institutes run for four weeks, seven hours per day. During the first week of the first cohort's June 2005 Summer Leadership Institute, the Lead Teacher community took on particular characteristics of a knowledge community. Author and MLI Manager, Sack, in her previous position as a middle school mathematics classroom teacher, had experienced knowledge community first-hand through her school's internal structure of academic teams. Aware of the empowerment potential of membership in a knowledge community, Sack explicitly sought to create a workable learning community among the MLI Lead Teachers, hoping that small knowledge-community groups would evolve. However, she was also aware of the elusiveness of knowledge communities, but when individual participants began to share their own secret stories to the whole cohort and to its manager, Sack knew that a large knowledge community had formed [10, 11]. Throughout the ensuing academic year and the first cohort's second year, including its second Summer Leadership Institute, the knowledge-

community character persisted. A difficult situation arose that threatened to disrupt the second Summer Leadership Institute when a visiting instructor failed to recognize the group's needs. Group members openly shared their concerns directly with Sack even though they were aware of her close professional and personal relationship with this instructor. As a result, the instructor and Sack were able to work together to resolve the problem through their knowledge-community relationship. This story of the teachers' empowerment, afforded through knowledge-community membership, has been documented elsewhere [10].

The following sections of this article reflect evidence and impact of the intellectual and professional growth that resulted from the existence of this particular knowledge community. Quantitative achievement data were obtained from testing sources. Supporting data were culled from the MLI Manager's ongoing field notes and from an academic year focus group discussion using participants' written comments (November 2007). For the focus group discussion, Lead Teachers were asked to discuss and write how the MLI teacher community had impacted them personally, in their classrooms, and in their interactions with peer mathematics teachers and administrators on their campuses. The focus group comments were then organized by emergent themes. The authors and the MLI's external evaluator compared their analyses and agreed by consensus on the following themes that are presented in this article: personal confidence, collegial support, communication skills, raising the bar, risk taking, and interactions with peers and administration at their own schools. During transcription to a data file, focus group comments were dissociated from teacher identity. In the following sections, " T_n " refers to any teacher, where n ($n=1,2,3,\dots,22$) is a non-identifying label used to distinguish unique teachers. The comments associated with any T_n were culled from the focus group discussion. The data in this document were shared with participating Lead Teachers during their February 2008 academic year meeting, serving as the member check for the research dissemination.

Impact of MLI—Personal Confidence

Teachers' self-confidence grew through their membership in the MLI community. Of note, T1 benefits from validation of ideas through sharing; T2 expresses the personal sense of status from this community; and, T3 combines both in his/her sense of personal worth.

T1: "The leadership program has helped me to grow as a person in self confidence and have more self assurance, to share my thoughts and ideas and feel they may

be of some importance or value. (I often tell my students not to be afraid to be wrong, you just might be right.)”

- T2: “My confidence as a teacher, as a teacher of teachers, as a mathematician, and even as a member of my community has grown beyond my dreams. Understanding mathematics and especially being able to teach math puts us in a sort of higher standing in our community because so many people cannot understand mathematics, thus they honor those who can. But I never really had the confidence that goes with that status. Because of MLI and the opportunities to learn more mathematics and more about teaching math, I feel very comfortable in that role now.”
- T3: “I have great self doubts at times. The group has helped me to feel more confident. I am a smart person who has something to share with others.”

Impact of MLI—Collegial Support

Closely related to growth in personal confidence, several teachers specifically referred to mutual support within the MLI Lead Teacher community which has resulted in an individual and collective sense of empowerment, especially when in need of support in the face of difficult conduit directives.

- T4: “I have made such good friends through MLI and have established partnerships with people I know I can call on for help.”
- T5: “This program has empowered us as a group to collectively and cooperatively address both positive and negative issues. I now have cohorts on all campuses to help deal with a myriad of issues from teaching strategies to district policies.”

After completing two Summer Leadership Institutes, Lead Teachers in the first MLI cohort were offered the opportunity to obtain an advanced certification, the Texas Master Mathematics Teacher Certificate (8-12) (MMT). Unlike other states, Texas does not require teachers to obtain graduate degrees to maintain their certification credentials following their induction years as teachers. The MMT certification was introduced in 2001 “to ensure that there are teachers with

special training to work with other teachers and with students in order to improve student mathematics performance” [12]. To obtain the MMT certificate, candidates must enroll in a rigorous preparation course consisting of 120 contact hours. Candidates were expected to complete extensive mathematics assignments across the high school curriculum, as well as readings on professional development standards for teacher mentors and leaders. Finally, candidates must pass a rigorous five-hour examination that includes both mathematics content and a written response to a difficult case study dealing with pedagogical content knowledge. Daunted by the challenge of revisiting upper-level mathematics that many Lead Teachers had left behind when they completed their undergraduate studies many years before, many shied away from this opportunity for professional growth. “Jane,” fictitiously named to protect her identity, encouraged the whole cohort to register for the program, promising study group support for the entire year.

The MLI’s goal was to increase the number of MMT-certified high school teachers by 15% across the state. Jane’s unsolicited recruitment efforts and teachers’ beliefs that they would receive support from each other resulted in twenty-two out of thirty Lead Teachers registering for the course. All nine AISD teachers, including Jane, registered. The MLI co-manager also enrolled to provide additional support throughout the year. Jane lived up to her promise and arranged study group meetings throughout the MMT preparation year. During Summer 2007, of the twenty-two Lead Teachers who participated in the course, nineteen tested (86%) and fifteen (79%) were successful on the examination. This MLI achievement increased the number of grades 8-12 MMT-certified teachers in Texas by 56%. In May 2008, the number of MLI MMT-certified teachers increased to sixteen and raised the MLI impact on the initial number of MMT-certified teachers in Texas to 59% (see Appendix F).

Collegial support extended beyond personal interactions. The result of close collaboration during the Summer Leadership Institutes and the intensity of the MMT experience made a huge difference in Lead Teachers’ classrooms as noted in the following focus group comments:

T6: “I can assist my students better from having shared experiences with others.”

T7: “If I am unsure of a way to handle a situation, I have a great number of people to share with and try to find a solution.”

- T8: “Being part of MLI has helped me see that I am part of a community, a movement, a force of people who are in education not for the summer vacations, not for themselves, not for political reasons, but for a belief that they can help young people learn, achieve, and succeed. This knowledge that you are not alone is powerful, especially when you feel like a lone warrior in the classroom who battles indifference, lack of motivation, and the immaturity of ninth graders daily while pushing back the low standards of public education.”

Impact of MLI—Communication Skills

The MLI’s focus on leadership included formal communication development. A small group of Lead Teachers accompanied the MLI co-manager to a leadership institute sponsored by the Center for Leadership and Learning Communities following their second Summer Leadership Institute [13]. The group then provided the same development for the whole cohort during the academic year. Several focus group comments attested to the value of becoming better listeners and more supportive as a result of their MLI experiences.

- T9: “I know that I have grown. I am more patient and willing to understand others’ plight. I am more positive in situations where others may be more negative.”
- T10: “During the summer meetings, I learned a lot about coaching in a non-threatening manner. My personality is very straightforward and to the point. I have learned how to be straightforward and to the point and also encouraging and gentle at the same time.”
- T11: “As a math teacher, I feel more confident, but also more humbled. Because I have just left the classroom, once again, after completing the Master Mathematics certification and MLI training, I remember what it is like to be a student. I am more receptive to change and to respecting individual learning styles and moods. I am more concerned about my classroom milieu than I once was. However, I am also more serious and demand more from my students. I set high standards because they are expected of me, by MLI, RUSMP [Rice University School Mathematics Project], NCTM [National Council of Teachers of Mathematics], and HCC [Houston Community College] and Rice

University. And now that I know what HCC requires, I can better prepare my students to be successful when they take math from the college.”

Impact of MLI—Interactions with Peers at Own School

Developing good communication skills through MLI enabled Lead Teachers to develop trusting relationships with teachers on their campuses.

- T12: “Being the math Lead Teacher has allowed me to spend a larger amount of one-on-one time with teachers that need help. Some of our conversations have been very candid and being the Lead Teacher has opened that door.”
- T13: “I want to say they now seek my advice but they kind of always did that. But now I actually know what I’m saying to them...”
- T14: “I always have a good rapport with my peers, but going through the training [at MLI], I became much better as far as communicating or dealing with situations that involve the other teachers.”

Impact of MLI—Interactions with Administration at Own School

Lead Teachers are comfortable sharing stories of school with MLI management who share membership in the Lead Teacher knowledge community. Generally, in their focus group comments about interactions with campus-level administrators, Lead Teachers were very positive.

- T15: “My efforts and hard work to improve the department is being appreciated. Administration is now more willing to take action on my suggestions.”
- T16: “They somehow listen to some suggestions, provided that they are in a "good mood."
- T17: “We've always had a good rapport and it strengthens...and grows.”
- T18: “I rely on them less unless I have problems; they relegate responsibility to me and I find other supportive systems besides administrators—they respect me for my resourcefulness!”

In some schools, the MLI opportunity was initially seen as a worthwhile professional development opportunity for interested teachers. In others, newly placed principals inherited programs, including the MLI, from past administrations. Many schools are struggling to avoid the punitive “low-performance” Annual Yearly Performance grade [14]. Consequently, many intervention programs, instituted by a variety of specialists and consultants in schools funnel down the conduit and interfere with teachers’ daily practice. Lead Teachers’ focus group comments were not all positive and reflected these situations.

T19: “We have a new set of administrators. I know, all they know is, I am the Algebra II leader.”

T20: “They [administration] are already planning who to blame if the scores drop. They are not planning for the future, they are planning for the excuse.”

T21: “The administration seemed to have a lot of hidden agendas and did not ask for or listen to [Lead] Teachers.”

T22: “No comments.”

How do Lead Teachers respond to administrative decisions and directives that negatively impact student learning and ultimately, student achievement? By sharing stories through existing trust relationships with other members of the MLI knowledge community, Lead Teachers are empowered to deal with difficult situations. For example, schools and district-level offices demand additional assessments be conducted in many schools, some on a weekly basis. The data are used to identify areas of content weakness. These directives impact more than 20% of classroom instructional time, in testing and then reviewing after the test. “Rosemary,” with MLI support, chose to allow only ten minutes to be devoted to the weekly test, especially when she knew most of her students would fail. This way, she maintained her instructional time, kept the stress levels in her classes down, and focused on instruction. Remarkably, within a few weeks, Rosemary’s students began to pass her ten-minute tests. Her students’ passing rate was about 28% on the high-stakes state-mandated test the year before and increased to about 68% after she had taught them for a year.

Another Lead Teacher, “Andrea,” stepped out of typical high school teacher boundaries in response to challenges from administration that threatened her sense of professionalism. As

leader of her school's Algebra I instructional team, she was required to meet in the same room and at the same time as other mathematics teams, devoid of resources and a place to demonstrate instructional strategies. After moving her team to an adjacent room, she was formally admonished by her administrator. In protest, after getting nowhere with requests to negotiate better meeting arrangements, she resigned from her leadership role. The MLI Manager supported Andrea's decision and marked the event up as an administration roadblock. Andrea demonstrated an ability to step beyond her comfort boundaries in other ways. The following comment was culled from a communication she e-mailed directly to the MLI Manager:

I have not only learned in an intellectual sense, but also in an emotional sense when relating to students. I grew up in a traditional Asian family, and the teacher was thought of as an authority figure, distant from her students. This paradigm seemed to work in a private school setting where students are more motivated and self-contained, but it is more challenging to teach high-risk students in inner-city schools. Listening to other Lead Teachers during the summer sessions taught me that I had to go beyond my comfortable boundaries to reach students who come from very different backgrounds than I do. As one of the youngest members of the MLI group, I feel privileged to be around a group of teachers with so much experience, wisdom, and heart. It takes heart (or stubbornness, or both!) to stay in education for twenty-something years. I learned to ask students about their lives and show them that I care about them as people. Students respond emotionally, not so much rationally, and they will work for you if they see you are working for them. I learned that from my MLI colleagues.

Conclusion

The MLI Lead Teacher knowledge community has empowered its members to stand up for themselves and for each other in particular ways. It represents a center of refuge when members feel the pressures from the conduit, a place to vent out of reach of the conduit, and a wide circle of support when teachers enter into difficult or challenging professional pathways. Members share secret stories about how they respond to sacred stories, join hands when interesting opportunities arise and celebrate their membership in this community at every gathering opportunity. Through membership in this community, teachers have raised the bar on standards for learning in their own classrooms and have shown ultimate proof of the value of the MLI MSP through their own students' achievement scores (see Appendices G-J).

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Appendix A
Administrative Characteristics of the School Districts, 2005–2006 and 2006–2007

	<u>AISD</u>	<u>HISD</u>
TEA Accreditation	Full	Full
Comparative Size [^]	12 th largest in Texas	Largest in Texas 7 th Largest Nationally
Square Miles [^] (approximate)	111,000	301,000
Number of Schools [^]	86	295
<hr/>		
Years Teaching Experience (Average)	10.2	11.6
<hr/>		
<u>Annual Salaries*</u>		
Beginning teachers	\$36,343	\$36,114
6–10 years	\$42,694	\$41,308
Over 20 years	\$60,910	\$58,441
<hr/>		
Teacher Turnover Rate	16.8%	14.9%
<hr/>		
Secondary Mathematics Class Size	22	24
Student Teacher Ratio	15 to 1	17 to 1
Attendance Rate*	95.8%	94.7%
Drop-out Rate (Gr. 7–12)*	3.3%	4.7%
<hr/>		
<u>Expenditures*</u>		
Per-pupil	\$8,378	\$9,691
Instruction and Instructional- Related Services	\$4,755	\$4,671

Sources: Texas Education Agency, Academic Excellence Indicator System, 2005–2006* and 2006–2007 and District websites[^] Expenditures represent all funds, per-pupil.

- HISD is geographically about three times the size of AISD, with over 200 more schools.
- Districtwide, AISD teachers have an average of 1.4 fewer years of teaching experience than HISD teachers, are paid at a higher rate, and have a higher turnover rate.
- On average, AISD teachers had two fewer secondary mathematics students in their classes and an overall student-teacher ratio that was lower by two than HISD teachers.
- Attendance and dropout rates differed by 1.1 and 1.4 percentage points, respectively, in favor of AISD.
- Per-pupil expenditures were \$1,313 higher in HISD, while instruction/instructional-related services expenditures were \$84 higher in AISD.

Appendix B
District Student Demographics, 2006–2007

	<u>AISD</u>	<u>HISD</u>
Total Enrollment	58,596	202,449
<u>Ethnicity</u>		
African-American	31%	29%
Asian	2%	3%
Hispanic	62%	59%
Native American	<1%	<1%
White	4%	8%
Total	100%	100%
Economically Disadvantaged	81%	78%
At-Risk	68%	66%
English Language Learners (ELL/LEP)	28%	27%
Bilingual	26%	26%
Special Education	9%	10%
Gifted/Talented	5%	12%
Recommended HS Program Graduates, 2006	73%	85%
Disciplinary Placement, 2005–06	2%	2%

Source: Texas Education Agency, Academic Excellence Indicator System, 2006–2007

- Reflecting their relative geographic sizes, HISD student enrollment was more than three times AISD student enrollment.
- The districts serve ethnically and socio-economically diverse, urban populations.
- Across districts, Hispanic and African-American students represent the largest groups, with twice as many Hispanic than African-American students.
- Overall, AISD and HISD student populations reflect more similarities than differences.
- With the exceptions of Gifted and Talented students and Recommended High School Graduates, the districts varied by no more than 4 percentage points within student groups.

Appendix C
MLI Lead Teacher Demographics, 2006–2007

	<u>AISD</u>	<u>HISD</u>	<u>Total</u>
Current Participation	13	38	51
Male	7.7%	26.3%	11
Female	95.3	73.3%	40
Age	36–48	31–73	—
Teaching Experience	8–19	2–51	—
Race/Ethnicity			
African-American	69.2%	36.8%	23 (45%)
Asian	15.4%	23.7%	11 (22%)
Hispanic	0%	5.3%	2 (4%)
Native American	0%	0%	0
White	15.4%	31.6%	14 (27%)
Other	0%	2.6%	1 (2%)

Source: MLI Databases, 2005–2008

- MLI Lead Teachers mirrored the relative sizes of the districts, with a one-to-three ratio of AISD to HISD participants.
- Excluding one to three outliers, in both districts the vast majority were in their 30's and 40's and possessed 8–20 years of teaching experience.
- They were typically African-American, White, or Asian.
- MLI teachers in HISD represented a more diverse group based on age, teaching experience, and race/ethnicity.

Appendix D
MLI Cohort I and Cohort II Teachers, 2005–2008

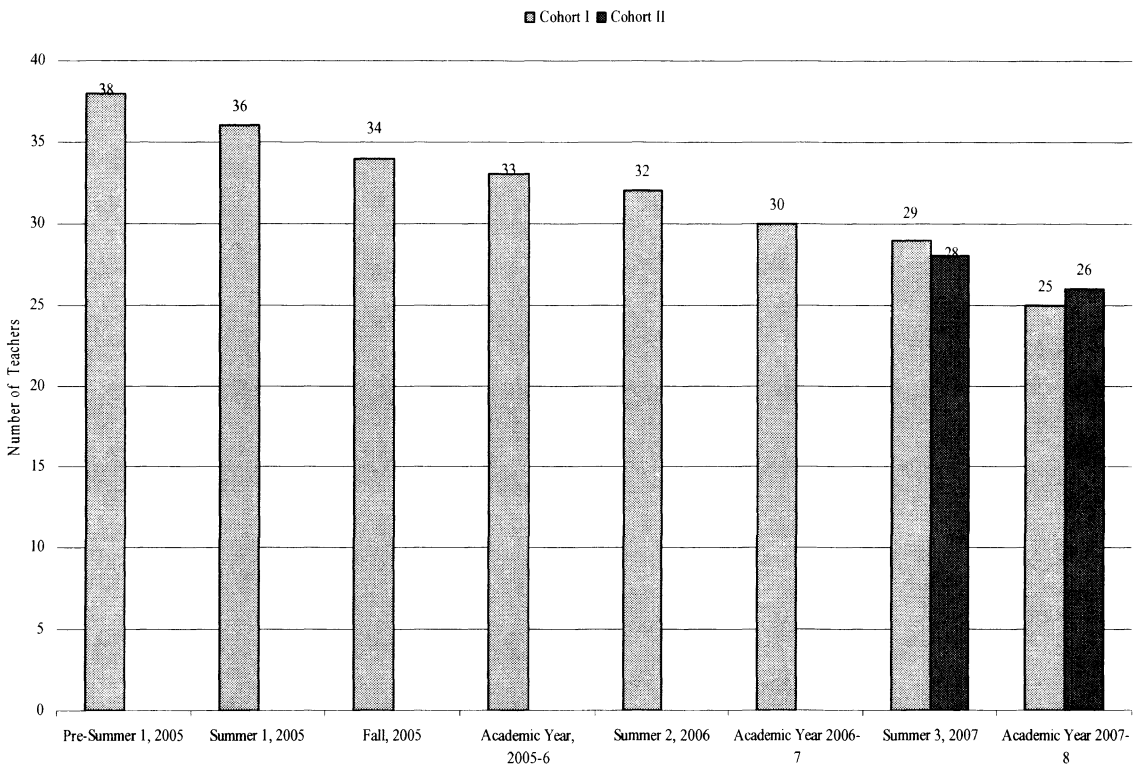


Figure 1. MLI Lead Teacher participation by year, 2005–2008.

- A combined total of 33 AISD and HISD Cohort I MLI Lead Teachers participated in the first Academic Year in 2005–06.
- The number of Cohort I MLI Lead Teachers decreased to 30 by the second Academic Year, 2006–07.
- With the addition of Cohort II, the number of MLI Lead Teachers grew to 51 by the third academic year, 2007–08.

Appendix E
MLI School Participation, 2006–2007

	<u>AISD</u>	<u>HISD</u>
<u>MLI Schools</u>	9	25
<u>MLI Teachers</u>		
1 MLI Teacher	5	16
2 MLI Schools	4	6
3 MLI Schools	-	2
4 MLI Schools	-	1
Total Teachers	13	38

Source: RUSMP databases and pre-program surveys, May 2005 through January 2008.

- There were 34 campuses across the districts with MLI Lead Teachers.
- HISD was represented by nearly three times the number of AISD schools (nine and twenty-five schools, respectively).
- There was one MLI teacher on twenty-one (62%) of the participating campuses and two MLI teachers on ten (29%) of the campuses.
- None of the AISD campuses housed more than two MLI participants, while two HISD campuses (6%) housed three MLI teachers and one campus (3%) housed four.

Appendix F
Number of Master Mathematics Teacher (MMT) Certifications in Texas

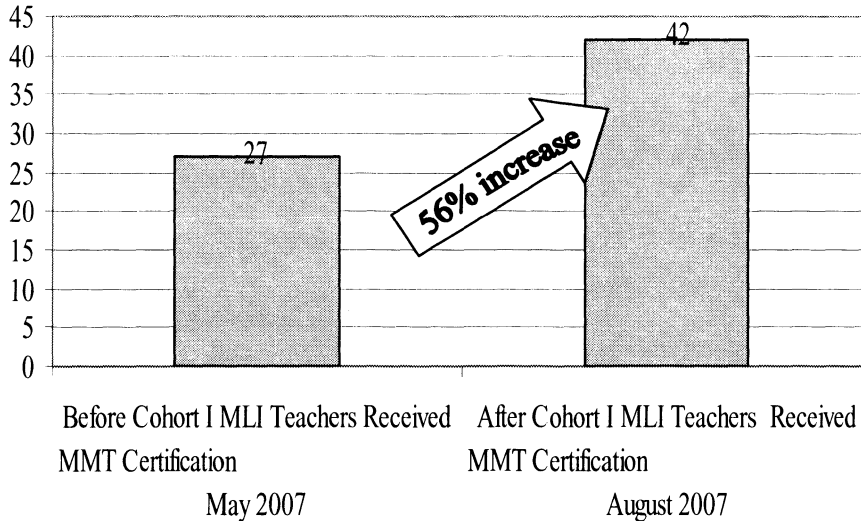


Figure 2. The impact of MLI Lead Teacher MMT certification in Texas, 2007.

Source: TEA, State Board for Educator Certification communication with MLI Manager, September 11, 2007.

- The number of MMT Grades 8–12 certifications across the state was twenty-seven in May 2007.
- The number increased by 56% when fifteen MLI teachers received certification in August 2007.
- Additional information indicated this increase far exceeded the MLI strategic plan for a 15% increase with the first cohort and the 20% goal projected for both cohorts.
- In May 2008, the number of Cohort I MMT-certified teachers increased to sixteen resulting in a 59% increase in the number of MMT-certified teachers in Texas relative to the number of MMT-certified teachers prior to MLI's participation.

Appendix G								
TAKS Scale Scores for Students of MLI Teachers, 2005–2007								
	Year 1				Year 2			
	<u>Spring 2005</u>		<u>Spring 2006</u>		<u>Spring 2006</u>		<u>Spring 2007</u>	
% Met Standard => 2100	55.3		62.7		61.1		65.5	
% Commended => 2400	11.5		10.9		12.8		15.5	
Lowest 10% Range	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>High</u>	<u>Low</u>	<u>High</u>
	1276	1909	1654	1936	1034	1924	1597	1945

Source: School Districts' TAKS Databases, Spring 2005 through Spring 2007.

Data Analysis: Students' scale scores on the state-mandated, criterion-referenced Texas Assessment of Knowledge and Skills (TAKS) were assessed. Baseline 2004–05 student performance preceded the first MLI program in summer 2005. Year 1 (2005–06) and Year 2 (2006–07) test scores of students in Cohort I MLI teachers' mathematics classrooms were analyzed. Year 1 student achievement results for thirty-one of the thirty-three Cohort I MLI teachers (94%) were analyzed in Spring 2006. Omitted teachers were not in instructional positions during the 2005–06 academic year. Year 2 results were available for all thirty Cohort I MLI teachers in Spring 2007.

- The percentage of students of MLI teachers meeting or exceeding the 2100 TAKS passing score increased in Year 1 from baseline (Spring 2005) by 13.4% and again in Year 2 by 7.2% from Spring 2006 to Spring 2007. Overall, 18.4% more students of MLI teachers passed the TAKS from baseline to Year 2.
- In Year 2, the percentage of MLI teachers' students achieving commended status increased 21.1%. Overall, 34.8% more students of MLI teachers achieved commended status on the TAKS from baseline to Year 2.
- Students' lowest scores increased 29.6% in Year 1 and 54.5% in Year 2.
- Students' scores on the upper end of the lowest 10% increased 27 points in Year 1 and 21 points in Year 2.

Appendix H
Gains on Lowest TAKS Scale Scores for Students of MLI Teachers, 2005–2007

	<u>Lowest Scale Score</u>	<u>% TAKS Knowledge Possessed</u>	<u>% Knowledge Needed to Pass TAKS</u>	<u>% Annual Gain</u>
<u>Year 1</u>				
Spring 2005	1276	60.8%	39.2%	
Spring 2006	1654	78.8%	21.2%	29.6%
<u>Year 2</u>				
Spring 2006	1034	49.0%	51.0%	
Spring 2007	1597	76.0%	24.0%	55.1%

Source: School District TAKS Databases, Spring 2005 through 2007.

- Based on the 2100 TAKS passing score, gain in the lowest score from Spring 2005 to Spring 2006 (Year 1), improved the knowledge needed to pass the TAKS by 29.6% (from 60.8% to 78.8%).
- Gain in the lowest scores from Spring 2006 to Spring 2007 (Year 2), improved the knowledge needed to pass the TAKS by 55.1% (from 49.0% to 76.0%).

Appendix I MLI Cohort I Teachers' Student Achievement

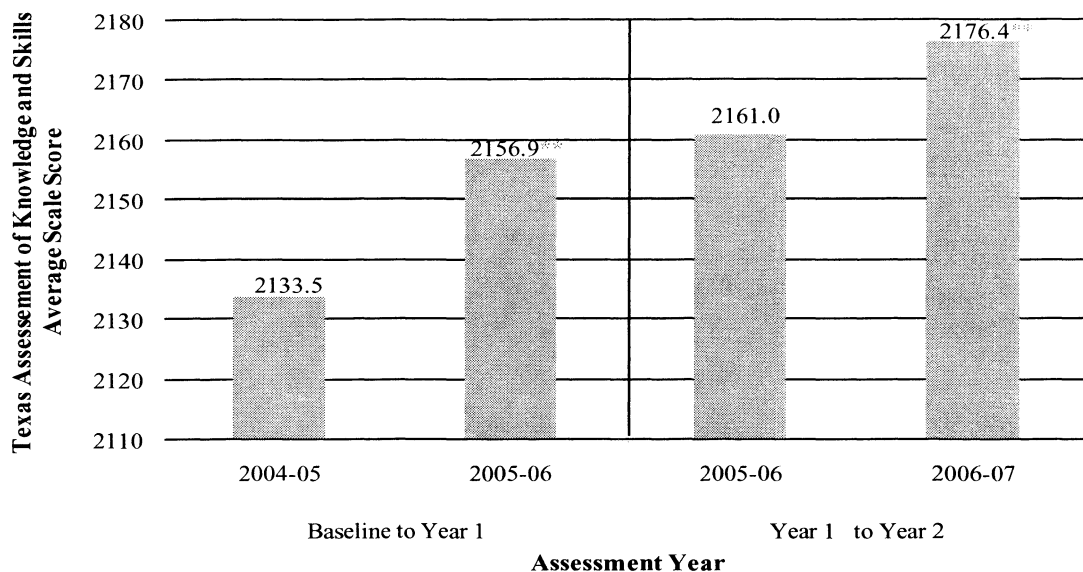


Figure 3. Year 1 and Year 2 TAKS achievement gains of the students of MLI teachers.

Source: AISD and HISD TAKS databases, Spring 2005 through Spring 2007.

Data Analysis: Student achievement results for Cohort I MLI teachers were analyzed in 2005–06 (N=31) and 2006–07 (N=30). Omitted teachers were not in instructional positions during the 2005–06 academic year. Aggregated scale scores on the state-mandated, criterion-referenced Texas Assessment of Knowledge and Skills (TAKS) were assessed. Baseline 2004–05 student performance preceded the first MLI program in Summer 2005. In Year 1, 2005–06, an independent *t*-test analysis was conducted to compare the mean scores of students in MLI teachers' mathematics classrooms to the scores of students in MLI teachers' 2004–05 mathematics classrooms. This strategy was repeated in Year 2 (2006–07) by comparing MLI teachers' 2006–07 student scores with their 2005–06 students' scores.

- The mean scores of students of MLI teachers exceeded the 2100 TAKS passing score in Year 1 and Year 2.
- MLI teachers' students achieved statistically significant gains each year.
- A 23.4-point gain in student achievement was achieved in Year 1 [$t(6,237)=4.9, p.<.000^{**}$].
- A 15.4-point gain was achieved in Year 2 [$t(7,453)=3.3, p.<.001^{**}$].

Appendix J MLI Teachers' Student Achievement

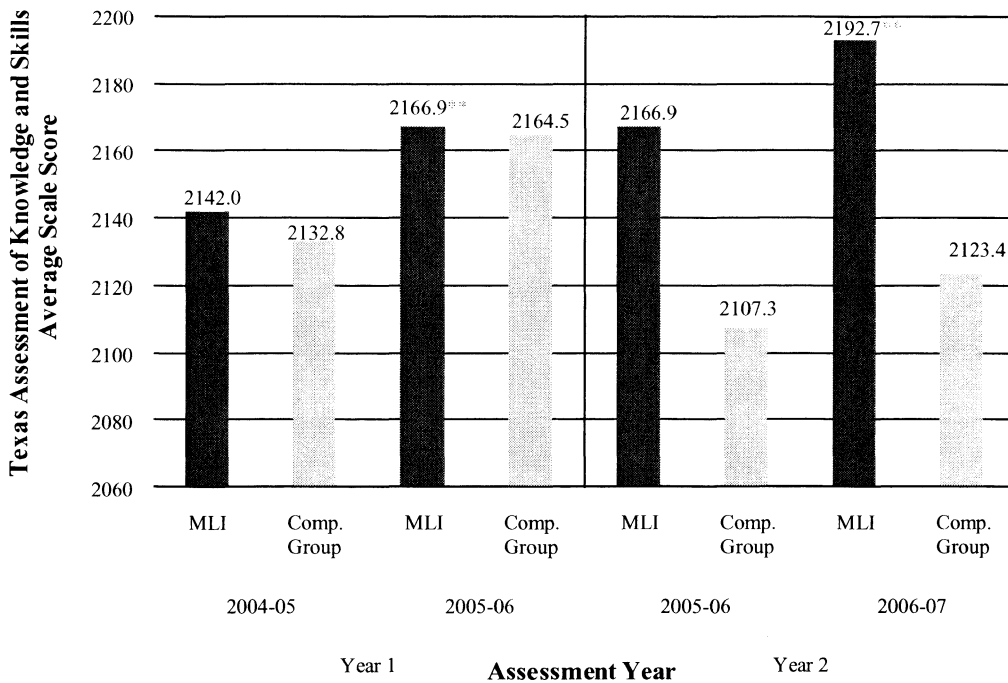


Figure 4. Year 1-Year 2 TAKS achievement gains of MLI and comparison teachers' students.

Source: AISD and HISD TAKS databases, Spring 2005 through Spring 2007.

Data Analysis: Student achievement results were analyzed for Cohort I MLI teachers for whom a comparable group of teachers was available. In Year 1, 2005–06, MLI (N=23) and comparison teachers (N=19) were matched on school district, geographic location of the school, subject taught, and years of teaching experience. This strategy was repeated with MLI (N=22) and comparison teachers (N=25) in Year 2, 2006–07.

Aggregated scale scores on the state-mandated, criterion-referenced TAKS were assessed. The passing scale score on the TAKS was 2100 points. Baseline 2004–05 student performance preceded the first MLI program in Summer 2005. In Year 1, 2005–06, an independent *t*-test analysis was conducted to compare the mean scores of students in MLI teachers' mathematics classrooms to the scores of students in MLI teachers' 2004–05 mathematics classrooms. This strategy was repeated in Year 2 (2006–07) by comparing MLI teachers' 2006–07 student scores with their 2005–06 students' scores. The performance of MLI students is highlighted in this analysis.

- The mean scores of students of MLI teachers exceeded the 2100 TAKS passing score in Year 1 and Year 2.
- MLI teachers' students achieved statistically significant gains each year: 24.9 points in Year 1 [$t(4356)=4.12$, $p.<.000^{**}$] and a higher gain of 25.8 points in Year 2 [$t(5596)=4.6$, $p.<.000^{**}$] compared to Year 1.
- The students of MLI teachers consistently outperformed the students of comparison teachers. In Year 2, this performance gap increased to 69.3 points, which was statistically significant [$t(5341)=12.5$, $p.<.000^{**}$].
- Additional findings indicated that in Year 2, MLI teachers showed higher percentages of students achieving commended status (2400 points or greater) on TAKS than comparison teachers (17.9% versus 11.1%). Students of MLI teachers also showed more of an increase in students reaching commended status (3.0 % pts. versus 1.7% pts) from 2005–06 to 2006–07.

UNDERSTANDING ELEMENTARY TEACHERS' USE OF SCIENCE TEACHING TIME: LESSONS FROM THE BIG SKY SCIENCE PARTNERSHIP

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Introduction

The Big Sky Science Partnership (BSSP) serves grades K-8 science teachers in schools on and near three American Indian reservations in Montana. The BSSP is led by Salish Kootenai College, in partnership with Montana State University, the University of Montana, and numerous, mostly rural, school districts. This article presents how we addressed the project's need to know how much time teachers in the Partnership had available to teach science, how that time was distributed and used, and key influences on teachers' decisions regarding science teaching time. During the first full year of professional development activities in our Partnership, 2007-2008, it became apparent that some teachers in the program allocated little time to science instruction and that their perception was that this was for reasons beyond their control. This first came to our attention in conversations with the teachers, and when an unexpected number of baseline observations scheduled well in advance by staff were of lessons that were either greatly abbreviated, sometimes lasting just fifteen minutes, or on non-science topics.

This disheartening circumstance appeared to be at odds with staff observations and external evaluators' reports showing that teachers found the face-to-face and on-line workshops and graduate coursework on science teaching relevant and valuable. Indeed, in the spring of this first full year of operation, twenty-two of the forty-five teachers served by the project voluntarily increased their workload by entering a Master of Science in Science Education program that added twelve graduate credits, distributed over three years, to the twenty-four earth science, astronomy, and physics credits they were already earning through the BSSP.

How could it be, we wondered, that teachers who diligently attended science workshops, read and posted on-line, and many of whom exposed themselves to greater rigors by joining the master's program, nonetheless reported having very limited time for science instruction? Speculation abounded. Potential culprits included the following issues: historical primacy of reading/language arts and mathematics in the elementary curriculum, an imbalance that has

increased significantly since the federal No Child Left Behind (NCLB) legislation took effect in 2002; lack of resources to teach science in certain Partnership schools, even down to the absence of any hands-on materials or textbooks; and, teachers' level of preparation and confidence to teach science [1]. Our immediate concerns included the likelihood that teachers lacking regular opportunities to teach science would not benefit from the deeper learning that occurs when actually teaching a topic, the realization that well-attended workshops and popular on-line coursework would be pointless if these were only marginally increasing grade school students' opportunities to learn science, and the apprehension that if we didn't learn more about this situation quickly, our opportunity to maximize the impact of our Partnership would disappear.

Consequently, in early 2008, staff working with the Partnership's eastern cohort of fourteen teachers agreed to analyze data already being gathered by the project evaluation, and to collect additional forms of data to better understand the teachers' allocation and use of instructional time for science, as well as influences on their decisions in this realm. This article presents what we learned about methods for monitoring instructional time for science, how the project benefited from the first cycle of data collection, and implications for other partnerships, school districts, and organizations working to further elementary school science.

Relevant Literature

Our first step was to study the literature to learn what is known about instructional time for science, and how to frame and measure it. Our hunch that today's elementary schools are focusing more time on reading/language arts and mathematics, often by subtracting from other academic areas, was confirmed by a national survey study conducted by the Center on Education Policy (CEP) [1, 2]. The Center identified a sample of 491 school districts varying according to size, location, demographics, presence of at least one school identified for improvement under state guidelines in response to federal No Child Left Behind legislation, and other factors. Of the 349 districts completing the CEP survey, many matched the profile of the seven districts served by the BSSP eastern cohort teachers in that they were rural (116), small (192), and included at least one school identified for improvement (151). A comparison of district survey results from 2001-2002, one year prior to implementation of NCLB, to 2006-2007 showed that 58% of the districts increased instructional time for reading/language arts, and that the average gain was 142 minutes per week (see Table 1). Similarly, 45% of responding districts increased instructional time for mathematics, and did so by an average of 89 minutes per week. Those districts increasing instructional time for reading/language arts and/or mathematics decreased the time allowed for other subject areas and recess by an average of 145 minutes per week. For districts

selecting science for reduction, the decrease averaged 75 minutes per week, but the magnitude of such changes varied widely. For example, more than half of the districts decreasing science instruction even minimally did so by 75 to 150 minutes per week (see Table 2).

Table 1

Changes from 2001-02 to 2006-07 in Instructional Time for Elementary School Science for Districts Reporting Increases in Reading/Language Arts and Mathematics

Subject	Average total instructional time pre-NCLB (minutes per week)	Average total instructional time post-NCLB (minutes per week)	Average change (minutes per week)	*Average change as a % of total instructional time
Reading/ Language Arts	378 (6.3 hrs)	520 (8.6 hrs)	+142 (2.4 hrs)	+ 47%*
Mathematics	264 (4.4 hrs)	352 (5.9 hrs)	+ 88 (1.5 hrs)	+ 33%*
Science	226 (3.7 hrs)	152 (2.5 hrs)	- 74 (1.2 hrs)	- 43%*

*Adapted from McMurrer (2008) [1].

The percentages in the final column were first calculated for each district, then weighted according to how many national districts each responding district represented, and finally averaged across districts to generate the numbers reported here. The methodology link for McMurrer can be found on the Center on Education Policy's website [2].

Table 2

Magnitude of Decreases Since 2001-2002 in Instructional Time for Elementary Science

Subject	Fewer than 25 minutes per week	25-49 minutes per week	50-74 minutes per week	75-149 minutes per week	150 minutes per week or more
Science	3%	15%	29%	42%	11%

*Adapted from McMurrer (2008) [1].

How do these findings compare with those from other studies, and what methodologies did the others use? The *Teacher Questionnaire Schools and Staffing Survey (SASS)* is administered periodically, in intervals ranging from three to six years, by the National Center for Education Statistics (NCES), U.S. Department of Education [3]. Since 1987, the *Teacher Questionnaire SASS* has included an item that asks elementary teachers working in a self-contained classroom, "During your most recent full week of teaching, approximately how many

hours did you spend teaching this subject in this school?" For each subject area, respondents may answer "none" or provide a response rounded to the nearest hour [3]. First through fourth grade teachers completing the *SASS* during the 2003-2004 school year reported spending an average of 2.3 hours per week on science instruction, a decline of 18 minutes from the 2.6 hours per week reported by respondents to the next most recent *SASS* in 1999-2000 [4]. The *SASS* results show that the average science teaching time per week across all 1,596 elementary teachers included in the 2003-2004 sample was 2.04 hours per week ($SD=2.25$), with 31.9% reporting that they had not taught science the most recent full week of teaching, and the remainder reporting 1 hour (14.1%), 2 hours (17.5%), 3 hours (17.2%) or 4 or more hours (19.4%). Results for 2007-2008 are not yet available [5].

These figures are not dissimilar from those reported by fourth grade teachers in the United States responding to the Trends in International Mathematics and Science Study (TIMSS) in 2003 and 2007 [6, 7]. Each teacher of a class included in the TIMSS assessment completes a teacher questionnaire [7]. They are first asked, "Is science taught mainly as a separate subject to students in the TIMSS class?" If the response is "yes," the teacher is asked, "How many minutes per week do you teach science to the fourth grade students in the TIMSS class?" If "no," the teacher is asked to "estimate the number of minutes per week that you spend on science topics with the fourth grade students in the TIMSS class." Results from 2003 and 2007 are shown in Table 3. In 2003, 85.7% of respondents reported teaching science as a separate subject, and spending an average of 143.1 minutes per week (2.38 hours) on science instruction [6]. This figure was considerably higher than the 122.7 minutes per week (2.04 hours) reported by the 14.3% of teachers who taught some science, but not as a separate subject. In 2007, the proportion of respondents teaching science as a separate subject had risen to 91.0%, and the average minutes per week they devoted to science had increased to 150.5 minutes per week (2.51 hours) [8]. In the same year, the 9% of teachers who blended science with other subject areas reported devoting 122.5 minutes per week (2.04 hours) to science, an almost identical response to that in 2003.

Table 3
Instructional Time for Science Reported by Fourth Grade Teachers on
the 2003 and 2007 TIMSS

Science taught as separate subject			Some science taught, but not as separate subject		
Percentage of respondents	Average instructional time in minutes	Median	Percentage of respondents	Average instructional time in minutes	Median
2003					
85.7%	143.1 (2.38 hrs)	135 (2.25 hrs)	14.3%	122.7 (2.04 hrs)	100 (1.67 hrs)
2007					
91.0%	150.5 (2.51 hrs)	150.0 (2.5 hrs)	9.0%	122.5 (2.04 hrs)	100 (1.67 hrs)

The National Assessment of Educational Progress (NAEP) is administered by the NCES every few years, with science last assessed in 2005. Part IV (Science) of the NAEP *Teacher Background Questionnaire* includes a question for fourth grade teachers about instructional time for science [9]. The teachers are asked, "About how much time in total do you spend with this class on science instruction in a typical week?" They must then select one of five responses ranging from "Less than 1 hour" to "4 hours or more." Their answers to this question on the 2005 NAEP are shown in Table 4 [10]. The modal response of 2-2.9 hours per week is within the range of the responses reported by the studies above, including the CEP survey (2.5 hours per week), the *SASS* (2.04 hours per week), and the TIMSS (2.51 hours when science is taught separately, otherwise 2.04 hours).

The National Center for Education Statistics, which oversees the NAEP, allows researchers to perform simple analyses of NAEP data using the on-line NAEP Data Explorer tool. This resource allowed us to examine the relationship between the time fourth grade teachers devoted to science and the performance of their students on the NAEP. The average NAEP fourth grade Scale Score for science was 152 in 2005, which was close to the median score of 153 the same year, and significantly higher than the 147 average score achieved by fourth graders in 2000 [11]. As a group, students receiving at least 2-2.9 hours of science instruction met or exceeded the national average Scale Score on the NAEP in 2005, and those receiving less science instruction scored below the average (see Table 4). Table 5 provides the results of statistical analysis of these differences. This indicates that students receiving the least science instruction

(ranging from less than an hour per week up to 1-1.9 hours weekly) performed significantly lower on the NAEP science assessment than students in the three groups receiving more science instruction ($p = 0.0000$) [10]. There was also a significant difference in performance ($p = .0159$) between students receiving less than an hour of science per week, who attained an average score of 141, and those receiving 1-1.9 hours of science weekly, whose average score was 145. Yet the performance differences between the three groups receiving 2-2.9 hours or more science instruction weekly were slight, and statistically significant in only one case. This suggests that when instructional time for science reaches a certain level, apparently in the vicinity of 2-3 hours per week for fourth graders, merely increasing time for science does not affect student learning, at least not in ways measured by the NAEP.

Table 4
Instructional Time for Science Reported by Fourth Grade Teachers on the 2005 NAEP

Hours per week for science instruction	Percentage of fourth grade teacher respondents	Average fourth grade science Scale Score (out of 300)	Standard Error
Less than 1 hour	6	141	(1.4)
1-1.9 hours	17	145	(0.7)
2-2.9 hours	34	152	(0.5)
3-3.9 hours	27	153	(0.6)
4 hours or more	17	154	(0.7)

Table 5
Significance of Differences in NAEP Fourth Grade Science Scale Score by Instructional Time for Science

Hours per week for science instruction	Less than 1 hour	1-1.9 hours	2-2.9 hours	3-3.9 hours
1-1.9 hours	*Diff = 5 > $p = 0.0159$			
2-2.9 hours	Diff = 11 > $p = 0.0000$	Diff = 7 > $p = 0.0000$		
3-3.9 hours	Diff = 12 >	Diff = 8 >	Diff = 1 =	

	p = 0.0000	p = 0.0000	p = 0.1808	
4 hours or more	*Diff = 14 > p = 0.0000	Diff = 9 > p = 0.0000	*Diff = 3 > p = 0.0028	*Diff = 2 = p = 0.0754

> Significantly higher, = No significant difference.

* Differences between Scale Scores tabulated for Table 5 sometimes vary from the simple arithmetical differences between any pair of average Scale Scores reported in Table 4 due to variability in the original data sets.

The *2000 National Survey of Science and Mathematics Education* was designed and carried out by Horizon Research, Incorporated [12]. Fulp reports results from a national sample of 655 K-5 teachers completing the survey [13]. Elementary teachers were asked to respond to the following prompt regarding instruction in each of four subject areas, including science: "In a typical week, how many days do you have lessons on each of the following subjects, and how many minutes long is an average lesson?" The K-2 teachers in the sample reported spending 21 minutes per day (1.75 hours per week) on science instruction, compared to 30 minutes per day (2.5 hours per week) for the grades 3-5 teachers, and 25 minutes per day (2.1 hours per week) for all grades K-5 respondents combined. These responses, gathered two years prior to implementation of NCLB, are consistent with the range reported in the other national and international studies described above. The slightly low overall average (2.1 hours per week) is closest to that reported for the *SASS*. In both instances, this may be attributed to the effect of primary grade teachers, who typically teach science less frequently than teachers at other levels, and were not included in the other studies.

The Council of Chief State School Officers (CCSSO) and the Wisconsin Center for Education Research (WCER) developed the Surveys of Enacted Curriculum® (SEC®) in 1999, piloting it in a large field study involving over 600 teachers in eleven states [14]. The SEC® is currently used in numerous states and school districts. The "Survey of Instructional Practices: Teacher Survey, Grades K-8 Science" is completed at the end of each school year by the teachers in our Partnership [15]. Regarding time allocated for science, teachers are asked, "During a typical week, approximately how many hours will the target class spend in science instruction?" and must round their answer to the nearest hour. They are also asked, "How many weeks total will the target science class/course meet for this school year?" and must choose between 1-12, 13-24, and 25-36 weeks. A third item queries, "What is the average length of each class period for the targeted science class?" with response options ranging from 30 minutes to 2 hours. As we

learned once SEC® data for our own Partnership was in hand, asking teachers to describe the time devoted to science in several different ways was critical to obtaining a reasonably accurate understanding of their practice. Knowing only the average hours per week devoted to science would have provided a highly inaccurate picture for the many BSSP teachers who reported not teaching any science for one-third to two-thirds of the school year. Yet even with three distinct data points regarding science teaching time provided by the SEC®, we needed to know more. For example, science lesson length is an important consideration for reform oriented projects like the BSSP, since longer lesson periods facilitate inquiry science. Yet the shortest SEC® response option for lesson length is 30 minutes—two to three times longer than many science lessons recorded in our project.

Our review also revealed extensive literature on internal and external influences on teachers' decisions about science instruction. One factor often cited in the literature is teachers' beliefs about their ability to teach a particular subject, such as science. Such self-efficacy or capability beliefs are among the best indicators of decisions teachers make about their professional practice [16-18]. Soodak and Podell comment that decisions about practice often center on a highly specific capability belief: teachers' sense of their ability to bring about change in their students [19]. Woodbury and Gess-Newsome comment that teachers' beliefs, or what they term "teacher thinking," is shaped by personal factors that affect practice, among them the nature and extent of pre-service preparation and ongoing professional development [20]. Fullan and Hargreaves note that teacher thinking is influenced by teachers' earlier life experiences, current life and career stage, values, attitudes, confidence, and gender [21]. Ford describes teachers' context beliefs regarding how supportive teachers believe the environment will be to the success of a given instructional decision, such as teaching science [18]. Instructors may weigh factors within the school, such as physical space, scheduling, equipment availability, or administrator's and colleagues' opinions, as well as factors outside of school, such as anticipated opposition or support from parents and the local community, or from policies at the district, state or national level. Weiss, Banilower, McMahon and Smith found that structural factors, such as degree of access to basic resources including textbooks and other science teaching materials, access to technology, and adequacy of time for educators to plan, teach or learn more science, were often cited in the teachers' responses to the *National Survey of Science and Mathematics Education* [12]. As the literature suggests, a range of internal and external factors soon emerged as influential in the decisions BSSP teachers made about science instruction.

Among the data collection instruments described earlier, only the SEC® explicitly addresses influences on science instruction. Respondents to the Teacher Survey are asked to, “indicate the degree to which each of the following influences what you teach in the target science class.” The teachers are then provided with ten choices including state or district curriculum framework or content standards, state or district tests or results, *National Science Education Standards*, textbook or instructional materials, pre-service preparation experience, the special needs of students, and the influences of parents and community [22].

We first determined to investigate how much time the elementary teachers in our Partnership were able to devote to science teaching, how this time was distributed, and the influences guiding the teachers' decisions about time allocation for science. Needless to say, even in the absence of a reasonable amount of time set aside for science instruction, a dual focus on the quality of the learning experiences provided is necessary. This is analogous to ensuring that students are not only receiving enough calories, but that their caloric intake is nutritionally balanced to fill their growth and energy needs. This article focuses on the calorie-equivalent question, “Are students getting enough science?”—a simple question that is surprisingly difficult to answer well. We also describe our current efforts to answer the quality question, “Are students receiving the right science experiences?” Clearly, getting enough science and a balanced blend of experiences are both needed, even if the issues are occasionally examined independently as part of broader research endeavors.

Methods

To investigate teachers' allocation of time for science, and what influences it, we selected a mixed methods approach for the overall research [23, 24]. To paraphrase Denzin and Lincoln, our purpose in using multiple approaches to data collection and analysis was to capture as much of the reality as possible, even if this meant confirming the possibility that science teaching occupied a minor place in BSSP teachers' classrooms [25]. All fourteen teachers in the first BSSP eastern cohort were invited to participate in this component of the project's data collection, and ten agreed to do so during the 2007-2008 school year. Seven of the teachers were assigned to self-contained, first through fifth grade classrooms. The other three teachers included a technology specialist, a reading/language arts and mathematics specialist, and a special needs teacher. These three teachers worked with different classes or small groups throughout the day, and were permitted by their administrators to integrate science into their instruction to a certain degree. The ten teachers worked in seven different schools on or near two American Indian

reservations, and these included five public schools, one tribal school, and a private Catholic school.

We gathered teachers' perspectives through two survey instruments, one administered at the end of the 2007 and 2008 school years, and the other completed weekly during an eight-week period in Spring 2008. We explored issues that emerged through the surveys during teacher interviews conducted in early Summer 2008. We also used the results of a baseline classroom observation of each teacher and science portfolios all BSSP teachers completed in Spring 2008 to extend our understanding of how Partnership teachers allocated time for science, and the factors driving their decisions. Each of the five data collection tools described below, including three developed and widely tested by other national or regional projects, and two that were created or adapted for the BSSP, contributed significantly to our investigation.

The Surveys of Enacted Curriculum® (SEC®), developed by the Council of Chief State Schools Officers (CCSSO), the Wisconsin Center for Education Research (WCER), and state partners in 1999, was introduced earlier in this article. The surveys were intended to provide "reliable, objective data on instructional practices and subject content" as reported by teachers [26]. Some items were adapted from previous studies or instruments including "Reform up Close," the *National Survey of Science and Mathematics Education*, the *Third International Mathematics and Science Study* teacher questionnaire, and the NAEP teacher background surveys [12, 27, 28]. In a study on an early version of the SEC®, Porter found that teachers' responses on surveys administered infrequently (once a semester or once a year) matched the results of daily logs or classroom observations involving the same teachers reasonably well [27]. Thus, the SEC® team determined that teacher recall was acceptable on surveys administered annually. Yet when student data was collected in 1999 to determine the consistency between student and teacher reports on science instruction in the same classrooms, the results were mixed. There were significant positive correlations between student and teacher responses for just 57% of the items, compared to positive correlations for 94% of the items on corresponding surveys in mathematics [14]. This discrepancy may be due to more variability in teaching patterns in science than in mathematics, making accurate characterization of instructional content, methods, or even the classroom time allowed for science, more difficult for teachers and students to pin down.

The Big Sky Science Partnership teachers completed the entire SEC® "Survey of Instructional Practices: Teacher Survey, Grades K-8 Science" at the end of the 2006-2007 and 2007-2008 school years [15]. We asked the teachers to respond in terms of the school year that

had just ended. The items regarding time allocated to science instruction and what influences science instruction are of particular interest in this study.

The “Weekly Teaching Survey” (WTS) is a Likert-style questionnaire developed for this study. The survey focused on four components of science instruction: teaching practice, teaching time, culturally responsive practices, and influences on teaching. A number of the twenty-four items on the WTS were selected or adapted from the SEC®, as well as the “Cultural Competency Survey” designed by Regina Sievert, Director of the Indigenous Math and Science Institute, Salish Kootenai College, the lead institution for the BSSP. The Cultural Competency Survey was used to gauge culturally responsive practice among BSSP teachers, as teachers of American Indian students. The first version of the survey was piloted for three weeks by a dozen elementary school teachers not associated with the BSSP, and the survey was revised based on their comments regarding clarity of the questions and format, and the time needed to respond. Our sample of ten BSSP eastern cohort teachers completed the WTS during eight consecutive weeks in Spring 2008. Their responses regarding science teaching time and relevant influences will be reported in this article.

The *Classroom Observation Protocol (COP)* developed by Horizon Research in 2005 is designed to provide accurate information about the alignment of instruction with standards-based practice in science and mathematics classrooms [29]. The BSSP science and education staff have attended formal *COP* observer training and conduct annual observations of every teacher in the program. The Spring 2007 and 2008 observations were used to provide additional context regarding the time BSSP teachers allocate for science.

The “Scoop Notebook” is a data tool that uses classroom artifacts and teacher reflections to characterize teachers’ science instruction with respect to key dimensions of reform-oriented practice. This approach was developed by Hilda Borko and colleagues at the University of Colorado at Boulder, University of California, Los Angeles and RAND® Corporation [30]. A pilot study was conducted in 2004 involving thirty-nine middle school science teachers in two states. Each teacher completed a Scoop Notebook, modified for the BSSP, to document instruction for a lesson series, and was observed two to three times by the same researcher. Some of the teachers were also audio taped, thus providing samples of classroom discourse. The data sources were scored independently along eleven dimensions associated with reform oriented science instruction. The design team concluded that the Scoop Notebook is a “reasonable” tool for describing instructional practice, especially for dimensions that are unlikely to vary greatly

from day to day. When the Scoop ratings were compared to “gold standard” ratings carried out by the observer assigned to a given teacher after reviewing all the information available about that teacher’s practice, the correspondence was slightly stronger. As part of our Partnership’s formal evaluation, each teacher completes a Scoop Notebook once a year; this includes a timeline, activity plans, student work samples and other documentation for three or more lessons, all focused on a single science topic. Through the Scoop, we were able to obtain an additional snapshot of the BSSP teacher’s practice at the end of the Partnership’s first full year of professional development in Spring 2008. Since the teachers knew that at least one Scoop lesson per teacher would be observed by project staff, we conjectured that various lesson dimensions, including the time necessary for a lesson, would reflect the teachers’ visions of “best practice” for science teaching.

Interviews were conducted with each teacher in the study sample in early Summer 2008 after other forms of data had been gathered. The interviews were semi-structured, with questions relatively standardized, but open-ended. The interview themes included science teaching time, science teaching practice, connections of science with historical or contemporary American Indian culture, and influences on science teaching time and practice. Some questions were adapted from a protocol designed to gauge teachers’ beliefs about science as inquiry and science teaching developed by Roehrig and Luft in 2006 and from the *COP* post-observation interview [29, 31]. In this study, the interviews were used, in conjunction with other data collection methods, to gather descriptive information in the participants’ own words.

Findings

This study was designed in part to help our Partnership understand the amount of time elementary teacher participants are able to devote to science teaching, and how this time is distributed. Each of our data sources contributed to this understanding. Time is an educational resource that always seems to be in short supply, and if we want to improve science instruction, then partnerships like BSSP need to influence the current distribution of time for science. From the SEC® end-of-school-year responses in 2007 and 2008, we gleaned estimates from the ten teachers in our sample regarding how many hours during a typical week each teacher’s class spent learning science. Each year, four to five of the teachers selected 1 hour per week, two to three teachers selected 2 hours, and the remaining one to two teachers selected 3 or 4 hours per week, with one response omitted in 2007 (see Figure 1). This yields a mean response of 1.8 to 1.9 hours per week for science in 2007 and 2008, respectively. On the SEC®, the teachers also estimated the average length of science lessons taught during the year that had just ended, with

six teachers choosing the shortest option, 30-40 minutes in 2007 and 2008, one to two teachers selecting 41-50 minutes, and two to three teachers stating that lesson length varied due to scheduling, integrated instruction, or other factors (see Figure 2).

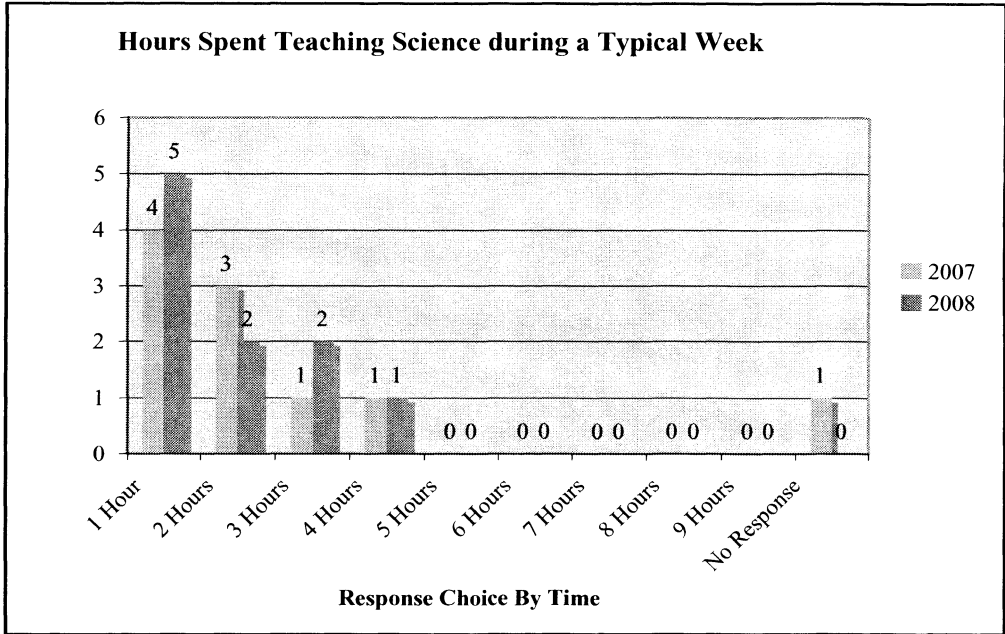


Figure 1. Estimated hours per week for science—SEC® responses (*n* =10).

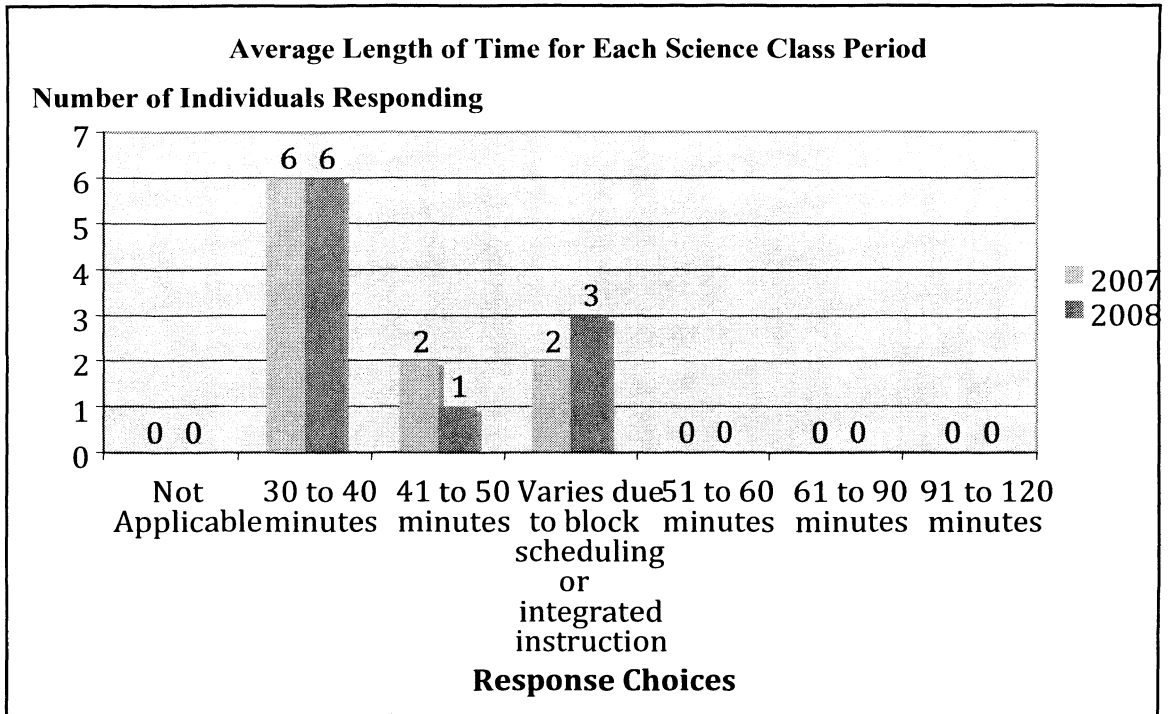


Figure 2. Average minutes per science lesson—SEC® responses (n =10).

Perhaps the most telling results from the SEC® concerned the number of weeks devoted to science instruction each year. A majority of states and districts still stipulate a 180-day school year, with the days spread across about forty weeks when holidays are taken into account. In each of the two years we administered the SEC®, two to three teachers indicated that they taught science during 1-12 weeks of the school year, six to seven teachers selected 13-24 weeks, none selected 25-36 weeks, and one teacher did not respond each year (see Figure 3). If we postulate that the two-thirds of our sample selecting the 13-24 week response option actually taught science for twenty weeks per year on average, multiplying this by the 1.9 hours per week for science reported by the teachers in June 2008, we can estimate that those teachers were able to spend an average of 38 hours that year on science instruction, far lower than the 76 hours we might assume based on a forty-week school year. Using the same heuristic, we can estimate that the two teachers selecting the 1-12 weeks response taught science for 22.3 hours or less during 2007-2008. Information of this nature can be of tremendous importance in helping a partnership like the BSSP plan how to proceed with “eyes wide open” regarding the degree of focus on science in Partnership classrooms.

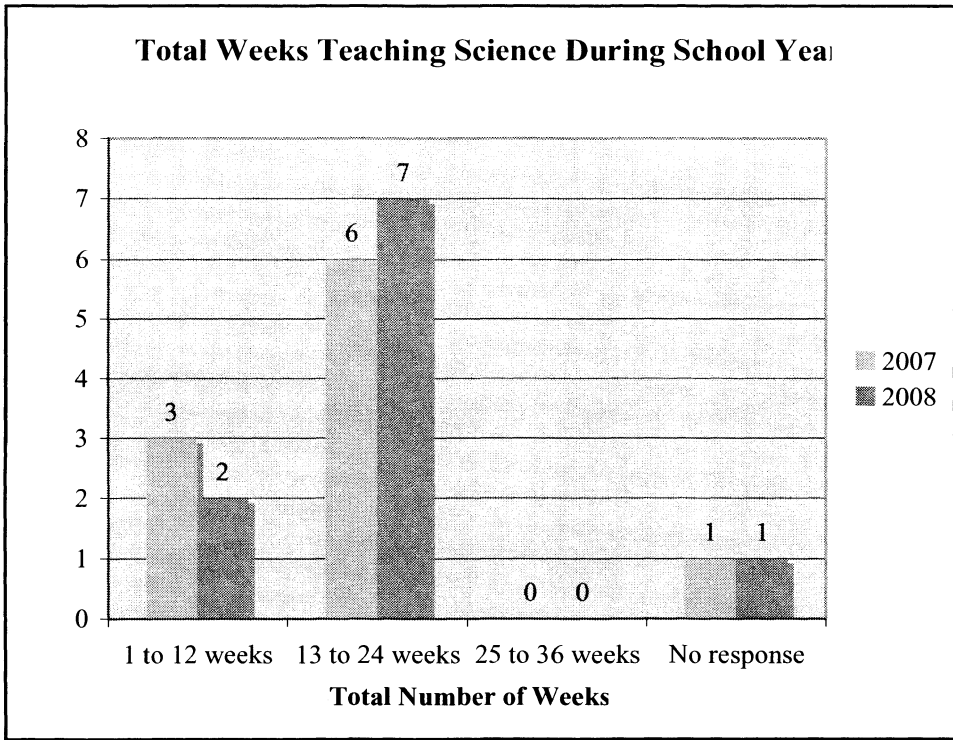


Figure 3. Estimated weeks per year for science (n =10).

To summarize, the SEC® results indicated that the elementary teachers in the BSSP eastern cohort typically teach science for 1.8 to 1.9 hours per week for somewhere between thirteen and twenty-four weeks of the school year, or roughly 25-46 hours per year, and that a typical lesson lasts 30-40 minutes.

What more did we learn by supplementing the retrospective SEC® with the WTS, an electronic survey developed by the project and completed by ten eastern cohort teachers for eight weeks in Spring 2008? The WTS contributed several unique insights. First of all, the WTS clearly showed the great variation in the time devoted to science teaching per week when making comparisons across instructors, or examining an individual teacher’s practice across the eight-week data collection period. Although we purposely scheduled the WTS during a lull in the school year when State testing was over in most schools and end-of-year schedule disruptions

were still distant, WTC results illustrate that time devoted to science was far from steady or stable. Table 5 shows the wide range in time allowed for science in the classrooms of the ten teachers filling out the weekly surveys. The teachers recorded the number of minutes for each science lesson at the end of the week, and these results were converted to hours per week for science to allow comparisons with SEC® results. The WTS data yielded an average time for science instruction of 1.64 (SD = 1.35) hours per week. At times, the across-teacher differences are easy to interpret. For example, “Jessica,” “Sarah,” and “Tiffany” taught science a modest .63, .81, and 1.07 hours per week—understandable given that they are the only grades 1-2 teachers in our sample, although far lower than the 1.75 hours per week found for primary teachers in one national study [13]. “Kimberly” taught science even less, averaging .31 hours per week, which we later learned was influenced by directions from her supervisors to focus first on raising the reading performance of the special needs students she teaches full-time. Other variations across teachers have no obvious explanation. For example, “Heather,” a fourth grade teacher, provides 2.58 hours of science instruction per week, compared to 1.77 hours per week of science offered by “Melissa,” a fifth grade teacher just down the hall. Sizable standard deviations indicate large swings in several teachers’ science scheduling. The case of “Christina,” a full-time technology teacher who often integrates science into upper elementary technology classes, illustrates this within-teacher variation. Christina provided science experiences for each of her classes an impressive 3.57 hours per week. Yet the associated standard deviation of 2.54 hours per week makes it clear that time available for science in her classroom fluctuated greatly.

Table 6
Average Weekly Science Teaching Time in Hours Based on Eight Weeks of Reporting Using the WTS

Hours	Sarah	Melissa	Christina	Heather	Angela	Jessica	Tiffany	Rebecca	Michelle	Kimberly
<i>M</i>	0.81	1.77	3.57	2.58	1.42	0.63	1.07	2.29	1.74	0.31
<i>SD</i>	0.14	0.73	2.54	0.66	1.26	0.37	0.88	0.27	0.7	0.04

In addition, the WTS allowed us to see the considerable variation in the length of the teachers’ science lessons more clearly, as well as the many days when no science was taught. Table 7 shows that no science was taught on 183 days, which comprised 45.7% of the 400 instructional days reported on in the eighty weekly surveys the teachers completed. When science was taught, the most prevalent lesson length was 21-30 minutes, accounting for sixty-one lessons, or 28.0% of the 217 lessons reported. It is instructionally significant that the actual reported values for

seventy-two lessons, 33.2% of those taught, fell between 5-20 minutes. Combining these with the lessons in the popular 21-30 minute range, we find that 133 lessons out of 217 taught (61.3%) lasted 5-30 minutes, somewhat below the expected outcome given the 30-40 minute average lesson length that six out of ten teachers in our sample selected on the SEC®.

Table 7
Number of Minutes of Science Instruction per Day—WTS (*n* =80 weekly reports)

Minutes	Monday	Tuesday	Wednesday	Thursday	Friday	Total
None	34	26	41	25	57	183
1 to 10	7	5	5	7	4	28
11 to 20	8	14	7	8	7	44
21 to 30	8	15	12	20	6	61
31 to 40	3	0	0	1	0	4
41 to 50	12	16	8	15	4	55
51 to 60	1	1	1	0	1	4
61 to 90	5	1	4	1	0	11
91 to 245	2	2	2	3	1	10

To summarize, the WTS results regarding time the teachers were able to devote to science instruction showed that the teachers spent on average 1.64 hours per week on science, well below the 1.9 hours per week they reported soon thereafter on the SEC®. Using the thirteen to fourteen weeks per year for science selected most frequently on the SEC®, we can estimate roughly 21.2-39.4 hours of science instruction per year, per teacher. Two patterns that stand out in the WTS data are the great variation in time allotted for science across teachers, and from week to week for individual instructors. Equally evident is that no science is taught on many school days, true for 45.7% of the 400 days for which we collected WTS data. Finally, 61.3% of the lessons lasted 30 minutes or less, well below the 30-40 minute range we expected based upon our teachers' SEC® responses.

The Scoop Notebooks prepared by eastern cohort BSSP teachers in Spring 2008 provide a window into the lesson length the teachers aim for when asked to provide a sample of their science teaching practice for sharing with their peers, the project staff, and evaluators. Each Notebook provided documentation for three to five science lessons, focused on a single topic, and taught during Spring 2008. Each teacher was observed by a BSSP staff member at least once

during the Scoop lesson series, and received written comments from staff on the Notebook contents. In addition, the Notebooks were shared with peers in a poster session format, and a photocopy of each Notebook was sent to the project evaluators. Although the teachers were encouraged to choose lessons that were “typical” of their science teaching, it seems likely that they selected for public display lessons they considered exemplary, even more so since student work samples produced during these lessons were required in the Notebooks. Table 8 shows the length of thirty Scoop lessons planned by seven of the teachers in our sample who completed a calendar for the Notebook. Whereas 61.5% of the lessons recorded for the WTS lasted 30 minutes or less, the teachers expected 63.3% of the lessons for the Scoop to exceed 30 minutes. The Scoop calendars provided a window into teachers’ perceptions of the optimal lesson length for their students when the teachers prepared to share their practice and the usual constraints are temporarily lifted.

Table 8
Length in Minutes of Science Lessons Reported in Scoop Notebook Calendars

	Lesson 1	Lesson 2	Lesson 3	Lesson 4	Lesson 5
Heather	45	45	45	120	--
Christina	50	50	50	50	50
Melissa	50	45	45	60	--
Angela	25	30	45	60	45
Sarah	30	30	30	30	30
Michelle	80	80	60	--	--
Jessica	25	20	30	20	--

* n=10, missing data for three teachers.

The BSSP staff conducted a science lesson observation for each of the ten teachers in this study during Spring 2008 using the *Classroom Observation Protocol* [29]. The observations were scheduled to coincide with each teacher’s Scoop lessons. The lessons observed ranged from 10 minutes to one hour long, with half of the lessons lasting under 30 minutes. This suggests that teachers’ ability to carve out time for longer science lessons fell slightly short of the intentions shown in their Scoop Notebooks.

A portion of the interview conducted with each teacher in June 2008 addressed the time the teacher was able to devote to science teaching. In general, teachers’ statements during the

interviews were consistent with the information provided on the WTS. For example, the estimates given during interviews by Jessica, Tiffany, and Melissa for the minutes per week devoted to science were almost identical to the averages computed from their weekly surveys. However, in “Angela’s” interview, she stated that in her school, “we’re maybe allowed one hour a week to teach science,” but this is lower than the 1 hour 25 minute average we calculated based on the eight weekly surveys she submitted. Apparently, she was teaching more science than her school’s policy allowed. Although interview data can be used to gauge the accuracy of other sources, we believe the WTS reports to be most reliable concerning time devoted to science.

In addition to investigating the amount of time elementary teachers in the BSSP devoted to science instruction and how it was distributed, we also wanted to know what influenced teachers’ decisions about the level and use of science teaching time. Our primary data source for addressing this question was a cluster of six items on the WTS regarding influences on what and how science is taught. We adapted these from a longer series in the SEC® pertaining to influences on the content of science instruction. On the WTS, the teachers were asked to “Reflect back on your science teaching this week,” when responding to each item. The influences included the following: those of parents or community; State or district curriculum frameworks, standards, tests or results; and, the textbook or curriculum materials selected by the district. As shown in Table 9, the teachers in our sample generally viewed these factors as having an influence midway between “little or no influence” (3.0) and a “somewhat positive influence” (4.0). The influences of State and district curriculum frameworks and standards, as well as State tests were rated as slightly greater than those of district-level tests and parents or community. The responses were quite consistent across teachers, with means ranging from 3.50 to 3.78 for nine teachers, and an even more positive average response of 4.36 for the tenth teacher.

Table 9
Influences on What and How Science Is Taught—WTS ($n = 80$ weekly surveys)

1 = Strongly negative; 2 = Somewhat negative; 3 = Little or no influence;
 4 = Somewhat positive; 5 = Strongly positive.

Weekly Teaching Survey Item	All (<i>M</i>)	All (<i>SD</i>)	Strongly negative	Somewhat negative	Little or no influence	Somewhat positive	Strongly positive	
19. The parents or community influence what and how I teach.	3.44	0.42	1	0	46	29	4	
20. State tests or results influence what and how I teach.	3.69	0.27	0	0	21	56	3	
21. State curriculum framework or standards influence what and how I teach.	3.79	0.32	0	0	21	55	4	
22. District curriculum framework or standards influence what and how I teach.	3.72	0.37	0	0	27	49	4	
23. The textbook and/or curriculum materials selected by the district influence what and how I teach.	3.64	0.48	1	0	32	40	7	
24. District-level tests or results influence what and how I teach.	3.47	0.36	1	0	43	33	3	
Total ratings (out of 480) regarding degree of influence				3 (<1%)	0	190 (39.6%)	262 (54.6%)	25 (5.1%)

Interestingly, just three responses regarding influences on instruction were lower than “neutral or no influence” (3.0) on any of the eighty weekly surveys gathered. In other words, on seventy-seven of the eighty weekly surveys, the teachers rated as neutral to somewhat or strongly positive the influences of district and State standards and tests, and textbooks and other materials provided by the district, and parents and community. The positive nature of the teachers’ responses was expected in some respects, and unexpected in others. For example, the teachers

became very familiar with the State of Montana science education standards through the Big Sky Science Partnership activities, which may have affected their generally favorable view of the influence of standards, and even testing, on the previous week's science instruction. Concomitantly, several formerly low performing districts had recently witnessed a fairly dramatic rise in their students' performance on State reading tests, a circumstance their teachers spoke of with pride and which may have produced a generally favorable view of standards and testing. However, we observed ample justification for lower ratings for some items; for example, item 23 where there was a lack of current textbooks or resources of any kind for science in several of the districts. This raises the question of how to determine the quality and influence of resources and support structures for elementary science if teachers are too accustomed to scarcity to name these as potential influences.

In addition to the Likert-style items regarding influences on science teaching, the WTS included an open-ended question that allowed the teachers to write a brief statement regarding one or more factors that had the greatest influence on their science instruction during the previous week. This question was left blank in seventeen of the eighty weekly surveys completed by BSSP teachers. Twenty of the remaining sixty-three statements pertained to reading, and typical responses included Jessica's comment that, "Everything is correlated with our reading materials"; or, "Rebecca's" that "Science this week focused on reading vocabulary." Thirteen responses noted the influence of the BSSP on science instruction in the previous week. Examples included the following responses:

- "Because of the lack of resources, I used what I learned in the BSSP courses to develop this unit." (Rebecca)
- "The BSSP class has had a great influence on what I am teaching in science this year. I have used a lot of materials from books that I was given by them. They have been a great help." (Melissa)
- "We also created concept maps on what students know about rocks. This is going to be our next unit because it is of interest to the students, it's in the science curriculum, and I am working with this in BSSP classes." (Angela)

Six statements, including the following examples, referred to the influence of students' prior knowledge and teachers' efforts to take into account students' knowledge and interests when planning for instruction.

- “I try really hard to bring in what students already know about rocks in this area by what they observe. Then, I moved them into how those are used in everyday things that they don’t know about.” (Sarah)
- “What students know and what they wondered about will help to design lessons for the fossils unit. I found that some of the questions they asked were the same questions I came up with when developing the unit.” (Rebecca)

Culture was cited in six of the eighty weekly surveys as influencing the week’s science instruction, and examples like the following ones were given:

- “Our culture teacher [provided] community resources for us to determine which frogs reside in our area.” (Tiffany)
- “The cultural element was present when we discussed rocks that made good arrowheads.” (Kimberly)

The remaining influences on the previous week’s science teaching included the following: State testing, which inadvertently overlapped with administration of the weekly surveys in several respondent’s districts (8); the district curriculum (4); miscellaneous scheduling constraints (3); State standards (1); parental support for science (1); and, suggestions from other staff members regarding the teacher’s science program (1). Lack of time for science surfaced relatively often in conjunction with the other themes above. Each teacher made at least one specific reference in the WTS to the lack of adequate time for science due to district scheduling and curriculum requirements, especially regarding reading. However, there was no single culprit responsible for the observed outcome that time for science was often minimal or unpredictable. As “Michelle” explained, “Science is the first subject to go whenever our schedule gets interrupted.”

During individual interviews conducted in June 2008, the teachers once again responded to questions regarding influences on their science teaching. School scheduling requirements surfaced frequently in the teachers’ responses.

- “Well, the school does get in the way of it [science] a little bit because we have so little time. Seems like if I teach it at all, I have to grab time from here or there or someplace. And like I said, we just don’t have a lot of time for it, so that influences it quite a bit...A lot of the time, I end up doing something just out of the book because I’ve got fifteen, twenty, thirty minutes and you really can’t set up for anything hands-on in that amount of time.” (Melissa)
- “We have a very limited time schedule. So we’re maybe allowed an hour a week to teach science. I’m free to do whatever I want in that time. And I can kind of integrate it wherever I want as long as I am still teaching the math and reading. That’s the most important at our school.” (Angela)
- “Well, scheduling. We had...little time [for science] each week and then we have to follow our district benchmarks.” (Sarah)

Many teachers commented during interviews on their schools’ strong focus on reading/language arts and mathematics which they attributed to district, State, or national policies. Teachers did not negate the importance to their students of strong skills in reading/language arts and mathematics. However, they wondered aloud where the additional instructional time would come from now that fourth graders in Montana were being tested in science, and the results would be made public for the first time in Fall 2004. According to one teacher, even parents’ attention was being channeled toward a focus on reading. Tiffany stated, “My parents are wonderful, but since the push was reading...basically what they got from the school was how the child was doing in the reading department.”

Although no direct questions were posed about the influence of the BSSP on science instruction, the majority of teachers referred to the Partnership’s positive influence on their science teaching during the interviews. They frequently commented on the lessons and resources provided by the project as enabling them to teach science more often than before, or moving their practice toward more hands-on and/or inquiry-focused approaches. To summarize, the interviews indicated that the time devoted to science teaching by BSSP teachers was influenced by time constraints that were often beyond the teachers’ control, especially the squeeze imposed by the current emphasis in their districts on reading/language arts and mathematics. As in their WTS responses, they also cited their students’ prior knowledge and interests, their own efforts to incorporate in science the culture of the American Indian communities where the schools were

located, parental involvement, teacher colleagues, and the BSSP as influencing how much science was taught, and the science content and pedagogy implemented. However, these latter factors appeared to take effect within a diminished sphere, influencing only time that was not already off limits due to school and district mandates reserving a specific number of hours, often at a prescribed time of day, for reading/language arts and mathematics. At times during the interviews, it appeared that fitting science into the instructional day was not just variable, but covert.

Conclusions and Implications

We initiated this study to better understand why elementary teachers who were actively engaged in face-to-face and on-line activities of the Big Sky Science Partnership (BSSP), many of whom had voluntarily ramped up their involvement by entering an MS in Science Education degree program, nonetheless reported that their opportunities to teach science were quite limited. We set out to learn how much time BSSP teachers devoted to science teaching, what influenced their decisions, and how this might affect the Partnership's ability to be an agent for positive change in school science programs in our region. To accomplish this, we used data already being collected by the Partnership evaluation, including the annual Surveys of Enacted Curriculum® (SEC®), classroom observations using the *COP*, and the Scoop Notebook created by the teachers to document a science unit or lesson series. We also implemented a Weekly Teaching Survey (WTS) designed for this study, as well as individual teacher interviews to follow up on issues raised in the earlier phases of data collection. Our teacher sample included ten, grades 1-5 teachers representing the fourteen instructors in the BSSP eastern cohort. Their experience ranged from four years to more than twenty years in the field, and they taught in seven different schools.

We learned that the anecdotal reports we had received from BSSP teachers regarding the relatively limited amount of time they teach science were generally true. The results of the SEC® that the teachers completed in June 2007 and 2008 provided the "best case scenario" in one sense. The BSSP teachers' responses on the *SASS* indicated on average that they taught science 1.8-1.9 hours per week, not too far below findings in large-scale studies like the *Schools and Staffing Survey (SASS)* and the *National Survey of Science and Mathematics Education (NSSME)*. The *SASS* and *NSSME*, like our study, included both primary and upper-level elementary school teachers, and their respondents reported teaching science for 2.04 to 2.1 hours per week, just slightly above the average for our teachers. However, the BSSP teachers' responses to an SEC® item regarding weeks per year spent teaching science provided a reality

check regarding the amount of science instruction they were able to fit into a typical school year. The majority of the teachers reported teaching science for 13-24 weeks per year, a handful responded 1-12 weeks, and none chose the higher option of 26-36 weeks. Based on these results, our best case scenario was looking less positive. How could we assist elementary teachers to adequately address our State's comprehensive and challenging science standards when even the most active were able to teach science for only 60% of the forty-week school year, and then only for a limited number of hours per week?

Our efforts to learn more about the time BSSP teachers were able to carve out for science via the Weekly Teaching Survey (WTS) provided insights into the considerable variation among the teachers, and the improbability of developing a one-size-fits-all solution to the low profile—even invisibility—of science in some classrooms. We learned through the WTS that although the teachers taught science on average for 1.64 hours per week during the eight instructional weeks we monitored with the WTS, there were wide variations across instructors, and across weeks for individual instructors. Even more tellingly, no science was taught on 45.7% of the teaching days reported. Teachers' comments during interviews built a picture of a "catch as catch can" science curriculum. This circumstance often appeared to be the unintentional result of district adoption of highly structured, time-intensive curricula to raise student performance in targeted subject areas, especially reading/language arts and, secondarily, mathematics. In these priority areas, teachers reported that their schools' expectations were clear regarding when to teach and for how long, the materials to be used, and student performance criteria equated with success. In coming out strongly for high priority subject areas, the districts appeared to be inadvertently working against learning opportunities in sidelined subjects. The result was clear in the highly variable scheduling of time for science.

The WTS results also revealed the brevity of the majority of science lessons taught, bringing into question at what point lesson duration affects the coherence and quality of the curriculum. Teachers' WTS reports showed that on one-third of the days when science was taught, the lessons lasted 20 minutes or less, and 27.9% of the lessons lasted 21-30 minutes. These were substantially shorter than the 30-40 minute estimate for a "typical" science lesson reported by the teachers when responding to the end-of-year SEC®. In contrast, the science lessons teachers planned when sharing their practice with BSSP colleagues lasted more than 30 minutes over 60% of the time, indicating these experienced teachers' sense of the time necessary for model science lessons. We hesitate to state where the divide lies between lessons that are too short to advance students' science learning, and lessons providing enough time for genuine

learning to occur. Yet common sense tells us that predictable instructional time of moderate length is needed to meet national, state, and district science standards that place an emphasis on inquiry, on challenging content rolled out gradually through coherent learning progressions, and on making connections to students' lives. Science programs heavily weighted toward short teaching segments offered on an ad hoc schedule seem destined to fail.

On the WTS, the teachers were also asked to report on major influences on their science instruction for the previous week. Their responses showed that district and State standards, curriculum, testing, textbooks and other teaching materials provided by the district, and parents or community were all fairly influential. During interviews, the teachers sometimes chafed against restrictions on their teaching, particularly what they saw as a disproportionate focus on reading/language arts stemming from their districts' State test results. Yet when given the opportunity on the WTS to voice misgivings about the influence of State assessments, they did not. Indeed, the teachers assigned almost every factor influencing their science instruction, including testing, as having a "somewhat positive" effect. During interviews, the teachers also frequently cited the positive effect of BSSP on their science instruction, primarily through providing them with teaching resources, a repertoire of strategies, and increased confidence in their content knowledge.

In the BSSP, we are moving forward with the knowledge that the time Partnership teachers have available for science teaching is significantly less than anticipated. Also, it appears that teachers' opportunities to teach the State standards-based science content provided in the professional development and master's degree experiences offered by the project will remain restricted in the short term. We also know that the tightly prescribed curricula many districts in our region have adopted, especially in reading/language arts and to a lesser extent in mathematics, leave little room for integration of science across the curriculum. In response, we are pursuing several options. First, we are continuing to gather data through periodic administrations of the WTS regarding teachers' patterns of science instruction. We are also making use of an assessment developed by the BSSP evaluation staff that documents not only participants' opportunities to learn science content through the project, but also opportunities to teach the content. This enables us to tailor professional development to instructional segments that are real, rather than to an unattainable ideal that assumes far more time for elementary science than is actually available. Secondly, as we recruit the Partnership's second cohort of elementary teachers, we are meeting with school administrator/teacher pairs to work out a mutually agreeable schedule of science instruction given the unique context in each school. The original memoranda

of agreement with partner schools now seem too generic. Updated versions will include specific information on instructional time for elementary science. We will also do everything feasible to enable BSSP teachers to do more with the time available for science, and to avoid a “less is less” outcome for their students. Classroom observations of BSSP teachers using the *COP* show that the quality of instruction in BSSP teachers’ classrooms is relatively high compared to that of national counterparts in the areas of collaborative/cooperative learning, connecting science to students’ lives, and some aspects of science inquiry [32]. In addition, WTS results show that teachers were able to connect the previous week’s science instruction to contemporary and historical tribal and community issues more than 40% of the time. These are some of the strengths upon which the Partnership can and will continue to build.

Finally, we will attempt to extend our Partnership’s influence by sharing knowledge in the policy arena. As illustrated with NAEP data shared earlier in this paper, time on task in science has a demonstrable connection to student performance. Our State, like many others, has developed truly visionary K-12 science standards, yet has not established a holistic vision for balancing learning opportunities across subject areas in elementary classrooms. The result is purposeful, intentional instruction in certain subject areas, and an almost accidental curriculum in others. Our Partnership is going on record here as opposing elementary science as an accidental curriculum.

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The Journal of Mathematics and Science: COLLABORATIVE EXPLORATIONS

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PART II: REGULAR JOURNAL FEATURES

Virginia Mathematics and Science Coalition

HELPING KINDERGARTENERS MAKE SENSE OF NUMBERS TO 100

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Abstract

The authors share what was learned about kindergarteners' abilities to make sense of numbers to 100 when one of the authors, Linda Jaslow, took over a kindergarten class from February through the end of the school year. Through examples of how she engaged her students in nine weeks of problem solving and discussions focused on making sense of the number system, we provide evidence that the children grew substantially in their ability to count and show understanding when counting by 10's and using 10's during problem solving. Suggestions for tasks to promote continued growth are also provided. Throughout this teaching experience, Mrs. Jaslow was reminded of the complexity of making sense of our number system, and this article showcases her instructional decision making that was based on inquiry into children's thinking. By valuing children's existing ideas, Mrs. Jaslow could use that thinking to help guide her instruction.

Introduction

When young children are asked to build a train of cubes and find the number of cubes in that train, their counting can be quite creative! They may accurately count the first few cubes and then continue the verbal counting sequence to a seemingly random stopping point. During their counting, they may skip cubes, reuse cubes that have already been counted, or fail to link their counts to any cubes at all. This creative counting is an indicator of the complexity of learning about numbers. To make sense of numbers, children must learn not only the verbal counting sequence (1, 2, 3,...), but also the way to connect each count with an object (one-to-one correspondence) and the fact that the last spoken number corresponds to the number in the counted set (cardinality). After many counting experiences, children gain these initial understandings of our number system. However, what happens when children begin counting to larger numbers or when they start grouping and counting by 10's? What do they learn about numbers and, in particular, the role that 10 plays in the structure of our number system?

For numbers greater than 10, developing understanding becomes more complex than for smaller numbers. First, the verbal number sequence becomes longer and harder to memorize. Second, quantities associated with large numbers are bigger, thus providing more opportunity for miscounting. To simplify counting a large number of objects, children sometimes group them, for example, into 10's. They then need to link each count to a group of 10 objects. They also need to monitor two attributes of a number simultaneously, switching fluidly between counting individual objects and counting groups of 10 objects [1].

In this article, we share what we learned about kindergarteners' abilities to make sense of numbers to 100 when one of the authors, Linda Jaslow, took over a kindergarten class from February through the end of the school year. This class was in an inner city school in which approximately 65% of the students were Hispanic and 35% were African-American. We also illustrate how her inquiry into children's thinking enabled her to value their existing ideas and support their growth.

Mrs. Jaslow's instructional philosophy is consistent with the *Principles and Standards for School Mathematics* and draws heavily from Cognitively Guided Instruction [2-4]. Cognitively Guided Instruction (CGI) is a research-based framework of children's mathematical thinking, as well as a philosophy that instruction should elicit and build on children's existing understandings, including those developed outside of school. By posing carefully selected problems and allowing children to solve these problems in ways that make sense to them, teachers can learn about children's existing ideas, consider what those ideas mean in terms of children's understandings, construct subsequent problems to appropriately challenge and extend those understandings, and then repeat the cycle. In short, both mathematical goals and children's thinking guide teachers' instructional decision making. The following is a first-hand account of what Mrs. Jaslow learned when she inquired into her kindergarteners' thinking, and then used that thinking to help guide her instruction.

Mrs. Jaslow's Adventures in Kindergarten

I had never taught kindergarten and had no idea what kindergarten students were capable of doing. In this district, kindergarteners were expected to count to 100 by the end of the school year. With about nine weeks of school left, I learned that many children had one-to-one correspondence only with small numbers (up to 5) and that few could count to numbers larger than 29. I began analyzing what facilitated children's understanding of larger numbers. I decided that they first needed to learn the 10's counting sequence (10, 20, 30, 40, 50,...) because I naively

thought that if children could remember the names and order of the decades, they should be able to count by 1's past 29.

Getting Started

I set out to help the children count by 10's and was shocked to learn that they could all do so already. Now I was really puzzled—if they could count to 100 by 10's and they could count to 29, why were they unable to take that next step and say, “30”? I came to realize that counting by 10's was a rote chant unconnected to any quantities. Although the children may have had a sense of 10, they probably lacked meaning for the other numbers in the 10's counting sequence. I decided that this disconnection was similar to their experience in learning to count by 1's in that they knew the rote verbal sequence before they developed the ability to link each count to a quantity (one-to-one correspondence). In essence, I needed to help the kindergarteners develop *ten-to-ten* correspondence so that counting by 10's was more than a rote chant.

To build meaning into counting by 10's, I designed story problems that would require the use of numbers larger than 10 and encourage grouping by 10. The children were accustomed to solving story problems because almost all of my instruction on number was presented in a story context. I selected familiar contexts so that the children could draw on their informal knowledge about these contexts to help them reason quantitatively. I generally read a problem aloud to the children, made a variety of manipulatives available (e.g., unifix cubes, color tiles), and asked them to solve the problem in any way that made sense to them. I also encouraged, but did not require, children to represent their thinking on paper and to write number sentences related to the problem. After the children had time to solve a problem individually, several children shared their strategies with the whole class, and together we discussed how to clearly record strategies and which number sentences best represented the problem.

I initially posed a multiplication story problem involving 10's because I wanted my class to make connections between groups of 10 objects and the 10's counting sequence. Recognizing that many children could count only to 29, I began with a problem involving numbers less than 30: “There are two children at your table. How many fingers are there?” I used this context because it built on the children's existing knowledge that they have ten fingers. Furthermore, although the children generally solved problems by representing all quantities and then counting by 1's, I wondered whether, in this context, they would use their knowledge that fingers come in groups of 10 to help them count by 10's. None did! Every child solved the problem by counting one set of 10 fingers by 1's and then a second set of 10 fingers by 1's.

During our whole-class sharing, I decided to push on the children's understanding of 10's. Cecilia and Stasha came to the front of the class, held up their two sets of hands, and counted the first and then the second set of fingers by 1's. They determined that there were twenty fingers, and the class agreed. I then asked them how many fingers Cecilia had and how many fingers Stasha had. The class easily responded that they each had ten fingers. I asked if there was another way to count how many fingers we had if Cecilia had 10 fingers and Stasha had 10 fingers. Aisha responded that they could count the fingers by saying, "10, 20." To push them a little further, I had a third child join the first two and asked the class how we could count the fingers. Immediately, Miguel responded, "10, 20, 30," pointing to each of the girls in turn.

To provide opportunities for the children to build on these emerging understandings, I continued to pose multiplication story problems about groups of 10 (e.g., "There are 5 vases of flowers. There are 10 flowers in each vase. How many flowers are there?") and addition problems about 10's (e.g., "There are 10 cows, 10 horses, and 10 pigs on the farm. How many animals are there?"). I also posed problems with dimes, to reinforce the idea of 10's in a context in which counting by 10's is common (e.g., "Zandra has 3 dimes. How much is that worth?"). When constructing these problems, I chose numbers in the 20–60 range to encourage children to develop their counting skills for numbers greater than 29 and to ensure that the problems remained accessible to those children who were still struggling to count by 1's. I was nervous about having kindergarteners work with such large numbers, but I decided that even if the problems had no other effect, they would give the children practice in counting and one-to-one correspondence.

To solve these problems, the children used a variety of strategies that reflected a range of understandings of number. Some drew all items and counted by 1's (see Figure 1), whereas others counted on from 10, not drawing the first set (see Figure 2). Other children drew all individual items, but counted groups by 10 (see Figure 3). Finally, some children did not represent items at all and instead recorded how they had counted by 10's (see Figure 4).

I believed that these problems had the intended effect on the children's understanding. Over time, many children learned that they could count groups of 10 by counting by 10's, and others simply practiced counting by 1's to numbers greater than 29. More counting practice occurred during class discussions in which I purposefully chose children to share a range of strategies. If the sharer used a strategy of counting by 1's, then the whole class helped him or her

count by 1's. If the sharer counted by 10's, we counted with him or her as well. Thus, even those children who were not yet ready to count their own groups by 10's could participate in the class discussions.

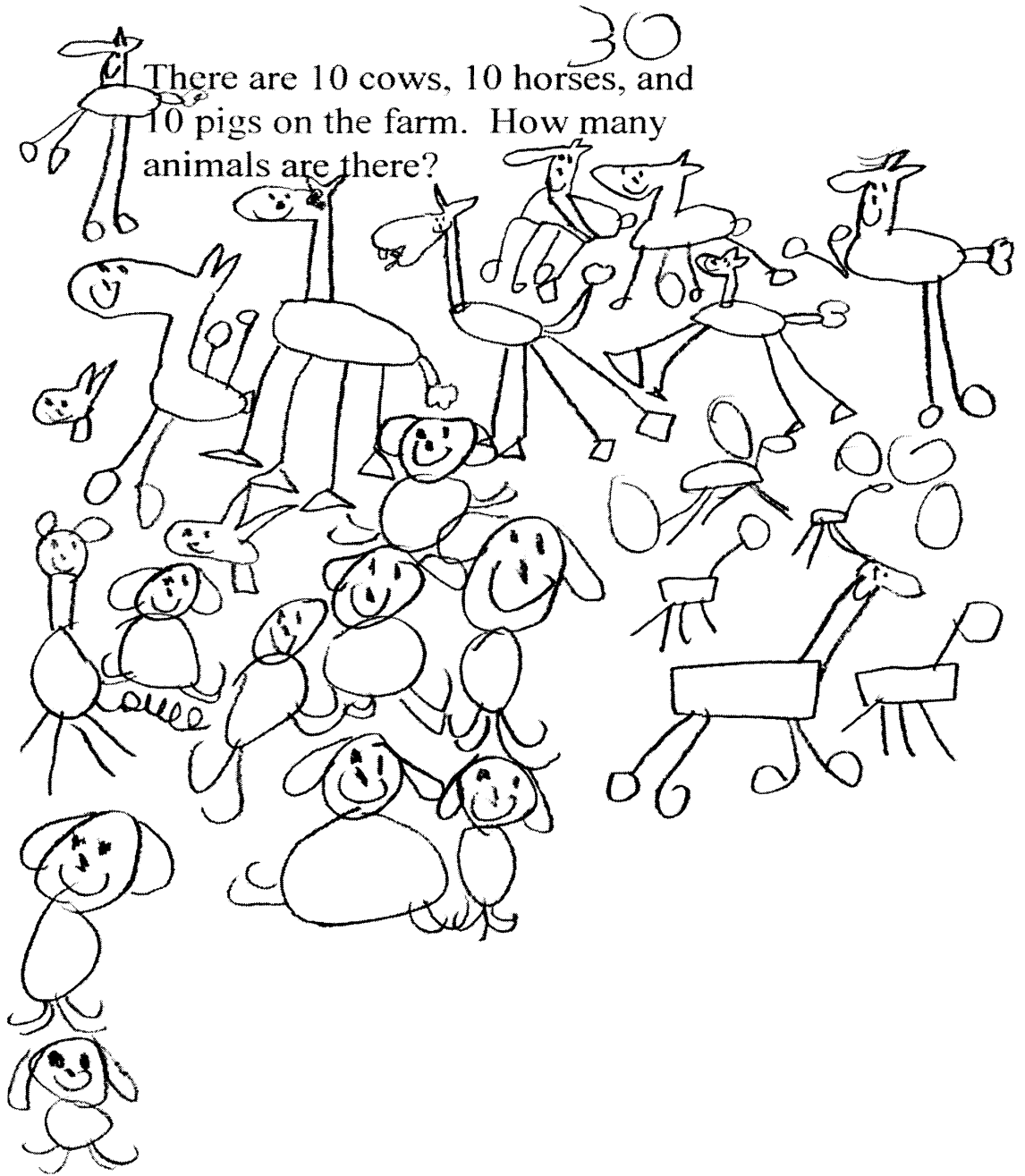


Figure 1. Representing all items and counting by 1's.

There are 10 cows, 10 horses, and 10 pigs on the farm. How many animals are there?

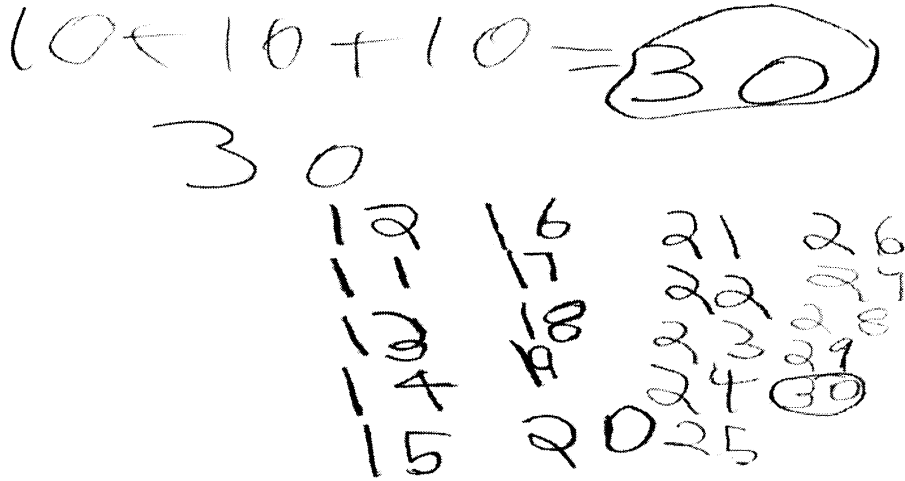


Figure 2. Counting on from 10.

There are 5 vases of flowers. There are 10 flowers in each vase. How many flowers are there?

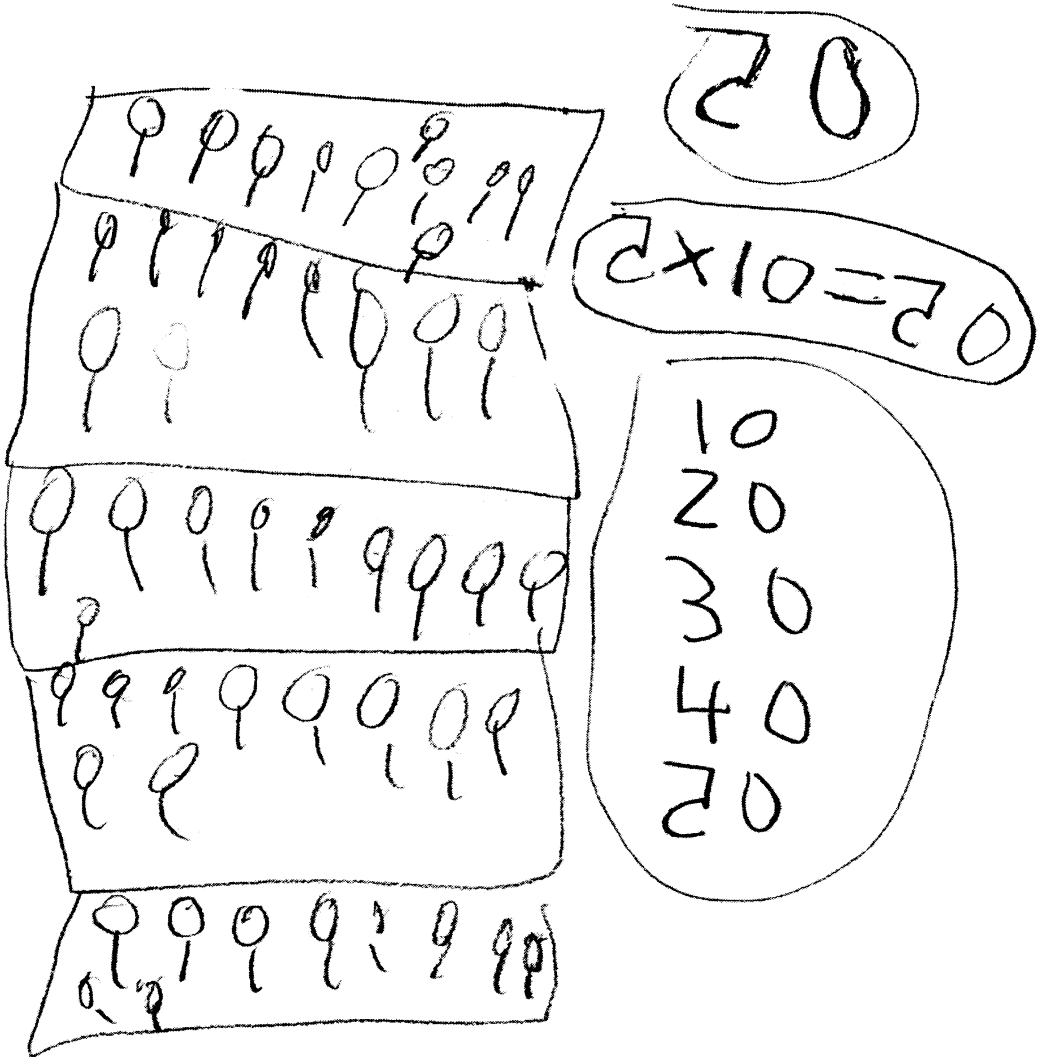


Figure 3. Representing all items, but counting by 10's.

Zandra has 3 dimes. How much is that worth?

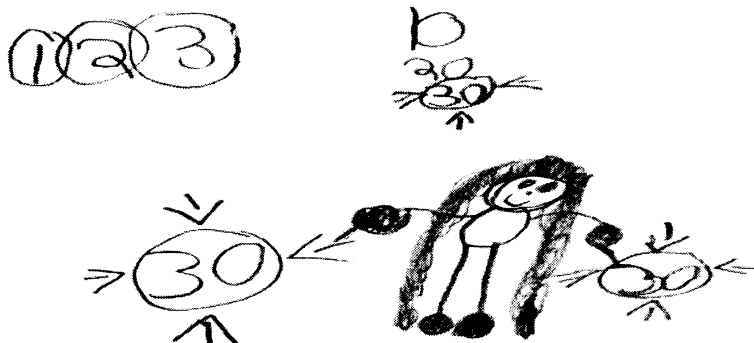


Figure 4. Counting by 10's.

What Next?

When the children became more proficient in working with multiplication and addition with 10's, I began to wonder what they would do with this problem: "There are 20 butterflies. Twenty more butterflies join them. How many butterflies are there?" Would they use their emerging knowledge of 10's to help them solve the problem? Most children counted only by 1's. They counted out 20 objects, then another 20 objects, and finally counted all objects to get 40. Only two children explicitly used their knowledge of 10, saying, "10 + 10 + 10 + 10 = 40."

Mrs. J.: Where did the $10 + 10 + 10 + 10$ come from? I don't see any 10's in the problem.

Stasha: $10 + 10 = 20$, and $10 + 10 = 20$.

Mrs. J.: Okay, so what did you do next?

Stasha: I said, "10, 20, 30, 40."

Stasha did not know that $20 + 20 = 40$, but she did know that 20 was comprised of two 10's. Because she frequently solved problems by counting by 10's, decomposing 20 into two 10's made this problem easier for her. I found this solution interesting, and it prompted me to wonder

whether a problem involving only one 10 might allow more children to recognize the 10's in a number.

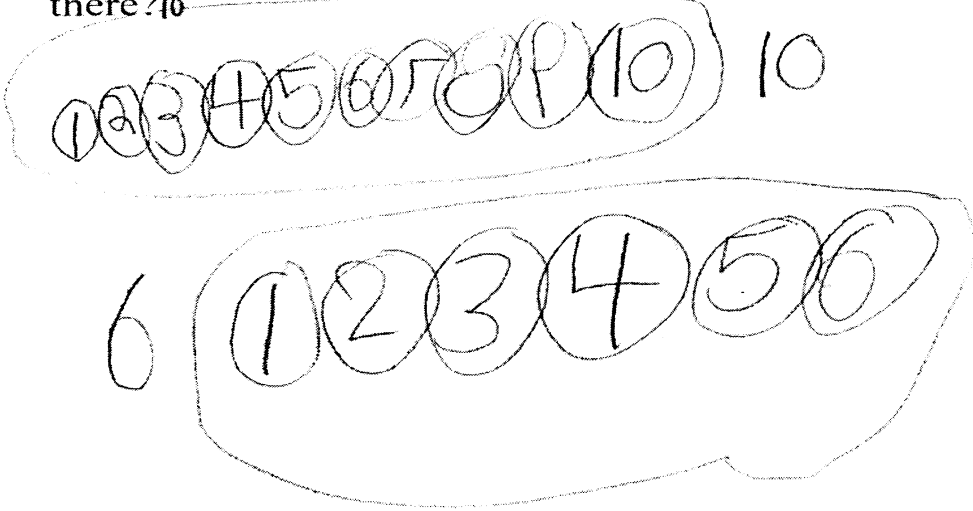
To explore this question, I posed the following problem: "You have 10 cookies. Stasha gives you 11 more. How many cookies do you have now?" I wondered whether the children would use their knowledge of 10's to decompose 11 into $10 + 1$ and simplify their problem solving by reconceptualizing the problem as $10 + (10 + 1)$. Although they were generally successful with this problem, none thought of the problem in this way! Most counted by 1's to make a set of 10 and a set of 11, and then counted all 21 by 1's.

Because none of the children decomposed 11, I realized that even those children who understood $10 + 10 = 20$ did not think about 11 as $10 + 1$. Was I surprised! I was again reminded of the complexity of making sense of our number system. All the children could count by 1's to 20 and by 10's to 100. However, they were still building their understanding of the underlying structure of the number system and the critical role that 10 plays. If the children were to understand numbers to 100, they needed to recognize that 11 is the same as 10 plus 1, 24 is made of two 10's and four 1's, and so on. I now had a new direction for my instruction.

Extending Children's Understanding

To extend the children's understanding of the role of 10 in our number system, I began to pose story problems requiring the addition of a single-digit number to 10 (e.g., "There are 10 butterflies. 6 more come. How many butterflies are there?"); or, the subtraction of a single-digit number to get 10 (e.g., "There are 19 giraffes eating. 9 walk away. How many giraffes are still eating?"). Most children counted only by 1's, making the first set and then adding or taking away the second set, depending on the problem context (see Figures 5 and 6). Gradually, however, the children's strategies for addition became more sophisticated and about half the children began to count on from 10. For example, for the butterfly problem ($10 + 6$), they recognized 10 as a group, and then counted on: "11, 12, 13, 14, 15, 16," to get the answer (see Figure 7).

There are 10 butterflies. 6 more come. How many butterflies are there?
16



16

$$10 + 6 = 16$$

Figure 5. Modeling the action in the addition story problem and counting by 1's.

There are 19 giraffes eating. 9 walk away. How many giraffes are still eating?

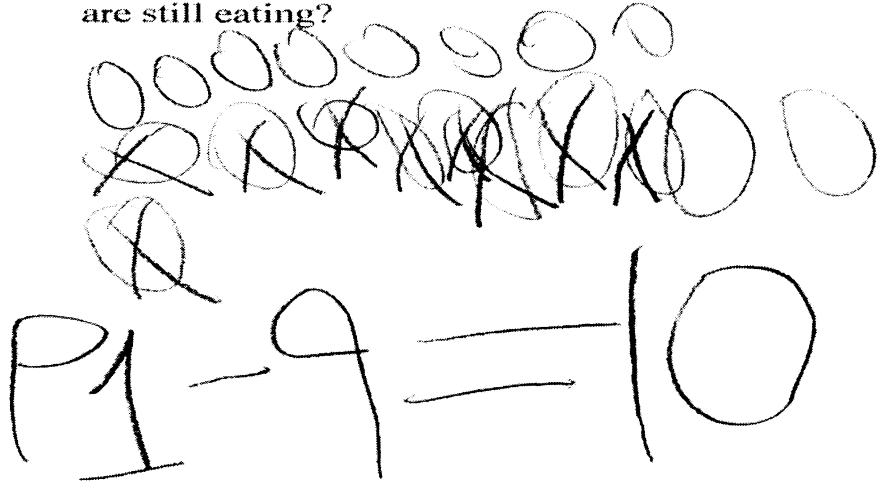


Figure 6. Modeling the action in the subtraction story problem and counting by 1's.

There are 10 butterflies. 6 more come. How many butterflies are there?

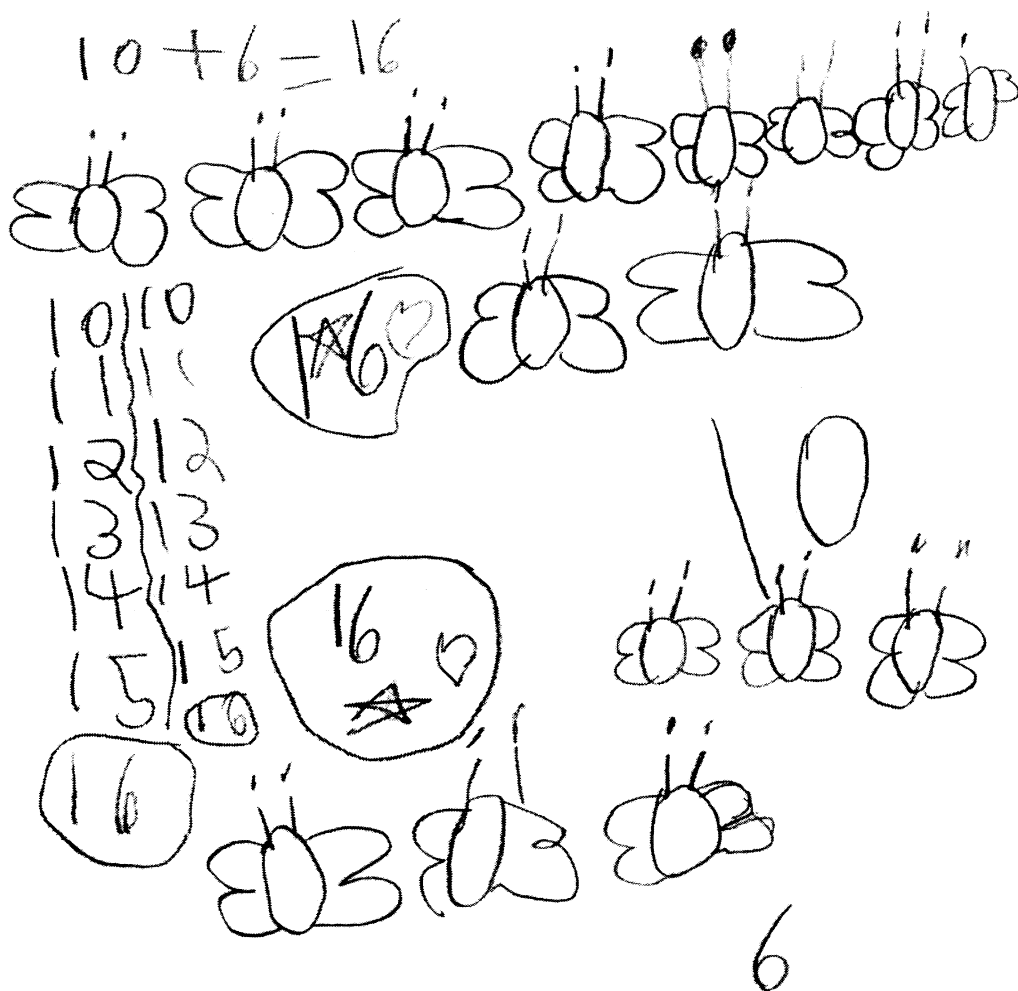


Figure 7. Modeling the action in the addition story problem, but counting on from 10.

These addition strategies reflected children's growth in sophistication of their problem-solving strategies and, in particular, in their abilities to group numbers. However, exactly what the children were learning was unclear. Were they focusing on decomposing 16 into a group of one 10 and six 1's, or were they focusing on solving addition problems by counting on from the larger number? The subtraction problems (subtracting a single-digit number to yield 10) helped me recognize that the latter explanation was more likely, and that the children needed more experience identifying 10 in teen numbers. To directly use knowledge of 10 to solve these subtraction problems, children would need to decompose a teen number into 10 and a single-digit number, but none did so. Instead, they represented all items and counted by 1's while they took away the required quantity.

At this point in my instruction, the school year was coming to an end. The children had grown substantially in nine weeks, but I had underestimated the complexity of learning about numbers to 100. On the one hand, the children's counting had improved. About 75% of the children could now count to 100 by 1's, even though we had done little rote counting and had focused our problem solving on numbers only to 60. Also, the children were beginning to show understanding when counting by 10's and using 10's during problem solving because (I believe) after making sense of the counting by 10's chant, they were able to recognize the underlying structure and extend their counting from 60 to 100. These counting abilities contrast with the children's counting when I arrived, at which time they could count (chant) by 10's, but could not count by 1's to numbers larger than 29! On the other hand, despite this growth, my class still had much to learn about our number system and, in particular, they needed more opportunities to decompose numbers into 10's and 1's. In the final sections, we reflect on possible future directions to extend these children's mathematical understanding.

Reflections and Future Directions

To support understanding of numbers to 100, Mrs. Jaslow engaged her children in nine weeks of problem solving and discussions focused on making sense of the number system. However, we recognize that this understanding, being quite complex, takes years to develop fully and that the children would need many more related experiences throughout elementary school. So what should come next for these children?

The use of story problems was the primary tool in the development of these children's understanding, and Mrs. Jaslow found two categories of story problems especially helpful: 1) grouping problems with 10 in each group; and, 2) problems designed to help children compose

new numbers from a 10 and 1's (e.g., $10 + 6$) and decompose numbers into 10 and 1's (e.g., $19 - 9 = 10$). Upon reflection, we identified several ways to extend these problem categories to further foster children's understanding of numbers to 100, and each is described below (see Table 1).

Table 1
Story Problems to Help Children Understand Numbers to 100

	Grouping Problems	Problems to Decompose Numbers Into 10's and 1's
Problems Posed	<ul style="list-style-type: none"> • <i>Multiplication (10 in each group):</i> There are 5 vases of flowers. There are 10 flowers in each vase. How many flowers are there? • <i>Addition (around 10):</i> There are 10 cows, 10 horses, and 10 pigs on the farm. How many animals are there? 	<ul style="list-style-type: none"> • <i>10 + a single-digit number:</i> There are 10 butterflies. 6 more come. How many butterflies are there? • <i>Subtracting from a teen to get 10:</i> There are 19 giraffes eating. 9 walk away. How many giraffes are still eating?
Potential Extensions	<ul style="list-style-type: none"> • <i>Division (Grouping by 10's):</i> You have 50 stamps to put in your stamp book. Each page holds 10 stamps. How many pages will you need? • <i>Grouping by multiples of 10:</i> The teacher has 2 new boxes of markers, and each box has 30 markers. How many markers does the teacher have? The clown had 20 blue balloons, 20 red balloons, and 20 yellow balloons. How many balloons did the clown have? • <i>Mixing 10's and 1's:</i> <i>(beginning with a decade number)</i> Aisha has 3 bags of candy. Each bag has 10 pieces. She also has 4 loose pieces of candy. How much candy does Aisha have? On Monday, Alicia earned 10 citizenship points. On Tuesday, she earned 10 more points. On Wednesday, she earned 11 points. How many points has she earned? • <i>Mixing 10's and 1's:</i> <i>(beginning with a non-decade number)</i> The class counted 22 watermelon seeds. Then they counted seeds from 3 more watermelon pieces, and each had 10 seeds. How many seeds did they count in all? Michael has \$23 in his piggy bank. He earned \$10 on Saturday and \$10 on Sunday. How much money does he have now? 	<ul style="list-style-type: none"> • <i>Decade number (greater than 10) + a single-digit number:</i> Raphael had 40 toy cars. His uncle gave him 6 more toy cars for his birthday. How many toy cars does Raphael have now? • <i>Subtracting a single-digit number from a non-decade number (greater than 20) to get a decade number:</i> There are 34 butterflies. 4 fly away. How many butterflies are left?

Additional Grouping Problems

In addition to using multiplication and addition problems focused on grouping 10's, teachers can pose division problems in which 10 items are grouped together (e.g., "You have 50 stamps to put in your stamp book. Each page holds 10 stamps. How many pages will you need?") Children naturally solve this type of division problem by making groups of 10, and thus, discussing their strategies can help children make sense of counting and grouping by 10.

Using Multiples of 10

Another potential extension includes the use of multiples of 10 rather than 10 itself. For example, teachers might present a problem asking children to recognize the 10's in numbers greater than the teens (e.g., "Raphael had 40 toy cars. His uncle gave him 6 more toy cars for his birthday. How many toy cars does Raphael have now?"). Even a child who knows that 16 is made of a 10 and a 6 may not know that 46 is made of four 10's and a 6. Children need multiple opportunities to decompose numbers into the appropriate 10's and 1's.

Similarly, multiples of 10, rather than 10 itself, can be used in grouping problems (e.g., "The teacher has 2 new boxes of markers, and each box has 30 markers. How many markers does the teacher have?"). In this problem, children have opportunities to use the three 10's in 30 to simplify problem solving.

Mixing 10's and 1's

Children who can count by 10's and by 1's independently may struggle when asked to do both in the same problem. Grouping problems can be extended to give children opportunities to consider groups of 10 and single items within the same problem (e.g., "Aisha has 3 bags of candy. Each bag has 10 pieces. She also has 4 loose pieces of candy. How much candy does Aisha have?"). Children who have trouble moving between 10's and 1's might correctly show three groups of 10 and four 1's, but when determining the total, incorrectly count, "10, 20, 30, 40, 50, 60, 70," by counting each individual item as 10. Grouping problems involving both 10's and 1's provide children opportunities to develop the necessary fluidity in moving between counting by 10's and counting by 1's.

A further extension is grouping problems children may solve by counting by 10's from a non-decade number. Children first learn to increment/decrement by 10 from a decade number

(i.e. 10, 20, 30,...), and to start counting by 10's from a non-decade number is more challenging and requires experience with such problems. For example, to provide children with an opportunity to count by 10's from 22, a teacher might pose this problem: "The class counted 22 watermelon seeds. Then they counted seeds from 3 more watermelon pieces, and each had 10 seeds. How many seeds did they count in all?"

Final Thoughts

We are not suggesting that the categories of story problems we describe are the only ones possible or desirable to use. In fact, children need opportunities to solve a wide variety of story problems that allow them to develop many mathematical concepts. We also recognize that some approaches to developing understanding of number do not depend on story problems, but we chose to highlight them, not only because they were powerful in helping these kindergarteners learn, but also because multiplication and division story problems, in particular, are often overlooked during instruction with young children. We encourage teachers to pose problems with strategically selected numbers even if their students are still struggling with counting. Children improved their counting skills and place-value understanding by working with larger numbers during problem solving, illustrating that consistent counting is not a prerequisite to engaging children in problem solving and other place-value activities.

A final caveat is in order. Although carefully designed story problems with relevant contexts and intentional number selections can be powerful instructional tools, the benefits do not reside solely in the design of the problems. Children must be allowed to solve problems in ways that make sense to them and be provided with opportunities to share their thinking. Teachers must consistently inquire into children's thinking and build on what they learn. Because there is no single best sequence of problems, teachers must pose a problem, listen to their children's thinking, consider their options, and then select an appropriate next problem. We encourage teachers to follow their curiosities about children's thinking and allow their instruction to constantly evolve on the basis of what they hear from their students. Children's mathematical thinking is often different from adults' mathematical thinking. At times, seemingly simple ideas may appear confusing to children and, at other times, young children will impress adults with the complexity of their own ideas.

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MATHEMATICS SPECIALISTS INCREASINGLY APPRECIATED AND SOUGHT

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Introduction

The overall goal of the National Science Foundation (NSF) Teacher Professional Continuum (TPC) program grant, now in its fifth and final year, has been to determine the effectiveness of a school-based Mathematics Specialist program. The grant's core has been the preparation and support of two cohorts of twelve Mathematics Specialists each, deployed in twenty-four elementary schools in five Virginia partner school divisions. This article reports and discusses the third round of parallel utilization interviews conducted in these divisions as part of the grant's policy research component.

Compared with the group of principals who received the first cohort of Mathematics Specialists in 2005 and who were interviewed in 2006, the group of principals who received the second cohort in 2007 and who were interviewed for this study in 2008 were more prepared to integrate the Specialists into their schools. They were more involved with the Specialists' activities and responsibilities, and facilitated their primary roles as teacher leaders.

These two groups of principals are identical in their enthusiasm for their Mathematics Specialists and the grant-sponsored model, namely—the built-in, everyday support for their schools' mathematics instruction programs. They also are united in their apprehensions about losing their Mathematics Specialists with the grant's conclusion. Said one, “We really need a Math Specialist in every building.”

Background and Methodology

The NSF-TPC grant's parallel utilization study focuses on local school and division implementation of the twenty-four Mathematics Specialists provided through the grant; particularly, the Specialists' actual roles in their schools and their acceptance by classroom teachers and the school community. The five partner divisions, which contribute significant funding and support for their grant-provided Specialists, are the cities of Portsmouth (four

Specialists), Richmond (eight Specialists), and Virginia Beach (four Specialists), and also the counties of Spotsylvania (two Specialists) and Stafford (six Specialists).

The findings from the 2006 interviews of the Cohort I principals are reported in “The Role and Impact of the Mathematics Specialist From the Principals’ Perspectives” [1]. The findings from the 2007 interviews of school division policy leaders, including school board members, division superintendents, and supervisors for instruction, are reported in “School Division Leaders Keen On In-School Mathematics Experts” [2]. The policy leaders interviews focused on division-level implementation decisions, which included the reasons behind the division’s participation and perceptions of the Mathematics Specialists’ impact on instruction and achievement.

During Summer 2008, both of the grant’s policy associates interviewed six principals. All principals were cooperative and spoke freely about their experiences with their Mathematics Specialists. The interviews were loosely structured using the same discussion items as had been used with the Cohort I principals. Areas addressed included the following: 1) school population information; 2) principal and faculty preparation; 3) supervision; 4) areas of focus; 5) activities included in the Mathematics Specialist definition used in the grant [3]; 6) classroom teacher response; 7) school responsibilities; 8) school and parent satisfaction; and, 9) expectations for the next school year.

This descriptive list of discussion items was provided to the principals well in advance of the interviews, and all principals were encouraged to speak about any areas not included in the discussion outline. Rapport was easily established and conversations flowed freely. The principals received and reviewed summaries of the interviewers’ notes for the purposes of corrections and additions.

Analysis of the principals’ responses revealed several central tendencies which illuminate positive growth since the first NSF Mathematics Specialists were placed in schools at the start of the 2005-6 school year. The observations and summaries which follow discuss program maturation in these areas: 1) principal’s familiarity with the Mathematics Specialists program; 2) knowledge and use of data; 3) specific plans for focus; 4) leaders, not teachers; 5) faculty acceptance; and, 6) school and community support.

Observations and Summary—Principals' Familiarity with Program

Understandably, the Cohort II principals had a much higher degree of awareness of the role and benefits of Mathematics Specialists than had their Cohort I counterparts. In the intervening two years between the two cohorts' school placements, experiences and discussions about Mathematics Specialists had increased at both the state and local levels. More information about the Specialists was appearing in professional journals and in newspapers, and the Mathematics Specialist was a topic at educational conferences.

The principals interviewed in 2008 reported contacts with division mathematics staff and their Cohort I forerunners. They had been following the local implementation with interest, "hearing that good things were happening in the Cohort I schools." These exposures led to the principals' determination to have Specialists in their own buildings, one principal saying, "I knew I needed one." Even though the school placements of Specialists had been predetermined by grant protocol, the principals reported begging the administration for inclusion. One principal who transferred from another division where she had had a math coach lobbied for one in her new assignment. Such familiarity publicized the Specialists throughout the divisions and likely accelerated the acceptance and use of the Mathematics Specialists in their new schools.

In one division, a foursome of principals, two in Cohort I and two in Cohort II, met during Summer 2007 to discuss the past year's experiences with Mathematics Specialists and lessons learned. Before the school year started, the four principals lunched with their four Specialists to discuss entry strategies and goals for the upcoming school year. They continue to encourage the Specialists to meet regularly for support and sharing. When a division budget oversight omitted local money for the Mathematics Specialists, threatening their continuation, the four principals became an ardent (and successful) team of advocates for restoration of the needed funds.

Observations and Summary—Knowledge and Use of Data

Comfort levels and capabilities in interpreting and using data to drive instruction rose considerably during the intervening two years. A principal observed that data use is becoming easier and more routine for teachers. This upward trend is related not only to the presence in their schools of Mathematics Specialists trained in data use, but also may be attributed to the intense focus on data by school division leadership and dedicated support from Virginia Department of Education (VDOE) staff. Principals were quick to praise accelerating division and VDOE efforts

in improving the use of data, sharing analyses of school and division data, and providing a range of professional development opportunities to faculties.

The principals have given major responsibility to their Specialists for disaggregating, analyzing, and interpreting the school mathematics data from both state and division testing. Data discussions occur between principals and Specialists, within administrative and data team meetings, and ultimately, with grade level teams. Notwithstanding, the principals remain the instructional leaders and communicators of priorities in their buildings.

Data typically is used to target the instructional needs of the teachers as well as the achievement needs of the students. One principal commented that, “It is important to learn from last year’s mistakes—how, for example, a specific instructional area needs to be taught differently.” Specialists share reviews of individual pupil or class deficiencies with classroom teachers to strategize instructional methods and interventions at the same time. Discussions such as these were described as “specific, not global.”

Data is used for reward as well as intervention. One Specialist has the responsibility of maintaining the “85% lists” in the library. These lists recognize both the students who have achieved a pass score of 85 or above and teachers whose classes have done the same.

Observations and Summary—Specific Plans for Focus

Each principal had several specific areas of focus for the Specialist, some identified by data analysis and some “the old-fashioned way,” through observation and experience. Some principals singled out specific grades for focus, generally those grades performing at an unsatisfactory level on previous testing or those grades where mathematics testing had been recently instituted.

The Mathematics Specialists had responsibilities for assisting teachers in addressing areas of deficiency. In many instances, Specialists were paired with new or weak teachers to boost their classroom instruction. One principal noted that the Specialist was “great at collaboration with teachers on problem identification and strategies for solving problems.”

The principals’ expectations are numerous and require a range of content and pedagogical skills on the part of the Mathematics Specialists. Among the areas of school mathematics focus listed by the twelve principals are the following: lessening traditionalism in a school’s

mathematics instruction program; stressing concepts and active engagement in instruction as well as memorization; arranging more mathematics instructional time in specific situations; focusing on teaching teachers to improve grouping for instruction; algebra readiness (“a thorn in our side right now”); problem solving as a whole; basic operations of multiplication and division; “teacher quality”; ensuring proper curriculum pacing and use of materials; and, “helping teachers teach the entire mathematics curriculum, not just what they are comfortable with.”

Data and the desire to improve student achievement appear to have increasingly focused schools on individual teacher skills. Principal and classroom teacher expectations for Mathematics Specialists in this regard are high and have resulted in more requests for coaching and resources.

Observations and Summary—Leaders, Not Teachers

Mathematics Specialists often find themselves in leadership roles in their schools. Many serve on planning or improvement teams that address division and school goals. One serves as school committee chair for math action and the mathematics Lead Teachers. Another is serving as the academic coordinator for the No Child Left Behind math tutoring program. Yet another is the school liaison to the division mathematics supervisor and introduces division ideas and materials to teachers. One principal noted that she appreciated “another set of eyes and hands to observe instruction.” Another principal stated, “As far as math goes, she *is* the leader.”

Principals frequently commented on how motivated and hard working their Specialists were, and admired how quickly they took the initiative in a variety of areas. More than one has assumed responsibility for the university instructors’ algebra readiness program. Some have assumed roles in leading or restructuring the school remediation program.

Another scheduled herself frequently with a long-term fifth grade substitute which, in the principal’s view, enabled the students “to hold their own in math” during their regular teacher’s absence. Yet another encouraged teachers to attend division workshops or other professional development opportunities, even finding specific programs for teachers according to their instructional needs. It was reported that the teachers appreciated this individualized assistance.

Many comments demonstrated that Mathematics Specialists also enhance the school mathematics climate in subtle ways. One Specialist is described as “carrying the torch” for mathematics. Another elevated the importance of mathematics at the school, establishing it as a

separate goal in the school improvement plan where previously it had been only embedded. Math clubs, math awards, math displays and contests, parent and Parent Teacher Association interactions have raised the importance of mathematics throughout the schools and communities.

In the 2006 interviews, some principals had reported assigning the Mathematics Specialist to be the math teacher on a daily basis for one class or scheduling the Specialist on a regular basis to provide student remediation or prepare the required assessment portfolios for certain students with disabilities. In the 2008 interviews, the talk was of Specialists teaching teachers, not teaching students.

Observations and Summary—Faculty Acceptance

The imaginary line tracking faculty acceptance of the Mathematics Specialist appeared initially to follow the same gradual upward curve that was estimated from the Cohort I interviews. There was initial apprehension and some push-back, most often from veteran teachers who had territorial issues. Some principals set precise expectations regarding staff consultation with the Specialist. One even required each classroom teacher to invite the Mathematics Specialist into the room a minimum of one visit per month, indicating that the frequency would be checked.

However, the acceptance curve seemed to turn upward sooner and more steeply than it had for the Cohort I Specialists. Comments included the following examples:

- “News of positive peer reception flew down the hall and encouraged all teachers to access this new resource.”
- “Once the faculty understood the role, the teachers embraced her; even the seasoned teachers welcomed her.”
- “The Math Specialist keeps the teachers from being overwhelmed.”
- “Trust was the key issue in the first year and the Specialist was able to build this. The faculty became supportive as the members saw the Specialist as benefiting their efforts.”

In one school, the Specialist soon was in such demand that teachers’ daily schedules had to be adjusted to allow more even access.

Overall, the faculties took to teaming and coaching very well. The teachers appreciated the Mathematics Specialist’s help with understanding and using assessment tools. They also

appreciated the versatility the Specialist brought to their teaching in terms of another point of view about their classrooms, teaching style, alternative instructional strategies, and new resources. Students were reported to be very accepting of the Specialist's presence, too.

Mathematics Specialists with good technology skills were particularly praised by teachers with multi-level classes or in fully-included schools, as they were of great help with the classroom instructional technology so valuable in differentiating instruction for students. Observed one principal, "The teachers reach out to her because she has what they need."

Observations and Summary—School and Community Support

Principals and teachers are enthusiastic. They are very pleased to have this new resource, one principal noting, "Math Specialists are a hot commodity now. Everyone wants one." Satisfaction is high. "I am absolutely satisfied. I need more Math Specialists." Another commented, "If the Math Specialist is taken out of our school, the teachers will fight!"

Principals also noticed that the Specialist's expertise and resourcefulness extended into the parent community. In several schools, the parents increasingly realized the importance of mathematics instruction for their children and stepped up their interactions with teachers. Others began calling on the Mathematics Specialist for guidance and assistance. Some Specialists became involved with parent groups requesting their expertise with teaching and reinforcing math skills at home.

One principal is proud that some of the school's community partners began asking for the school's *Standards of Learning* test scores. Some partners are supporting the achievement and attendance awards given at the local "Saturday School" for reading and mathematics remediation.

Nevertheless, as delighted as principals are with their Mathematics Specialists, they are considerably concerned that their divisions will discontinue these positions when the grant terminates at the end of the 2008-2009 school year. When the grant ends, so will the \$25,000 payments made by the NSF toward the first two years of each Specialist's salary.

Indicating high regard for the contributions of Mathematics Specialists, the Commonwealth of Virginia made a one-time appropriation of \$12,500 in salary support for Cohort I Mathematics Specialists who continued for a third year. So appreciative were the

partner divisions that they continued their local funding and made up the \$12,500 gap in the third year, and then funded all costs for a fourth year.

Reflecting their strong beliefs in the effectiveness of in-school Mathematics Specialists, the Cohort II principals most heartily recommended that the current Specialists be maintained in place and that the program be expanded to other division schools. Policymakers, in turn, have supported their principals' insistence that Mathematics Specialists have high value in their schools. At the time this article was submitted for publication, all five partner divisions had included sufficient funding in their 2009-2010 budget proposals to continue their current Specialists for another year. While these budgets have yet to be adopted, division policymakers' inclusion of such funding during hard financial times is noteworthy.

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FORMULATING A STATE APPROACH TO PROFESSIONAL DEVELOPMENT

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Abstract

When viewed from the perspective of an entire state's needs, the challenges of designing professional development to meet the requirements of the federal No Child Left Behind legislation of 2001 are daunting. In Oklahoma, the concerns about delivering to rural and urban populations which contain a variety of underserved populations are further complicated by the differences in the way science and mathematics are structured as disciplines. We describe two model programs, one in science and one in mathematics, which take much different approaches. However, the programs have three common elements that make them highly successful. Each program engages teachers strongly, seeks to change learning by altering both teachers' behavior and content knowledge, and is continuously reflective.

The Professional Development Challenge

The American educational landscape has become much more complex and challenging over the last decade. In mathematics and science, the higher education partners who work with school districts in professional development must provide standards-based training in areas subject to testing while not abandoning other areas of the curriculum. They must do this in ways that are accountable, and the training must address the needs of diverse student audiences.

This challenge can be met by developing a portfolio of programs that are diverse in the way they approach science and mathematics professional development, yet are based upon some common elements that make them effective. In this article, we describe strategies and two model programs we have implemented in Oklahoma, a state that has many traits in common with other states.

National Background

The Elementary and Secondary Education Act (ESEA), part of the nation's longstanding commitment to educational quality, became the federal No Child Left Behind (NCLB) legislation of 2001 when it was signed into law on January 8, 2002. This federal legislation made significant changes in education policy, such as new testing, accountability, and teacher quality provisions which impacted every school district in the country. These changes have altered the landscape of school reform and had a major effect on professional development delivered by higher education.

The No Child Left Behind (NCLB) legislation, with its requirements for highly qualified teachers, has increased national attention on state policies and practices regarding the teacher preparation, certification, and professional development. In 2001, the Carnegie Corporation of New York awarded a grant to State Higher Education Executive Officers (SHEEO) to work with Institutes of Higher Education (IHE) on teacher quality policy issues. The ultimate goal of this project was to improve the capacity of elementary and secondary school teachers by identifying key issues where higher education has a clear responsibility to improve teacher quality. The report suggested two important characteristics that should be part of NCLB professional development: 1) more visible and tangible collaborative efforts to improve teacher preparation among preK-12 and postsecondary education in the project states; and, 2) wider involvement of arts and science faculty in the education of prospective teachers and in the development of standards and curricula [1].

The Oklahoma Situation

The challenges of implementing the NCLB legislation at the higher education level in Oklahoma mirror those faced by many states. The Oklahoma State Regents for Higher Education (OSRHE), as the designated State Agency for Higher Education (SAHE), manages the higher education portion of Oklahoma funds used to address the NCLB targets. In their role, the Regents are charged to provide high quality, continuing professional education workshops for teachers or teams of teachers from individual schools and/or districts.

The Highly Qualified Teachers and Improving Teacher Quality State Grants program is one aspect of NCLB funding. A principal goal of the program is to ensure that all students have highly qualified teachers; that is, teachers with the subject matter knowledge and teaching skills necessary to help all students achieve high academic standards, regardless of individual learning styles or needs. State funding for it supports scientifically based practices that improve teaching so as to raise student achievement in core academic subjects.

In common with other states, Oklahoma faces a range of challenges in addressing these charges. First, differences in the State's population density make equitable delivery a challenge. About 64% of the population resides in higher density urban or suburban settings where needs are great, but the remaining 36% is spread throughout rural regions with sparse populations, where the distances make delivery of services more challenging [2]. Second, Oklahoma has substantial populations of underserved students who have historical achievement gaps. The African-American student population (10.8%) has important needs; there is a growing Hispanic population (9.6%); and, the Native American student population (19.2%) is among the nation's largest [3]. Overlaying these issues is a long history of local control which has resulted in 429 independent school districts (K-12) and 111 dependent school districts (K-8). The net result is that services must be provided in a range of locales, addressing the needs of a variety of students in ways that impact many individual districts.

Needs in Mathematics and Science

The Oklahoma teaching standards, the Priority Access Student Skills (PASS), parallel the national standards in science and mathematics [4]. Testing on the mathematics standards in fifth grade is a key factor in determining a school's academic ranking and an important concern in the State. Based upon National Assessment of Educational Progress (NAEP) scores in the fourth grade, there has been improvement in mathematics success over the last decade. Oklahoma's NAEP score in mathematics was 237 in 2007, just under the national average of 239, and up from a score of 220 in 1992 and 229 in 2003 [5]. Although the mathematics scores have shown steady improvement since 1992, the achievement gaps of about 22 points for African-American students and 17 points for Hispanic students have remained consistent since 1992.

Oklahoma benefited from a Collaboratives for Excellence in Teacher Preparation (CETP) award from the National Science Foundation (NSF) which reformed the mathematics training of elementary teachers and was coupled with an increase in mathematics hours (to twelve) required for an undergraduate pre-service degree. Evaluation has shown that the program produced more standards-based instruction in mathematics and science instruction and some indications of enhanced student learning, but the enhancements in science may have been greater than those in mathematics [6-8]. New methods of instruction have had a positive effect on those who recently entered the profession, but much of the elementary teacher workforce is made up of teachers who have twelve to thirty years of experience and training that predates reform methods. In general, these teachers have a higher level of math anxiety and more of a tendency to teach in traditional ways.

In elementary science, the PASS standards also parallel national standards and emphasize inquiry-based instruction. However, because there is no state testing and no effect on a school's academic rating, there are a wide range of implementations. A few urban and suburban districts support kit-based instruction, using materials like *Science and Technology for Children (STC)*, available through Carolina Biological [9]. Other districts offer some science that is structured in ways determined by the individual teachers. Still other schools and districts actively discourage science instruction in favor of additional instruction in reading and mathematics, areas subject to testing. This trend, one that has been cited nationally, has affected other core disciplines like social studies and fine arts [10-12].

Professional Development Response

Two projects, one in science and one in mathematics, illustrate how the State has responded and show how diverse strategies must be employed. At Southwestern Oklahoma State University, KESAM (Kindergarten-Eighth Scholars Appreciating Mathematics) was originally designed to serve the needs of rural teachers in western Oklahoma. In five years of operation, it has expanded to include coverage to both rural and urban areas across the State. It places special priority on recruiting teams of two teachers to build school culture and uses a word-of-mouth network, powerful in rural areas, in addition to normal recruitment to recruit teachers from rural areas with few professional development opportunities. University housing is provided and the teachers are encouraged to live on campus for the two-week program, opening participation to teachers from across the State.

The goal of KESAM is to communicate the fabric of K-8 mathematics in a way that reduces math anxiety and builds community. It uses an immersion approach to mathematics, and participants are involved in activities from 8:30 until 4:30, and informal groups work in the evening. Teachers do a range of activities in patterning, number sense, graphing, and estimation that build content knowledge. The activities are devised to build strong links between pedagogy and content, a principle shown to be important for effective standards-based instruction [13]. In addition, the teachers reflect upon vertical curriculum alignment, evaluation methods, and operational details like classroom management.

Building a professional community is an important element of the program. Much of the instruction in KESAM is done by master teachers and table leaders—teachers returning for a second year of participation, who work with small groups of first year participants. A Family Night during the program develops camaraderie and the teachers remain in touch during the

academic year using *Blackboard*® or *Desire2Learn*™.

At The University of Tulsa, “Sense-Sational Science” was begun in 2008 to address the needs of urban and suburban fourth and fifth grade teachers. Recruitment of teachers is done in partnership with two urban school districts and particularly targets teachers from schools that are underperforming or have high populations of underserved children. A central feature of the program is its partnership with five community groups: the Oklahoma Aquarium, Gilcrease Museum, Oxley Nature Center, the Oklahoma Air and Space Museum, and the Tulsa Zoo. The program includes two days of “authentic involvement” in science at each of these institutions during which the teachers engage in activities that use unique resources. For example, at Gilcrease Museum, the teachers spent two days discovering how the human’s sense of environment has changed over time through activities that included examining archeological artifacts and studying Native American and western artwork.

The goal of Sense-Sational Science is to develop interdisciplinary connections between science, mathematics, social studies, and fine arts. Using science as the foundation, teachers develop interdisciplinary teaching units that build upon the curricula already in place at their home schools.

Developing a professional community is emphasized through team activities and through extensive interaction with the education directors at each community institution. In its second year, the program plans to invite a group of teachers to return to assist in instruction.

Independent evaluation of these programs in a study commissioned by the Regents has shown that both are very successful. The pre-/post-testing has shown growth in content knowledge. Furthermore, questionnaires completed by the teachers have been positive, and pre-/post-concept mapping exercises have shown much greater understanding of concept connections.

Comparison of the Programs

The objectives of these two programs are very similar. Both began by addressing a particular audience and target achievement gap, and both grew to embrace additional populations. These two programs also seek to enhance content knowledge and pedagogical technique, build leadership skills, develop a professional community, and develop extended partnerships.

Table 1 shows that there are some common approaches to objectives, like partnership building, but several of the objectives are addressed in remarkably different ways.

Table I
Comparison of Successful Programs

Objective	KESAM	Sense-Sational Science
Address target audience and achievement gap	Initial focus on rural teachers who serve substantial Native American populations	Initial focus on urban / suburban teachers who serve substantial African-American and Hispanic populations
Enhance content knowledge	Immersion, focused on math	Authentic involvement, with broad disciplinary range
Enhance instructional techniques	Use of manipulatives, puzzles, fun activities	Interdisciplinary curricula
Build leadership skills	Team leaders, returning teachers	Returning teachers
Enhance professional community	Work with teacher teams, maintain professional environment, continue communication during the academic year	Include education professionals from community groups, build professional environment, maintain communication
Create extended partnerships	Includes teachers, arts and sciences faculty, and education faculty as presenters	Includes teachers, arts and sciences faculty, and education faculty as presenters

The KESAM program has a tight focus on mathematics content and provides an intense experience that continually reinforces basic mathematical concepts. In many ways, the activities are designed in a manner that mirrors the professional development provided to train Mathematics Specialists [14, 15]. The enjoyable tone set during activities tends to diminish any math anxiety while the intensity of the pace tends to galvanize relationships between teachers, forming a very strong professional community.

On the other hand, Sense-Sational Science has a broad focus on interdisciplinary connections that draws many elementary teachers who have little initial interest in science. It engages teachers in a way that allows them to overlay social studies and fine arts with science to

address teaching standards in a number of areas at once. The excitement of the authentic involvement experience generated by providing the teachers with exceptional resources tends to generate a strong professional community that involves education professionals from area non-profit organizations, as well as teachers.

What Are the Attributes of a Successful Program?

Given what seem to be specific approaches to different audiences in distinct disciplines, are there any commonalities that give an indication of why these programs are effective? What traits can be encouraged in new programs and used as guides as the mandates of NCLB are subject to change? Based upon the comparison above, three common directions occur.

First, successful programs engage teachers in a way that generates a bond with the content area and an enthusiasm for communicating it to the teachers' students. The participating teachers in fact become true partners who are motivated to use the ideas in new and exciting ways. Teachers greatly enjoy what they have learned and want to pass it on to their students.

Second, successful programs deliver solid content enhancement tied directly to pedagogical techniques. They provide a basic understanding of what material needs to be covered by students, how it should be presented, and how it relates to real life. Teachers emerge from programs with a more complete understanding of disciplinary knowledge and a new repertoire of ways in which to present it. In the analysis scheme presented a decade ago by Mary Kennedy, the programs seek to produce change by addressing multiple pathways: they alter teacher behavior and enhance teacher content knowledge [16].

Third, the programs themselves are reflective. Much has been said about the importance of reflective behavior among teachers, but the same characteristic is important in programs [17]. Programs must use the results of evaluation and teacher input in a reflective way to alter the approaches and content areas they cover. The programs change considerably over time to address new concerns and new audiences.

What ultimately makes professional development programs successful? All three of these elements contribute to bringing teachers into a partnership in which each contributor (from higher education, public schools, or community groups) takes ownership of the materials. The landscape changes for all. The net result is that each participant presents solid material in a way that is most useful to the students.

The ultimate measure of program success is embedded in the SHEEO call for partnership. Successful programs involve all of the stakeholders—schools, school districts, and higher education institutions—in a way that maximizes the effects each can make upon successful instruction. In successful programs, teachers ultimately emerge as a full partner in the characterization and presentation of disciplinary knowledge.

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CONNECTING MATHEMATICS AND THE APPLIED SCIENCE OF ENERGY CONSERVATION

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Abstract

To effectively teach science in the elementary classroom, pre-service K-8 teachers need a basic understanding of the underlying concepts of physics, which demand a strong foundation in mathematics. Unfortunately, the depth of mathematics understanding of prospective elementary teachers has been a growing and serious concern for several decades. To overcome this challenge, a two-pronged attack was used in this study. First, students in mathematics courses were coupled with physical science courses by linking registration to ensure co-requisites were taken. This alone improved passing rates. Secondly, an energy conservation project was introduced in both classes that intimately tied the theoretical mathematics base knowledge to problems in physical science, energy efficiency, and household economics. These connections made the mathematics highly relevant to the students and improved both their theoretical understanding and their grades. Together, the two approaches of tying mathematics to physical science and applying mathematical skills to solving energy efficiency problems have shown to be extremely effective at improving student performance. This five-year study not only exhibited record improvements in student performance, but also can be easily replicated at other institutions experiencing similar challenges in training pre-service elementary school teachers.

Introduction

To involve pre-service elementary education majors in applying mathematics to the sciences, two professors linked their mathematics and physical science classes. In these linked classes, the students completed a project that was based on energy efficiency retrofits that saved students hundreds of dollars, while also preventing tons of pollution. The results of this project show that the real-life applications of mathematics to physics and energy conservation improved the students' understanding of and the relevance of the mathematics they learned in order to prepare them to effectively teach their future students.

In order for future K-8 teachers to be effective in teaching science in the classroom, pre-service teachers need a basic understanding of the underlying concepts of physics. Unfortunately,

the depth of mathematics understanding of prospective elementary teachers has been a serious concern in the research of mathematics education for at least three decades [1-12]. The inadequate mathematics preparation for elementary education majors to enter a standard introductory physics course normally results in physics courses designed specifically for them. For students to be successful in these types of physics courses, the pre-service teachers need to perceive physics as an inquiry process in which they and their future students should be actively involved. They also need to realize that simply memorizing information is insufficient for effective teaching [13-15]. Past research has shown that connections of mathematical topics deepen student understanding [12, 16]. In order to build on this previous work, an initiative began at Clarion University of Pennsylvania to create a learning setting that connects mathematics to physics for future elementary teachers. This article reports on that initiative as realized through an innovative educational project on energy efficient compact fluorescent light (CFL) bulbs that spanned both the mathematics and physics classrooms. This project not only showed improvement in student grades, but also resulted in a significant reduction in the environmental impact of the families of the students that participated.

Linking Mathematics and Physics

In order to ensure that students are receiving identical course material across multiple courses, Clarion University has been experimenting with linked classes. In creating linked classes, the same group of elementary education majors who schedule one of the classes must also schedule the other class. This automatic scheduling connection assures that the class rosters of both classes are identical. One of the first experiments was linking a physical science course and a basic mathematics course in 2004. With the same professors, this initiative proved successful in raising student grades with 94% of the students in the linked class obtaining grades of C or better, compared with only 71% of the students in an equivalent, non-linked mathematics class. For this study, this linking was repeated utilizing the Making Connections Program at Clarion University of Pennsylvania. Two classes, *PHSC 112 Basic Physical Science: Physics and Astronomy* and *MATH 211 Fundamental Topics in K-8 Mathematics*, were connected as linked classes. The *MATH 211* class was scheduled on Tuesdays and Thursdays for one hour and 15 minutes, with the *PHSC 112* class immediately following it for the same length of time.

Efficient Light Bulb Project

Previous work has shown that students are more motivated to learn material if they see a connection to their own lives and have some self direction over the project [17, 18]. Thus, the students were assigned to collect data that was relevant to their lives so that they could see the

usefulness of the mathematics they were learning in connection to the physics concepts. The project that students were actively engaged in was a cost-benefit analysis for their families that compared standard incandescent lighting with more energy efficient compact fluorescent lights (CFL). The CFL bulbs use one quarter the energy to produce the same amount of light as a standard incandescent light bulb, fit in the average light socket, last longer, and cost less over their life cycle than incandescent bulbs. Thus, a light socket using a CFL produces only 25% of the greenhouse gas emissions as an identical socket using incandescent light bulbs. It is therefore possible to be fiscally responsible while reducing pollution, greenhouse gas emissions, and the concomitant climate destabilization as a result of retrofitting incandescent light fixtures with CFL's. However, despite widespread availability and ease of implementation, CFL's have not infiltrated the residential market in large numbers as quickly as economics would suggest was optimal [19]. Ten years after the original Energy Information Association study, most students in the linked classes were unfamiliar with CFL's [19].

Past work showed that advanced university classes can form interdisciplinary alliances on environmental education projects, such as CFL campaigns, and thus effectively address the gap between complex environmental problems in the real world and disciplinary curricula in a university [20]. This project built on this previous work and utilized the same methods and answered CFL frequently asked questions (FAQ) to improve the mathematics and physics understanding of less advanced students [21]. Being that the *MATH 211* course first studied a unit on "Data Analysis" and the *PHSC 112* course began with "Electricity," it was appropriate to begin both courses with the linked project, "Lighting Inventory of a Dwelling—or the Efficient Light Bulb Project." To prove to the students that the hi-tech bulbs were worthwhile and functional, the linked classes had funds from Clarion University's Making Connections Program to donate one bulb to each student in the linked classes. It should be noted that, as the penetration of CFL's increases in the lighting market, an investment in demonstrating the basic technology for the students is not as necessary as for those students who have never had firsthand experience with a CFL.

Data Collection

The first step in the student's cost-benefit analysis for their families' residences was a lighting survey. Students were presented with the chart shown in Figure 1, which they used to gather their data.

Room	Type of Lighting	No. of Fixtures, Wattage	Can it be replaced by a CFL? If "no," why not?	Average Hours/Day Lit
e.g., Living room	Incandescent lamps	4 each 100 W	Yes	6 each

Figure 1. Data collection worksheet.

Students were encouraged to be both precise and accurate by being awarded five points for both linked classes for gathering the data and presenting it correctly in the rubric of the assignment. In order to maintain a control on the experiment, a similar section of *MATH 211* that was not linked to the science class was used; these students took part in the project and also were awarded the same number of points for the assignment.

The students completed another related project for the *MATH 211* class for their Data Analysis unit using the data gathered about lighting from their homes. Students found the average number of watts used per room, and compared the mean, median, and mode of this data set. They also were required to create a stem and leaf plot, and a box and whisker plot of the wattages of each bulb in their house that could be replaced. In addition, they calculated the variance and standard deviation of the wattages. They then found the average (mean, median, and mode) of the watts used for the replacement CFL's and also created a box and whisker plot with that data. Finally, students were required to write at least one sentence in which they discussed the meaning of each of the required calculations and summarize their work by making conclusions that connected their calculations to the "Light Bulb Project."

Cost Benefit Analysis

Next, in *PHSC 112*, students learned about the concepts of electrical energy and electrical power. Using the data they had collected for the mathematics course, the students calculated the average energy that each of the light bulbs used. This was done by multiplying the power of the bulb by the number of hours used per day to establish an energy and then converting the watt-hours/day to watt-hours/year, and then finally kilowatt-hours/year (kw-hrs/year). As electricity is billed by the kw-hr, the students could then convert the energy used in each bulb into dollars. The average electricity cost in the Clarion area at the time this activity was conducted was \$0.063

per kw-hr. Since the CFL that provides an equivalent amount of light to an incandescent uses one-fourth of the electricity, the cost of each existing light bulb was multiplied by 0.25 to calculate the cost of using CFL's. The students used the same calculations to compare the cost of 40W, 60W, and 100W light incandescent bulbs with CFL's. By summing the savings from each fixture that could be retrofitted, students were able to obtain a total potential savings on a yearly basis.

In addition, students were exposed to the entire life cycle calculation by determining the number of incandescent light bulbs that would need to be replaced in order to provide light over the much longer lifetimes for the CFL's, and then calculating the total amount of energy consumed by both technologies over the entire lifetime. This can be conveniently presented in a chart format where students can input the total number of fixtures of each wattage. The most common power draw of 100W for incandescent light bulbs is shown in Figure 2 with the life cycle calculation computed for a single fixture. This table is not generalized, so other costs of bulbs, lifetimes, and price of electricity need to be corrected for a given location.

	100W equivalent CFL	100 W Incandescent
Number per package (#)	1	4
Price per package (Pt)	\$6.00	\$1.37
Price per bulb (Pt / #)	\$6.00	\$0.34
Lifetime (L) of the bulb	8,000 hrs	750 hrs
Number of bulbs needed to fill 8,000 hrs of illumination $N = (8,000 \text{ hrs/L})$	1	10.7
Price of bulbs for 8,000 hrs = $N *$ (Pt / #)	\$6.00	\$3.64
Wattage (W)	25	100
kw-hrs used = $(W*8,000\text{hrs})/1000$	200 kw-hrs	800 kw-hrs
Cost of 8,000 hrs of illumination at a rate of \$0.0615 per kw-hr (This rate is location specific)	\$12.30	\$49.20
Total cost over 8,000 hrs of light	\$18.30	\$52.84

Figure 2. Life cycle calculation computed for a single fixture.

In addition, the cash flow for the energy efficient retrofit can be plotted versus time as seen in Figure 3, which is an example cash flow for a single light fixture that is used eight hours per day over its entire lifetime. The retrofit pays for itself in under six months as can be seen where the line crosses the x-axis. From creating similar graphs for their data, students determined that they would always save the same amount of money over the life cycle, but that the payback time was inversely proportional to the number of hours that the bulb was used per day.

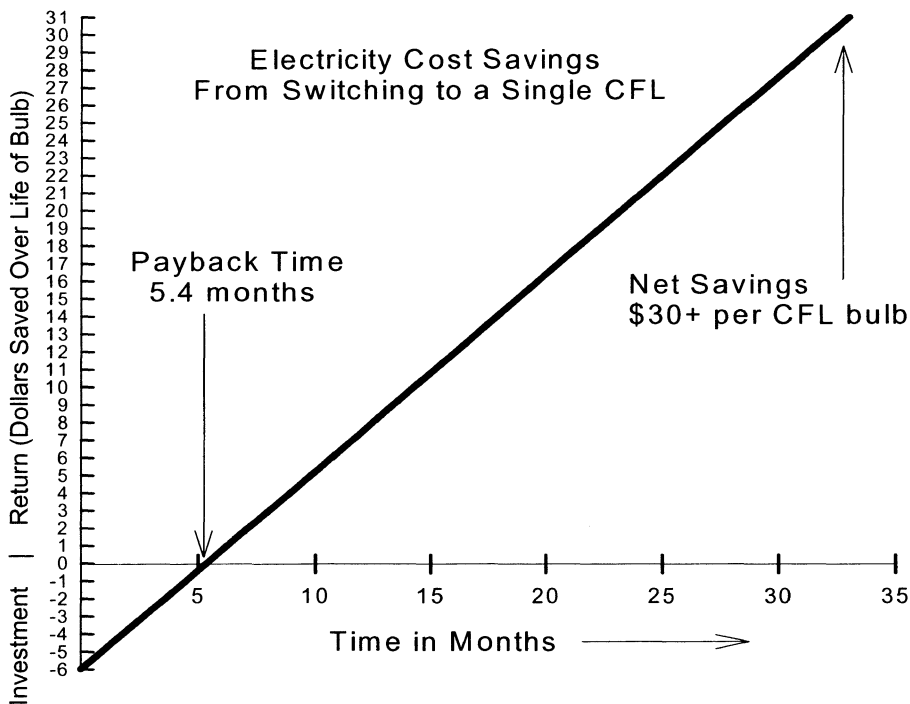


Figure 3. Life cycle electricity cost savings for a single CFL retrofit assuming the light is used for eight hours per day.

Results and Discussion

As a part of service learning, energy efficiency campaigns run in the past while full life cycle calculations were used based on the lifetime of the CFL [20]. These programs, although successful, were limited by cash flow arguments and lacked information on usage. In this study, the actual usage for each fixture was determined from the data collection section of the project.

In the linked class of thirty-one students, the average dwelling used 763 kw-hr/year for incandescent light bulbs, which at local rates would cost \$48.14/year. The range was fairly extreme, as one home used 2,474 kw-hrs or more which is more than a factor of three and costing \$155.91. As a whole, the families of the class members used 23,681 kw-hrs, costing \$1,492.26/year. They calculated that if they collectively switched to CFL's, they would save \$1,112.36 and 17,524 kw-hrs/year, respectively. Data was also collected from a non-linked physical science class for control and the results were found to be similar. This energy saving information also lends itself to environmental physics lessons concerning environmental stewardship and the burgeoning field of greenhouse gas mitigation. If this electricity saved from the CFL retrofits in the class was produced by a typical 500 megawatt coal plant, the class has the potential of saving 7.16 tons (14,300 pounds) of coal, 18.5 tons (37,100 pounds) of carbon dioxide, 0.626 tons (1,250 pounds) of ash, and 11,000 gallons of water every year [22]. It should be noted that this is the pollution offset if all of the energy came from the average coal plant, which is a reasonable assumption for the area. Actual emissions vary by the efficiency of the facility and quality of the coal. The larger correction in this figure is that roughly a third of Pennsylvania electricity is supplied by nuclear power plants. Although it is tempting for students to simplify the calculation and reduce the carbon dioxide emissions by 36%, it should be noted that nuclear power is actually responsible for considerable emissions over its life cycle and cannot be treated as an emissions-free source of energy [23]. This type of question enables students to begin to understand the more complex life cycle analysis which is needed to solve modern day energy problems.

At the end of the semester, students completed an anonymous survey in which they evaluated the linking of the two classes. All students responded that they would definitely schedule the link again if it were offered rather than take the courses separately. Responses by the students to the question, "What advice would you give a sophomore elementary education major about whether they should take these same courses linked with the same instructors?" were also overwhelmingly positive:

- "I would tell them that the link was very beneficial to me. Being with the same group of people every day allowed us to get to know each other better. Also, the profs worked great together."
- "I would tell them to do it. It's a more memorable experience and I think I learned more because of it."
- "I learned so much more than I probably would have by taking them separately. It's a great opportunity. Take advantage of it."

Students also responded to the question, “Do you think being in the linked class helped or hurt your understanding of the content and concepts in either *MATH 211* or *PHSC 112*? Why?” The salient themes that emerged from this question are summarized by the following student comments:

- “I think I understood more because we were linking ideas and concepts together and the professors were more willing to help us make the connections and understand.”
- “Helped. Conversions esp! [sic] Doing conversions in *PHSC* allowed me to have a better grip on them when they came up in *MATH*.”
- “It helped because I saw the connection.”
- “It helped because the math part helped with the physics class and vice versa. It helped because there is a lot of math in both classes.”

Many students indicated that the hands-on activities made learning more meaningful. Students were asked which concept or content they would remember in a few years and why.

- “The light bulbs, because they are [used] more every day.”
- “I will remember the hands-on because actually doing it helps me relate and remember things better outside the classroom.”

Not only did the students appear to appreciate both the linking and the energy conservation project subjectively, these two methods also improved their performance in both the mathematics and physical science classrooms. Of the students that passed the class, the grades improved significantly with the linking: 80% of the linked class received A’s, while only 32% received A’s in the non-linked section. However, both the linked and non-linked *MATH 211* classes completed the CFL project and this appeared to improve pass rates, and overshadow the effect of linking on providing students with enough intellectual growth to average over 60%. Although in the first linked class experiment grades improved, this linking showed no statistical difference in passing rates. For the *MATH 211* classes, 92% of the students in the non-linked course were successful in passing the class with grades of C or above, while only 88% of the students were successful in passing the linked class. For the class sizes observed, this small percentage is within error.

To determine if the CFL project actually improved mathematics knowledge, the next semester the CFL project was removed. The success rate for two *MATH 211* sections decreased to 79% and 64%, respectively, in the following spring semesters with the same professor. The connection to the physical science class and the CFL project was the only difference in the *MATH 211* curriculum; however, the class size increased due to the increased demand for the class. The connections in the linked experience and the CFL project had the highest success rates in the *MATH 211* classes in the past five years.

These improvements observed in student learning and the success rate can be explained by both the motivation that the energy efficiency project brought to the classroom, but also the connection of abstract mathematics to physical realities of everyday decisions. Tying physics and mathematics to money in the energy efficiency project seemed to help solidify many of the course concepts for the students. One very useful method to get student attention is to give a CFL bulb to each student after completing the calculations which shows them that CFL's will save them over an average of \$35. As CFL's continue to scale in production, their prices continue to drop as CFL's can now be acquired from many vendors for less than \$3/bulb, whereas the bulbs we based this project on were \$6/bulb. If this cost is prohibitive for the number of students, CFL giveaways are not necessary, but a class demonstration of CFL's should be considered so that students can see for themselves that the quality of the light (color temperature) is high and the intensity of light is adequate.

Conclusion

This study has shown that the mathematics understanding of prospective elementary teachers can be improved by connecting mathematics education to physical problems. Here, a two-pronged attack was used. First, students in mathematics courses were coupled to physical science courses by linking registration to ensure co-requisites were taken. This alone improved passing rates. Secondly, an energy conservation project was introduced that intimately tied the theoretical mathematics base knowledge to problems in physical science, energy efficiency, and household economics. These connections made the mathematics highly relevant to the students and improved both their theoretical understanding and their grades. Coupled together, these two approaches—tying mathematics to physical science and applying mathematical skills to solving energy efficiency problems—showed to be extremely effective at improving student performance. This five-year study not only showed record improvements in student performance, but also can be easily replicated at other institutions experiencing similar challenges in preparing pre-service elementary teachers.

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LET'S OBSERVE!

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“What we have to learn to do, we learn by doing.”
--Aristotle, Greek philosopher

Abstract

Teaching the non-science major how to teach science is a challenge! No matter what science course is being taught, professors must model good teaching strategies that promote an inquiry approach that incorporates prior knowledge, connections, a social environment, relevance, and time to actively construct new understandings of scientific concepts.

Introduction

As twenty-five undergraduate early childhood education majors cross the threshold of our classroom each semester, I see their eyes going back and forth as if they are searching for something familiar to survive. They are starting their semester courses of *Elementary Science* or *Early Childhood Mathematics and Science* and are frightened. Inside, they are thinking, “I can’t do science or math!”; “I must endure this course, though, in order to teach!”; and, “What am I going to do?” Knowing that 90% of these junior and senior students do not have any confidence in these two subjects, I feel that it is my job to open their world to include science and mathematics education. They must be at ease with both before there is any hope that they will be at ease in front of twenty elementary students!

As we as a class progress through the semester, fear evaporates like a puddle of water because, as Ralph Waldo Emerson said, “Knowledge is the antidote to fear.” By helping the pre-service teachers confront their fears and learn how easily math and science can be included in a curriculum, they are empowered to begin their student teaching experience and eventually start their first year of teaching. Using the topic of observation, I will demonstrate how engaged the early childhood/elementary educators become and how easily they are immersed in science without fear. Using this lesson, the pre-service teachers see how easily science continues a child’s natural curiosity. By providing an inquiry-based approach to science that reflects the *National Science Education Standards*, the early childhood/elementary educator will learn how to

help channel the elementary students' energy, curiosity, and interest into a lifelong interest in the world of science [1-3].

Educational Theory

Even in the early grades, schools were traditionally considered to be warehouses of knowledge: students filed into them, systematically going down one row (one grade), receiving pieces of equipment (facts, school experiences) from the warehouse shelves and from the warehouse supervisor (the teacher), putting them into their baskets (brains) and magically putting all of the pieces together to know something in order to be promoted to the next row of the warehouse with new equipment and a new supervisor. Ira Shor states, "Classrooms die as intellectual centers when they become delivery systems for lifeless bodies of knowledge" [4]. There were no connections, discussions, or interactions between students. It was a sad and lonely way to learn. This has happened and is happening in many classrooms across the nation, from the elementary to the college level.

One way to change these classrooms would be to teach all students from a "learner-centered" perspective that would enable the transformation of these sad and lonely classrooms to dynamic, interactive classes that could help students become more comfortable with science [2,3,5]. Chickering and Gamson has a list of seven recommendations that should be the foundation for instruction for all teachers and professors in all "learner-centered" classes:

- 1) Frequent student-faculty interaction should occur;
- 2) Cooperative learning activities should be interspersed among other engaging instruction formats;
- 3) Students should be actively involved with learning;
- 4) Instructors should provide prompt, constructive feedback on student performance;
- 5) Instructors must keep students focused on learning, not on the fear of embarrassment or other distractions;
- 6) Teachers should communicate high expectations; and,
- 7) Finally, teachers must respect diverse talents and ways of learning [6].

Results from a survey sent out to professors within the state of Louisiana documented the fact that few professors are teaching with these recommendations in mind [7]. The lecture mode is still alive and well.

Looking at these recommendations, connections are important for students of all ages, and these connections promote active learning. Without being able to search the archives of the brain in order to pull out the file drawer containing some prior fact or experience that would connect to a new experience, long-term understanding and learning ceases [3, 8-12]. This is just as important for the twenty-year-old college student as for the six-year-old first grader. The student must be engaged in learning by being an active participant, not a passive one. Learning science is a process of knowledge construction (active), not of knowledge absorption (passive). Through active participation, the learners are able to internalize, reshape, or transform new information. This transformation only occurs through the creation of new understandings because the teacher has designed a learning environment that includes a curriculum that meets the interests, knowledge, ability, and background of the students [2, 13-16].

Learning is a social experience, not the stereotypically portrayed scientist in a white lab coat in the corner of the lab working alone. Students must be allowed to discuss, explore, investigate, and discover in order to actively construct new understandings. This constructivist approach to learning aligns itself well with the brain-based research that has developed over the past three decades [17-19]. Talking and doing is the vehicle for learning and, as Deborah Meier stated in 1995, "Teaching is mostly listening and learning is mostly telling" [20].

Another very important component of any educational theory or philosophy is that the experiences in the classroom should be relevant. Defining words at the end of the chapter in the science textbook has no relevance. By discussing the vocabulary and using it in a hands-on experiment, the scientific jargon will have meaning for the student. Science must not be taught as a laundry list of terms and procedures. Science is a dynamic field that surrounds every person and should be one of the easiest and most exciting subjects to teach if good, sound teaching strategies are implemented. As pre-service teachers in a methods class, they must experience this inquiry method of learning in order to teach science this way in their future classrooms [21, 22].

The Science Standards

It is imperative that pre-service teachers are acquainted with the *National Science Education Standards* because wherever they teach, they are accountable for meeting these standards as prescribed for each grade level [1]. Each lesson, as this simple observation lesson developed in the methods classroom, must refer to these *Standards*. In the *National Science Education*

Standards, Content Standard A for kindergarten through twelfth grade addresses the issue of observation:

[The] students can investigate earth materials, organisms, and properties of common objects. Although children develop concepts and vocabulary from such experiences, they also should develop inquiry skills. As students focus on the processes of doing investigations, they develop the ability to ask scientific questions, investigate aspects of the world around them and use their observations to construct reasonable explanations for questions posed [1].

These *Standards* provide the framework for all science lessons across our nation. For example, the New Mexico State Science Standards were drafted using the *National Standards* as the primary resource [23]. It is the same for many states; therefore, our pre-service teachers must know how to meet these *Standards* because they will be responsible for using them in their classrooms in different school districts.

There are other standards, such as the *Benchmarks for Scientific Literacy*, that also encourage the active participation of all students in making observations as a springboard to completing inquiry-based investigations [24].

One Science Lesson

If I had stood in front of the class of twenty-five pre-service teachers and lectured for two hours, as so many of their previous mathematics and science professors have done, I would have lost them on the first day. From the very beginning of the semester, I model how they should teach in their future classrooms. Keeping in mind that my educational philosophy mirrors what was discussed in the preceding section, I will demonstrate in the following paragraphs a typical lesson on a very fundamental scientific subject: observation.

Engagement Hook—What Happened to the Water?

With three styrofoam cups—one empty, one filled with confetti, and another with a little sodium polyacrylate—I ask the class to test their observation skills. I have a beaker with water and ask a student near me to tell the class how much I have in the beaker. Then I pour the water into the cup with the sodium polyacrylate. Of course, the water is absorbed immediately, but the class does not know what is in the cups. Now, I move the cups about while humming, of course! The students' mission is to tell me where the cup with the water is located. Every pair of eyes is watching carefully. Of course they choose the correct one, so I toss the "water" at the students, and nothing happens. Next, we try a cup they choose (one has confetti and the other is empty)

and each are tossed at the class. This is a wonderful way to begin discussions! Each group discusses and writes at least one hypothesis of what happened to the water. Eventually, one group will say that something in the cup, like a sponge, absorbed the water. As words are thrown out, a list of terminology is kept on the board by a student, such as “absorption,” “evaporation,” “liquid,” “solid,” “gas,” and others as the class talks.

The secret is out, it was the sodium polyacrylate. Then, we talk about Pampers® and how disposable diapers work. Each group tears apart a diaper and sees the white powder. They talk about how this substance could be used in the classrooms in different experiments that their students would like to try—just as they would like to try.

There is usually a discussion about how science is never “magic.” There are always explanations, but sometimes it takes years for scientists to explain phenomena. At this point, I bring in newspaper articles about something discovered and solved scientifically in New Mexico [25]. For example, this year the mystery of the formation of our famous Carlsbad Caverns was solved through scientific observations and experiments. The old trickle-down theory of carbonic acid seeping down to the limestone from rain runoff and slowly eating away six football fields’ worth of rock just did not provide an answer since there was no way to get rid of so much limestone (no streams or rivers). Our University of New Mexico biologist, Diana Northup, and geologist, Carol Hill, are proposing the theory that carbon compounds available in oil (pools of petroleum exist under the Carlsbad region) are eaten by microorganisms. The product they produce is hydrogen sulfide that rises through fissures and reacts with oxygen to produce sulfuric acid which certainly dissolve entire stadiums of limestone. The clues, such as blocks of gypsum, were there all along to be observed by the scientists. It just took time to put all of the observations together.

It is hoped that the students will also observe that two *women* scientists were responsible for this discovery. I talk about the stereotyping of scientists and how students of all ages still think of a scientist as a white male with glasses, a lab coat, wild hair, and holding beakers of bubbling liquid [26, 27].

Engaging Observation Activities—Where is My Pecan?

Each table gets a bag of pecans which are grown right here in the valley by Las Cruces. This is an example of making connections within a lesson to the environment of the student. From this bag of pecans, each student chooses a pecan, studies it, and returns it to the original

bag. The pecans are mixed up and then each student finds their new “friend/pecan” again. They have the task of describing to the group how they found their own pecan in the big pile of pecans. This encourages communication, builds vocabulary, and increases observation skills. To make it more difficult, two tables combine all of their pecans and again, only through observation, the students find their “special pecan.”

We then talk about the power of observation and extensions of this activity. For example, elementary students can make a center by writing descriptions of their pecan with a picture. Then, the pecans can be placed in a basket together and the student would need to match the descriptions and pictures with the correct pecan. Combining art and language arts, the students can make posters advertising their “lost pecan.” The ideas are only limited by the imagination of the students and their teacher.

Liquids, Liquids, and More Liquids

The student in the group wearing the most green is asked to come up to the lab table and take a tray back to their table. On this tray are six different liquids (labeled A-F), along with food coloring, paper clips, ice cubes, and small fishing weights. The six liquids are: water, 7UP®, vinegar, alcohol, seltzer water, and Karo® syrup. The liquids are clear, and the same amount of each liquid is in each cup. The instructions are simple: using the materials given and through observation, determine if these liquids are the same. Each group’s representative must be able to justify the group’s decision and illustrate the results to the other groups. At this point, conversation and activity fills the room. I supply graph paper, big sheets of paper, markers, and meter sticks.

Of course, each group comes to the conclusion that the liquids are not the same. Just through observation, the 7UP® has more bubbles than the seltzer water; the Karo® syrup is thicker when you tilt the cup; and, the clearness is different when the liquids are compared. They smell differently (I teach them how to safely smell substances). The food coloring drop diffuses differently in each liquid (many groups made pictures of this phenomenon). The ice cube sinks in the alcohol, but not in the others. Like the food coloring, the fishing weight migrates down the different liquids at different speeds. Normally, their conclusions are well thought out and their documented presentations very scientific.

Worms, Worms, and More Worms

Each group receives two styrofoam cups covered with foil, one marked *A* and the other *B*. The instructions are simple: observe what is in the cups, write down observations, beginning with cup *A*, and then compare the contents of cup *A* and *B*. Cup *A* has “soil” made from Oreo® cookies ground up in a food processor, along with five or six Gummy Worms. Cup *B* has live earthworms in real soil. I have rulers and scales available for use.

The students always have a great time as they measure, weigh, count, describe, and discuss the worms. The discussions include the ecology of the worm and the characteristics of living versus non-living. This is an intriguing observation activity that engages all of the pre-service teachers in using scientific terminology and process skills. It also emphasizes that there is so much data that can be gathered by simply observing.

NASA Needs Your Help

I introduce this lesson to the pre-service teachers as though they are in a third through seventh grade science class. I propose that NASA has sent us two samples, one from a space object NASA is called “Zercon,” and one from another space object, “Xelicious.” Their mission is to design a spacecraft that could land on both objects in order to study them. They are then to identify what they are and discover how to mine the resources on these objects for use on Earth.

The class brainstorms a list of possible things these space objects might be. A list is compiled on the board and different groups volunteer to find out information about that “space object” and report to the rest of the class. Wireless laptops with an Internet connection and an entire wall of resource science and mathematics books are available for their research.

One sample is “gluep,” made from combining a 4% borax solution (dissolve 112 grams of borax in one quart of tap water) and Elmer’s® Glue mixture (mix equal volumes of water and Elmer’s® white glue). The formula for this “gluep”: 25ml of the glue mixture, a drop of food coloring, and 19ml of the borax solution. These ingredients are combined inside an ordinary Ziploc® bag. After the bag has been securely sealed, the mixture is then gently kneaded.

The other sample is “oobleck” (four boxes of cornstarch, 1600ml of water, and several drops of food coloring) that has been divided into small plastic bags for distribution to the small groups of pre-service teachers.

Each group obtains a sample from each space object. Time is spent simply observing, exploring, and comparing the two samples. We discuss and design class definitions of the three states of matter, and then each group tries to classify/label the two samples of matter. A lively discussion about the sample from Xelicious evolves because the sample does not exactly “fit” the definitions that the group had constructed of a liquid, solid, or gas.

After the class and group discussions about matter, each group makes a chart with descriptions of the characteristics of each sample. These charts are placed around the room to be shared with the other groups. At least twenty minutes is used simply to discover the properties of the samples. It is important to give students of all ages time to explore. We have a tendency to rush through activities, and this does not engage the students in the critical thinking process.

Next, each group starts designing a spacecraft to land on both space objects. You may see students using pennies and other objects to determine if they sink down into the sample. Weight is a tested element; water resistance is a factor—the list keeps emerging and changing as groups design experiments in order to understand the characteristics of the “landing strips.”

The discussions are fantastic with very rich scientific vocabulary being used. The ideas are interesting, and students with prior knowledge are able to contribute this information to the group. The groups design spacecraft, draw designs of the spacecraft, and as visiting engineers from different states, they present the plans to a “NASA Board” at the next class meeting. This “NASA Board” consists of engineers and professors from the Colleges of Education, Physics, and Engineering. Members of the Board observe both samples before and are able to ask questions about the design of each group.

These pre-service teachers start by simply observing and then conclude the activity through presentations before a “Board.” Over the course of this activity, these teachers learn how to do the following: experience the dynamics of group work, experience the power of simply observing, build class definitions, use these definitions, research information, integrate art and language arts, communicate, and prepare a presentation for a group of “distinguished guests.” For students of all ages, this makes the classwork have relevance—they are not just doing the activity.

Ongoing Observation Activity

What happens when an egg is put in vinegar? The groups hypothesize, agree on one hypothesis, and put an egg in vinegar to be observed. Each group decides on an observation schedule and reports during the next class period within the next week (the class meets once a week for three hours).

When they return the next week, we discuss how the egg became rubbery, bouncy, and bigger. The words osmosis, diffusion, and other terminology are added to the students' scientific vocabulary. Through observation, the students can understand the definitions of these scientific words. Talking about their future classrooms, I discuss the advantages of using scientific jargon in early grade levels because the students can use it and they love it! These early elementary grades are building the foundation for future science classes. To extend this activity, you can put an egg in Karo® syrup and observe the shrinking egg as compared with the growing egg in the vinegar.

It is interesting to note that, in my many years of teaching this methods class, only one or two students have ever seen an egg in vinegar. Although this is an experiment that has been in many books for a long time, it is important to realize that many of the early childhood elementary education majors have had very little science; some of these "old" experiments are wonderful to use to discuss fundamental scientific concepts. Don't be afraid to use them!

Ongoing Research

Teaching the *Early Childhood Mathematics and Science* methods classes by using an inquiry approach gives the pre-service teachers opportunities to understand the scientific concepts as their students would. In order to verify that this type of college teaching makes a difference, it is imperative that observations are continued of the pre-service teachers in their classes as they begin their teaching careers. Using the "Collaborative for Excellence in Teacher Preparation Classroom Observation Protocol," pre-service teachers who have taken this methods class are observed in order to document the transfer of inquiry-based teaching of mathematics and science from their college classes into their classrooms [28].

Observing only teachers within our immediate geographic area excludes those pre-service teachers who have begun their careers elsewhere. To obtain data from a larger audience, a survey is being written to be sent to these teachers so that we can document their use of inquiry-based science in their elementary classrooms. To add to this data, the standardized scores of the

students who are in these classrooms will be collected and compared to the population of students in the classrooms of teachers who did take the inquiry-based mathematics and science methods course.

Through the triangulation of the observations, the surveys, and the comparison of standardized scores, the impact of this type of instruction in the college classroom will be documented. More importantly, we will be investigating the impact on learning for the students in those classrooms.

Conclusion

Observation is a very fundamental tool of all scientists, and we need to encourage students to develop this skill. We need children to be able to observe first and then make decisions based on these observations. In order to do this, they need practice, and kindergarten is a good place to begin. This will not happen unless pre-service teachers have experienced this inquiry-based approach to investigating the world around them in their own science classes. Professors must take the time to model this approach that reflects the national science standards. With the NASA activity, the pre-service teachers develop concepts through observations (states of matter), ask scientific questions, investigate aspects of the world around them (identifying possible space objects), and construct reasonable explanations for the question posed (developed spacecraft to land). These pre-service teachers are allowed to use prior knowledge, make connections, and complete the findings in a presentation to a “NASA Board” to add relevance to the lesson.

Since all of the activities could be used easily in the elementary classroom, the pre-service teachers are adding to their knowledge base of teaching science in this setting. As higher education educators, we must realize that the majority of pre-service teachers are afraid of science and resist it because of the way they were taught. By modeling good science teaching strategies in all the science classes, slowly but surely, science education will be transformed in future elementary classrooms. As Aristotle advised, the undergraduate pre-service teachers must learn by doing just as the future students who will fill their classrooms. There is *no such thing* as simply observing! By offering opportunities for pre-service teachers to engage in inquiry-based, constructivist science experiences, they will realize that observation is a fundamental scientific skill that opens the doors and allows the students to investigate the world around them in an exciting way.

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AIMS & SCOPE

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