Improving the Quality of Elementary Mathematics Student Teaching:

Using Field Support Materials to Develop Reflective Practice in Student Teachers

By Hillary S. Hertzog & Nancy O'Rode

Introduction

This article presents an "evidence-based" program improvement effort that sought to strengthen student teachers' implementation of subject-specific pedagogy for teaching mathematics in a K-8 multiple subject teacher education program. We report the process of how we used a research-based approach to gather evidence about "status quo" of the mathematics student teaching component that prepared elementary level teachers, changes that were made in the program to better prepare pre-service teachers to be reflective mathematics teachers who plan and implement effective subject-specific pedagogy, and how we measured levels of effectiveness. Specifically, we investigated whether mentoring strategies and materials designed to engage student teachers in applying aspects of mathematical knowledge for teaching (MKT) during the lesson planning/teaching/feedback cycle of student teaching would impact pre-service teacher reflective practice and teaching performance. In addition, we studied how we should change the

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supervision process used to develop the reflective thinking of student teachers as they engaged in teaching mathematics.

Theoretical Framework

What Student Teachers Need to Know about Teaching Mathematics

Recent studies have identified the need for improved classroom practices in teaching mathematics as a condition for improving K-12 pupil achievement in mathematics (Ball, Hill, & Bass, 2005; Ma, 1999; National Mathematics Advisory Panel, 2008; Stigler & Hiebert, 1999). To improve classroom practices, pre-service methods classes should focus not just on teaching general methods of instruction, but should engage pre-service teachers in learning how to successfully teach subject matter content using highly specific strategies that are specialized to that discipline (Shulman, 1987). We focused on three important components in the current literature base on teaching mathematics to guide us in developing a pre-service preparation program that develops mathematical proficiency in teachers: (1) Deborah Ball and her colleagues' work on Mathematical Knowledge for Teaching, (2) process standards formulated by the National Council of Teachers of Mathematics(NCTM), and (3) the National Research Council's (NRC) work on mathematical proficiency.

There are four common themes in these works: (1) Problem Solving—being able to pose good mathematical questions and problems that are productive for students' learning; (2) Explanations—communicating mathematical ideas, justifying reasoning, interpreting strategies of others, and responding productively to questions; (3) Representations—carefully choosing the best diagrams, examples, symbols, for maximum understanding; and (4) Mathematical Connections—making explicit how mathematical ideas are related to each other and applied to the real world (Ball, Hill, & Bass, 2005; Hill, Rowan, & Ball, 2005; NCTM, 2000; NRC, 2001). Our elementary teacher preparation program chose to emphasize problem solving, explanations, representations, and mathematical connections as four important subject-specific strategies that student teachers need to be able to implement to effectively teach mathematics.

Applying What Student Teachers Need to Know about Teaching Mathematics to the Student Teaching Experience

For years now, teacher preparation programs have been challenged with reforming how new teachers are prepared for teaching (Carnegie Task Force, 1986; Darling-Hammond, 1999). The student teaching experience has been identified as one of the most influential factors in preparing beginning teachers (Koehler, 1988; Lemma, 1993). Zeichner and Conklin (2008), in their description of characteristics of exemplary teacher education programs, cite dimensions of field experiences that can contribute to a program's success, including the need to closely connect supervision during student teaching to content of courses so that faculty and curriculum experiences reflect one vision of teaching and learning. In addition, early research found that few structures existed to support cooperation of supervisors, teachers and teacher candidates (Guyton & McIntyre, 1990). Later reviews of research pointed to the lack of quantifiable or qualitative data that could demonstrate whether the student teaching component of a program was producing more thoughtful, reflective teachers (McIntyre, Byrd, & Foxx, 1996). Good programs should integrate the instruction of candidates with contextual practice with pupils and connect learning about teaching to the actual problems of teaching practice (Darling-Hammond & Bransford, 2005).

Recent efforts to examine the development of reflective practice in pre-service teachers have been influenced by those who have applied theories of learning to the process of learning to teach. Borko and Putman (1996) frame the process through a cognitive lens, asserting that "learning is an active constructive process that is heavily influenced by an individual's existing knowledge and beliefs and is situated in particular contexts" (pp. 674-675). As teacher educators we can impact elements of that context and the components that pre-service teachers use to construct their knowledge. It has been argued that carefully designed student teaching experiences can "help novices go beyond having experiences to helping them learn from their experiences" (Rosaen & Florio-Ruane, 2008, p. 709) and that this can develop a pre-service teacher's ability to assess a situation, make judgments, create goals, choose a course of action and reflect on its success. Taking into account the cognitive factors that significantly influence the development of a pre-service teacher's thinking and the formation of habits of mind that the novice will take into their professional practice, we should carefully design student teaching experiences that activate those thinking processes. We must consider the potential influence that university supervisors, supervising teachers, learners, and focused program materials can have on the development of pre-service teachers' reflective thinking.

Research Questions

As we investigated the quality of the student teaching experiences in mathematics in our preparation program, we conducted a research study. We posed the following research questions as we engaged in each phase of the research:

1. What is the "traditional" focus of the observation/feedback cycle between the university supervisor and student teacher and does it include reflection on subject-specific pedagogy? (Phase 1)

2. How does the use of subject-specific field guides influence the observation/feedback cycle between university supervisors and student teachers? (Phase 2)

3. Does reflection on subject-specific pedagogy in mathematics during student teaching result in more effective mathematics teaching? (Phase 3)

Methodology

The research was designed and led by the program coordinator for the undergraduate credential program and the math methods instructor. In Phase 1, a needs analysis of the "traditional" multiple subject student teaching experience was led by the mathematics methods instructor/ researcher. A random sample of written observation feedback notes created by university supervisors across a three year period were analyzed to determine the focus of feedback on student taught lessons. A constant comparative analysis (Miles & Huberman, 1994) generated categories and themes that could be used as evidence to document the status quo of feedback given to student teachers during the planning/teaching/feedback cycle in student teaching.

In Phase 2, a qualitative case study approach (Patton, 1990) was used to provide in-depth data concerning use of newly created support materials intended to focus university supervisors and student teachers on aspects of subject-specific pedagogy during the planning/teaching/feedback cycle.

In Phase 3, a quasi-experimental design was followed which identified experimental and control groups from a larger group of student teachers. The experimental group used the newly developed subject specific field materials and worked with trained university supervisors. The control group completed student teaching with the traditional mentorship of university supervisors. We measured the development of mathematical knowledge for teaching in both groups by using the LMT assessment developed by Hill, Rowan, & Ball (2005).

Data Collection

In Phase 1, a needs analysis of current practices sought to gather evidence about traditional mentoring practices used during student teaching by university supervisors. Written observation notes randomly selected from all subject areas were analyzed. Six university supervisors, interested in improving the mathematics teaching of pre-service teachers, volunteered to work with the math methods instructor/researcher to learn how to code observation notes. Three questions guided the Phase 1 coding analysis: What lesson subjects do supervisors see most often? What aspects of lessons do supervisors record to help teacher candidates reflect about their developing practice? To what extent is subject matter and/or subject-specific pedagogy noted in the written feedback to student teachers? The frequency of subject area lessons observed in this sample was recorded as well as the kinds of written feedback given to the student teacher on the lesson. The university supervisors met with the researchers to discuss and tally all the categories of feedback found on the written observation notes.

In Phase 2, based on the findings from the needs analysis indicating that subject-specific pedagogy was not a significant component of feedback to student teachers (see Results section below), a "mathematics field guide" was developed for use during student teaching. The purpose of the guide was to have a focusing device that would cause student teachers and their supervisors to consider problem solving, explanations, representations, and mathematical connections as four important subject-specific strategies during the lesson planning/teaching/reflection process enacted during student teaching. Led by the mathematics methods instructor/researcher who had organized and led the needs analysis conducted in Phase 1, the six university supervisors who participated in the needs analysis data collection, together with support from a mathematics subject matter professor, conceptualized the packet of support materials. Seventeen first semester student teachers were randomly assigned to be supervised by the same university supervisors engaged in the development of the field guide. The student teachers were required to use the guide as mathematics lessons were planned, implemented, and evaluated. Data collected from the student teachers included lesson plans, lesson plan reflections, and teacher candidate post-conference reflections. Data collected from the university supervisors included written observation notes, audio taped feedback conferences and results from an interview at the end of the student teaching period. In addition, the observed lessons (approximately 3 per student teacher) were analyzed by the university supervisors using a scaled observation protocol that they were trained to use. The observation protocol asked observers to assign the observed lesson a scaled category of instruction labeled as one of the following: "Ineffective Instruction," "Elements of Effective Instruction," " Beginning Stages of Effective Instruction—Low, Solid, High," and "Accomplished, Effective Instruction" (Horizon Research Inc., 2006).

In Phase 3, 102 student teachers were divided into experimental (N=56) and control (N=46) groups in one program option in our credentialing program. The first student teaching experience required the student teachers to teach only language arts and mathematics for a nine-week period. The experimental group was clustered into specific student teaching seminar sections where they reviewed the subject-specific pedagogical strategies learned in the math methods course and included how to design mathematics lessons which focused on problem solving, explanations, representations and connections. In the seminar the experimental group was introduced to the use of the field guide for the lesson planning/teaching/reflection process and expected to use it as they wrote lesson plans. They were matched to the same six university supervisors who designed the field guides and participated in the lesson observation/feedback cycle using the field guides.

The control group had been introduced to the same subject-specific pedagogical strategies in the methods class, but engaged *only* in the traditional curriculum of the student teaching seminar. They did *not* use the field guide during student teaching, and worked with university supervisors who had *not* been trained in the use of the guide as part of the observation/feedback cycle. Both experimental and control groups did use the same lesson plan template for designing mathematics lessons which required written reflection after each lesson regarding problem solving, explanations, representations and connections. Both populations matriculated to a second student teaching experience in which they taught all subject areas for nine weeks, but did not use the field guides as part of the supervision process.

At the culmination of the two student teaching experiences, student teachers in both groups were assessed using the Learning Mathematics for Teaching (LMT) Survey developed by Hill, Rowan, and Ball (2005). The LMT Survey for Numbers and Operations consists of three subsections which can be administered separately. They include Knowledge of Content, Knowledge of Students and Content, and Knowledge of Patterns, Functions, and Algebra. For the purposes of this research, the sub-section which assesses Knowledge of Students and Content was used to examine growth of both content and how students learn content during student teaching experiences. In addition, lesson plans with written reflections and university supervisor written feedback notes were randomly selected from 10 student teachers in each group and analyzed to determine the amount and quality of reflective comments made about subject-specific pedagogy.

Results

Phase 1—Needs Analysis

The majority of lessons in the randomly selected sample of lesson observations notes were from language arts (30%) and mathematics (24%), with science (16%), social studies (9%), and art, health, or music lessons comprising approximately 7% of the lessons. (The university supervisors were surprised to find 14% of the lesson observation notes held no clue as to the subject area observed and immediately suggested that the subject area observed should be written on all written feedback notes.) Six main themes were identified by supervisors in the comparative analysis of the 200 sets of written observation notes as focal points for reflection during observed lessons and are shown in Table 1.

Table 1:
Emerging Themes from Classroom Observation Notes as Categorized by University Supervisors

Categories	*Subcategories*
1. Classroom Management	student behavior, positive reinforcement, classroom organization
2. Lesson Planning	instructional strategies, content standards
3. Lesson Implementation	modeling, explanations, pacing, sequencing
4. Student Engagement	student activity, involvement
5. Assessment	formal, informal questioning
6. Professionalism	punctuality, dress

Missing from the written supervisors' observation notes were references to specific pedagogical techniques for a subject area, subject-specific questioning, and depth or quality of subject matter in lessons. Strategies for working with special needs students and accommodations for English Learners were also missing from the supervisors' notes.

The results of the needs analysis confirmed that aspects of the student teaching observation/feedback cycle needed to change to better focus student teachers and supervisors on subject specific pedagogy. With leadership provided by mathematics methods faculty and mathematics department faculty, the university supervisors created support materials that could be used during lesson observations that they named the *Field Guide for Mathematics Lesson*s. The guide was intended to focus student teachers and university supervisors on aspects of mathematics that were being emphasized in mathematics content and methods courses: problem solving, explanations of mathematical ideas, use of varied representations, and mathematical connections.

Components of the guide included a "reminder" sheet for student teachers to use when planning and rehearsing the teaching of the lesson (called Student Teacher's Field Guide for Planning and Teaching Mathematics Lessons), a "reminder" sheet for university supervisors to use when observing a lesson (called Supervisor's Field Guide to Observing Mathematics Lessons), and a Lesson Reflection grid that focused the student teachers and university supervisors on indentifying valued components of the lessons during lesson debriefing (See Appendix A.)

Phase 2—Use of Field Materials during Student Teaching

Analysis of the use of the field guides focused on the performance of seventeen student teachers. Overall, changes in lesson plans, written observation notes, feedback conferences, and written reflections were noted by the university researchers. Emphasis on the use of these materials impacted the student teaching cycle as evidenced by artifacts gathered from the supervisors and student teachers. Changes are described below.

There was a change in the way that the university supervisors interacted with the student teachers regarding the planning and teaching of mathematics lessons. Interviews with the university supervisors indicated that all six were impacted by having the field guide materials to focus their observation of lessons. The six supervisors indicated that use of the guide changed their assessment of lesson plans, impacted what they were watching for during mathematics lesson observations, changed the way they recorded written observation notes, and significantly changed the focus and tone of the post-observation feedback conference. One supervisor described the process that all supervisors appeared to follow, reporting in an interview that "having a one page guide that I could have on the desk with me reminded me what to look for during the lesson and to integrate that feedback in my notes to the student teacher and conversations after the lesson."

Analysis of written observation notes demonstrated the level of change reported in interviews. Written observation notes for mathematics lessons archived from previous semesters for each university supervisor participating in the study were compared to the notes that each supervisor made for the current semester while using the field guide materials. Table 2 shows the categories used for analysis of observation notes and the relative frequency of comments specific to mathematics before and after the use of the field guides for the group of six supervisors.

Table 2:
Analysis of University Supervisor Written Observation Notes By Category before and after Use of Field Guides

Mathematics Comments	*Before*	*After*	*Classroom Practices Comments*	*Before*	*After*
Problem Solving	3.6%	8.9%	Classroom Management	26.3%	10.7%
Explanations	5.1%	31%	Lesson Planning	5.1%	3.6%
Representations	9.5%	13.1%	Implementation	25.5%	13.1%
Mathematical Connections	5.8%	8.3%	Student Engagement	11.7%	6.0%
Other 2.9%	2.1%		Assessment	3.6%	2.4%

Table 3:
Sample University Supervisor Observation Notes Before and after Use of Field Guides

Supervisor –Written Feedback Before	*Same Supervisor-Written Feedback After*
Good explanation from Group 1.	"Let's make it taller." Missed an opportunity to explain to students why the face would not be a square if we made the cube taller.
Your questions really made them think.	I liked the way that you let them solve the problem themselves prior to giving them the answers.
Consider using the overhead projector.	You might have modeled the making of the rectangle on the overhead.
How will you assess their work?	Assessed prior knowledge- you handled this well. Covered many understandings (bar graph, coordinate pairs, axes, circle graph, etc).
Thorough closure to lesson.	The closure is the most difficult to bring together because you don't know what children are going to say. Bringing out the mathematical thinking of students rather than 'telling' is something to work on.

After using the *Field Guide for Math Lesson*s, the data showed an increase in the use of comments specific to the teaching of mathematics by the university supervisors in their written observation notes of student teacher lessons. Further analyses revealed that the mean number of comments about mathematics increased from 4.1 to 16.4 when the guides were used, whereas the mean number of comments on general classroom practice declined from 11.1 to 9.4 with the use of the field guides. The "*value-add*" of using the guide is shown by an increase in the number of comments for specific mathematics pedagogy with relatively little change in the number of comments about general classroom practice. Approximately 10 more comments on average were were noted when supervisors used the guide.

Relative frequencies of the supervisor comments depict one way to document the changes in the feedback cycle. Table 3 illustrates how supervisors in the study used specific mathematical language to communicate their concerns about the lessons and focus their observations more precisely on the mathematics in the lesson.

Supervisors used mathematical terms and concepts to focus teacher candidate's thinking about what happened in the lesson or what teacher candidates might have done to push pupil's mathematical thinking. Overall, the supervision notes written while using the field guide materials show that supervisors gave more detailed suggestions and compliments specific to teaching mathematics, which included mathematical terms, processes, concepts and pupil explanations. Both the quantity and quality of university supervisors' comments to student teachers about mathematics teaching increased after university supervisors used the guide.

Immediately following lesson observations, the university supervisors were asked to complete an observation instrument that asked them to rate the quality of various components of the mathematics lessons, based on training they had received on use of the protocol prior to the student teaching semester. Data for all of the observed lessons are depicted in Table 4.

In addition, feedback conferences between the student teachers and university

Table 4:
Distribution of Observation Protocol Scores for Mathematics Lessons

Category	*Number of Observed Lessons Scored at this Level*
Level 1: Ineffective Instruction	4
Level 2: Elements of Effective Instruction	8
Level 3: Beginning Stages of Effective Instruction - Low	7
Level 3: Beginning Stages of Effective Instruction - Solid	10
Level 3: Beginning Stages of Effective Instruction - High	5
Level 4: Accomplished, Effective Instruction	8
Total Lessons Observed using Protocol	42

supervisors were audiotaped and analyzed. A case study approach was used by the university researchers to link together all data that was collected from student teachers and their university supervisors. Each case was assigned a "level of implementation" based on three sets of lesson plans, supervisor observations of teaching, observation notes and student teacher reflections about the lessons. A comparison of two cases gave description to the level of implementation of subject-specific pedagogy and the quality of reflection that took place between university supervisors and student teachers.

Karen's "Accomplished Instruction"

The first graders in Karen's student teaching classroom had been working on addition and subtraction story problems and continued that work the day her lesson was observed by the university supervisor. The children had been exploring numbers by forming combinations of numbers to 12 (i.e., 8+4=12, 7+5=12, 6+6=12, etc.) for the first 10 weeks of the school year and this lesson came at the close of the unit on number sense.

From Karen's Lesson Plan. After modeling a story problem, Karen planned to give the class a problem to work on about adding 5 and 6. An excerpt from that plan exposed her thinking:

> Present the problem:
>
> *Teacher*: (story on chart paper) I was cleaning the classroom the other day. I found 5 pencils on the floor under this table. I found 6 more next to the sink.
>
> *Teacher*: What can you tell me about what happened in the story?
>
> *Teacher*: Now I want you to solve this problem for me. Write down the number sentence that you came up with and the answer. I want you to write how you got your answer. You can use words, pictures, and numbers.
>
> At Closure:
>
> *Teacher*: Can someone with a silent hand tell me how they know that it is the answer? How did you figure it out? (If children say, "I just know," ask them how they could explain it to someone who doesn't know it by heart.)

Karen was prepared to elicit the children's understanding; she planned to probe further if students could not explain how they knew the answer.

From Karen's Observed Lesson—University Supervisor Feedback Notes. After students were given time to find and record their answers they met on the rug in front of Karen. The university supervisor captured the group conversation that took place:

> *Karen (Student Teacher)*: How did you know that 5 and 6 is 11?
>
> *Student M*: Because I know that 6 and 6 is 12 and one less is 11.

> *Karen*: Thank you. I saw a lot of people that had different ways of figuring that out.
>
> *Student E*: You have 6 and add five more. Then you count it all. 1, 2, 3, 4, 5, 6, and 7, 8, 9, 10, 11.
>
> *Student K*: If 5 and 5 equals 10, then 6 and 5 has to equal 11, because you are adding one more.
>
> *Student S*: If you know 4 and 6 is 10, then you just add one more because it is 5 and not 4.

The supervisor wrote "Karen, you kept an emphasis on students' thinking. You kept asking for various strategies in solving the problem and put several ways to represent student thinking on the board. … Wonderful lesson in bringing out student sense making and accepting many ways to work on a problem."

From the Audiotape of Karen's Post-Observation Conference. The supervisor used the *Field Guide for Math Lesson*s "Lesson Reflection Grid" to focus the discussion of the lesson (See Appendix A). A transcript of the discussion showed that Karen began the conference discussing wide ranging topics about troublesome traits of individual children, ways that children count, gains in student knowledge, and classroom management. The discussion became more focused when the supervisor suggested using the Lesson Reflection Grid. The following transcript from the audiotape shows how Karen's talk changed from vague notions of children's understanding to a focused and explicit description of student work:

> *Karen*: Overall I really liked how they were able to accomplish the lesson. And really understand and that they could give me some really good answers. And how you could figure out the answer.
>
> *Supervisor*: So now let's review our Lesson Reflection Grid. And I have one that we can actually fill out.
>
> *Supervisor*: So …for problem solving? What evidence of success is there for problem solving?
>
> *Karen*: The lesson in the very beginning was actually giving them combining and separating problems. They had to come up with their own number sentences and drawings to reflect their answer. And finish that. And then they had to come up with their own problem and solve those.
>
> *Karen*: And the game [played with dice before the task] was even problem solving. How do you see what these two die roll and see if the sum is on the game board. Or more, "How do I strategically place them to get five in a row?"
>
> *Supervisor*: Right, right. Ok, so let's jot down a few things.
>
> *Karen*: Also, the students, when they were writing their own problems, didn't have to ask me how to start the problem. They just wrote some like the ones they saw.

> This was new. The students might be thinking, "If I have to write my own, I'll put my own things, my own names, my own objects in the problem."

The audiotape captured Karen and her supervisor's continued conversation as they completed the Lesson Reflection Grid and that ended the feedback session.

A pattern of focused and explicit discussion about mathematics emerged in the data; specific talk about mathematics content and pedagogy permeated the feedback cycle between the supervisor and the student teacher. In the post-observation conference, Karen began to talk in vague terms about "some really good answers." After the Lesson Reflection Grid was introduced, she used mathematical terms for problem structures, identified three ways in which children were problem solving and new ways in which the children were engaged in doing mathematics. The analysis of Karen's lesson plans, written feedback from the university supervisor, and the transcripts of the post-observation conferences demonstrate that use of the field guide influenced the planning/teaching/reflection of the student teacher. Additionally, based on the observation protocol, the supervisor rated the lesson as a "Level 4: Accomplished, Effective Instruction" lesson.

Wanda—"Beginning Elements of Effective Instruction"

Wanda's first student teaching experience was in a fifth grade classroom. University supervisor feedback notes from a lesson observed during an integer unit demonstrated that classroom management was a problem for Wanda. For the second observation, she planned to introduce a new unit on statistics and graphing.

From Wanda's Lesson Plan. The lesson plan showed how Wanda wanted the students to "be able to read, interpret, and make line graphs." The plan proposed the following questions:

> *Teacher*: Can someone remind us what a line graph shows? Think about the line graph we constructed yesterday.
>
> *Teacher*: Line graphs can show many more kinds of data. (Show graph). This graph shows the change in population density in the US between 1940 and 1990. How would you read this graph?
>
> *Teacher*: Trend is another word for pattern. We can use the trend or pattern to make predictions about the data. What prediction can be made about this data?
>
> *Teacher*: What information is given on the x-axis? The y-axis? What is the interval for this graph? Look at the y axis, what is the difference between each number? What about the x axis?
>
> *Teacher*: Look at the graph to tell information. What is the population density in 1960? How would we find that information? Look at the x-axis and the y-axis. The point has coordinates (1960, 51).

The remainder of the lesson plan included additional convergent questioning that asked for information. It did not include problem solving questions and no further data trends were examined. Explanations by students were not proposed or anticipated in the plan, and connections were only hinted at.

From Wanda's Observed Lesson—University Supervisor Feedback Notes. The supervisor's scripted notes captured what happened in the lesson.

> *Wanda*: We're going to learn more about line graphs. We've learned about change in distance, and temperature over time. We can look at change in population and change in height over time. This graph shows people and years. What info is on the x axis?
>
> *Student A*: Years.
>
> *Wanda*: And on the y-axis?
>
> *Student C*: People per square mile.
>
> *Wanda*: What's the interval? (pause) Who remembers interval? (students shake heads negatively).
>
> *Wanda*: What was the population density in 1960?
>
> *Student G*: 50.
>
> *Wanda*: In what year were there about 44 people per square mile?
>
> *Student G*: 1957.
>
> *Wanda*: Are there any questions so far?

The supervisor wrote the following notes:

> How much information about the graph could be explained by students? How could you guide students to read the graph, explain the graph and ask questions about what the data is "saying" in the graph? Do you think the students could ask their own questions about trends that are in the graph? When you ask a question that asks for factual data, and you get heads nodding, what does that tell you about the level of thinking that is happening at this point in the lesson? Let's think about how to restructure the question/answer interaction to promote more problem-solving and student explanation.

From the Audiotape of Wanda's Post-Observation Conference. The supervisor audiotaped the post-observation feedback discussion and used the Lesson Reflection Grid to structure the conversation. A portion of the transcript from the conference follows:

> *Supervisor*: When we think about the level of problem solving and student explanations in this lesson, what are your thoughts?
>
> *Wanda*: To be honest, I'm working so hard to try to keep the class with me that I don't have time to think about problem solving in the lesson. I was trying to ask questions to different students around the room so I wouldn't lose them. They just

don't seem interested in paying attention more than five minutes. I just want to know that I'm getting them to read a graph.

Supervisor: What about graphing—do you think it might be interesting enough to them to keep their attention?

Wanda: They probably would be better off creating graphs, but how do I make it happen in such a way that I don't lose several students? If we were to create graphs, then I would have to let pairs or small groups make the graphs on chart paper so we could all see them to analyze the graph, the data, and the trends. I don't think I want to put them all over the room with chart paper. I'd never get them back again.

Supervisor: So it sounds like you're most concerned about the materials you'd be putting in their hands, but if we could solve that problem, do you think they would do more problem-solving with graphs if they had to create one?

Wanda: Of course, and their explanations would probably be more extensive, but I tried having them work in pairs last week and it terrible. I had to re-teach the lesson the next day at the board.

Based on the observation protocol, the supervisor rated the lesson as a "Level 2: Elements of Effective Instruction" lesson, perhaps because there were student work products that were planned and implemented that matched a lesson objective.

In completing a review of all of the data from this lesson, it was evident that Wanda was aware of the mathematics strategies that she should be using, and she could see the relationship between components of a mathematics lesson (e.g. representations and explanations), but she decided that she was not competent enough at classroom management and conducting discussions to allow those kinds of interactions to happen. Instead, Wanda chose to ask convergent questions that required controlled answers, and maintained control by not allowing too much student input. Use of the field guide was not successful at impacting instruction and reflection because of issues with classroom management.

Overall, the results from this phase of the research indicated that use of subject-specific support materials during student teaching focused the university supervisors and student teachers on critical components of effective mathematics instruction. Student teachers demonstrated varied ability to implement identified strategies and the use of the Lesson Reflection Grid often helped to discern which kinds of strategies were difficult for the student teachers. Perceived quality of implementation was impacted by general classroom management skills as well as specific management skills needed to implement some of the subject-specific strategies such as student explanations. Management ability also impacted the focus of reflective discussion between university supervisors and student teachers.

Phase 3—Use of Field Guides to Foster Teacher Reflection and Pedagogical Growth

In the final phase of the study, all 102 student teachers in both experimental (N=56) and control (N=46) groups were asked to reflect upon each mathematics lesson they taught during the first semester of student teaching by completing the "Reflection" section of the lesson plan format which directed their reflection into the four categories of mathematics subject specific pedagogy (problem solving, explanations, representations, connections). Both groups turned in those plans which were then kept for data collection. Lesson plans from a random sample of ten student teachers in each group were analyzed for reflective comments made after each lesson was taught. The number of comments for each category was analyzed to see whether the student teachers in both groups differed in the quantity of reflective comments they made. Table 5 shows a large difference between the experimental and control groups in the number of reflective comments.

The quality of reflection that the student teachers produced for the lesson plans also differed. Table 6 shows a representative sample of the types of reflections produced by the student teachers from each group. Many of the reflections written by the experimental group were focused on student understanding and student learning; written reflections discussed the amount and focus on pupil's mathematical reasoning and justification in the lesson. Pupil experiences were central to the thoughts of these teacher candidates as they thought about the mathematics lesson that they planned and implemented. Many of the comments were specific rather than general and gave a detailed account of what aspects of the lesson were effective and ineffective.

Analysis of the number of reflective comments and the content of the lesson reflections written by the experimental group demonstrated the impact of the use of the field materials. An emphasis on problem solving and explanations was clearly evident. The control group teacher candidates' lesson plans indicated that their reflection about the lessons focused on teaching rather than on pupil understanding

Table 5:
Number of Comments in Each Category Found in Mathematics Lesson Reflections by Two Sample Groups of Teacher Candidates

Category	*Experimental Group Sample (N=10)*	*Control Group Sample (N=10)*
Problem Solving	32	1
Explanations	39	8
Representations	40	19
Connections	33	13
Total	144	41

Table 6:
Examples of Written Reflections from Two Sample Groups of Teacher Candidates after Teaching a Mathematics Lesson

Experimental Group Sample (Student Understanding Focus)	*Control Group Sample (Teacher Action Focus)*
"When students began to set aside the amount that each item cost, they saw the relationship between money and price."	"When I began to make a relationship between the game and lesson, I heard a lot of 'aaahhs'."
"Students had to figure out what would happen if they used their personal foot measure to build a house."	"I think the variety of manipulatives I gave them helped to keep them engaged in the activity."
"Some students were bored, so making the lesson more interactive would help next time."	"Tomorrow I will give them another opportunity for discovering equivalent fractions with the fraction bar handout"
"It got a little complicated when the 4th graders had to measure the shapes and then make their own shapes."	"I wanted to bring real life to students"
	"My explanations during guided practice facilitated the assignment."

as evidenced by the large number of "I" statements in their reflective statements. Generalities rather than specificity characterized the comments made in the control group's lesson reflections. Overall, student understanding was not a large focus of reflection for the teacher candidates in the control group.

Did changes in the supervision process increase the student teachers' ability to use mathematical knowledge for teaching (MKT) in their lessons? Using the Learning Mathematics for Teaching (LMT) Survey (Hill, Rowan, & Ball, 2005; Hill, Ball, & Schillings, 2008), all student teachers were assessed at the end of the mathematics methods class and again at the end of the second of two student teaching experiences. The LMT survey reports scores as z-scores and was normed for implementation with a population of practicing inservice teachers (Hill, Rowan, & Ball, 2005). A reported z-score indicates the deviation from the mean of all inservice teachers who took the exam as part of the process used for establishing reliability and validity for the LMT instrument. A score of 1.0 indicates a score 1 standard deviation *above* the mean when compared to inservice teachers. A score of -1.0 indicates a score 1 standard deviation *below* the mean when compared to inservice teachers. Using the scores from Number and Operations Knowledge of Students and Content component of the assessment, described as an important aspect of MKT, allowed us to compare experimental and control group growth in MKT skills.

Scores from the ten randomly-selected experimental group student teachers and the ten control group student teachers, whose reflections we analyzed in detail, were compared. A t-test of the scores showed that there was no significant difference for each group after completing the mathematics methods class. However, at the end of student teaching, when the teacher candidates in both groups were assessed again, the experimental group scored significantly higher than the control group on the Number and Operations Knowledge of Students and Content construct ($p=0.0597$). They scored approximately one-third of a standard deviation higher than the control group ($z=0.373$) on the LMT, which is a noteworthy effect size.

When the MKT scores for all of the student teachers in the experimental ($N=56$) and control ($N=46$) groups were compared, similar results were found to those reported above for the randomly selected sample. The average gain for the experimental group ($n=56$), in z-scores reported from mathematics methods class to the end of student teaching was an increase of 0.314, similar to the randomly selected group of ten students from the experimental group. For the control group ($n=46$) there was, in fact, a small loss of -0.015. A matched pair t-test for the experimental group ($p=0.0007$) and control group ($p=0.412$) shows that there was a statistically significant gain in knowledge for the experimental group, but there was no statistically significant gain (or loss) for the control group.

Returning to our research question which asked "Does reflection on subject-specific pedagogy in mathematics during student teaching result in more effective mathematics teaching?," we learned that the results of this research indicate that purposefully directing student teachers and university supervisors to focus and reflect on subject-specific pedagogy during the student teaching component of a pre-service program can positively impact planning, teaching and reflection about those pedagogical elements. The teaching/observation/feedback cycle expands to include more specific reflection about the quality of subject matter learning in lessons. Using field materials that focus supervisors and student teachers is effective in creating more knowledgeable teachers. Based on the results of the LMT survey, engaging in deeper reflection about subject-specific pedagogy improves student teachers' knowledge of subject matter and their understanding of which strategies will be more effective in their teaching of mathematics.

Conclusions

The growing research base on the relationship of subject-specific pedagogical skills and pupil achievement compels us to consider how to infuse this knowledge base into pre-service multiple subject preparation programs. We are given little time to prepare novices who might consider how subject-specific strategies can have a profound impact on student learning. We are asked to develop general pedagogical skills, such as management strategies for guiding discussions, but we also need to help our pre-service teachers understand how those strategies are challenged by more complex subject-specific strategies such as eliciting mathematical thinking from learners. In addition, we must acknowledging that each elementary pre-service teacher will have personal affinities for some subject areas and may lack depth of understanding in others which can impact their motivation to improve their subject-specific pedagogical skills and they need a structured experience to develop skills in "weak" subject areas.

In addition to considering the needs of the pre-service teacher, we need to think about the role of the university supervisor in the development of subject-specific reflective thinking. Using field materials to focus university supervisors is a worthwhile strategy, but consideration must be given to the fact that supervisors, like pre-service teachers, will have particular affinities for different subject areas and may be more or less successful at promoting reflective thinking about subject-specific pedagogy. Development of subject-specific pedagogical skills during student teaching in multiple subject classrooms suggests that other models of supervision may need to be considered which allow subject matter specialists to mentor student teachers, rather than depending on the traditional relationship of one university supervisor to one student teacher. Additionally, our research adds to the growing research about the critical role that the cooperating teacher plays in the development of reflective practice of subject-specific pedagogy (Borko & Mayfield, 1995; Griffin, 1989; Shantz & Ward, 2000). We have begun to work with small groups of teachers who host our student teachers to determine how to structure a focus on subject-specific pedagogy that includes the classroom teacher. Finally, we need to apply what we have learned in our focused work on improving mathematics teaching to the other important subject areas that our teacher candidates will be responsible for.

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Appendix

Student Teacher's Field Guide for Planning and Teaching Mathematics Lessons		
	Planning	*Teaching*
Problem Solving	1. Does the teacher pose tasks that are based on significant and worthwhile mathematics (big ideas)? 2. Will active participation of all students be encouraged and valued? How will you provide for students with special needs? 3. Does the plan allow adequate time for children to investigate the problem? 4. How will the teacher encourage students to generate ideas, questions, and conjectures?	1. Did students understand the task or problem? 2. Did the classroom culture encourage a diversity of ideas and multiple pathways to solve a problem? 3. Are students actively engaged in solving the problem?
Explanations	5. Is the classroom set up so that children can discuss easily? 6. Does the plan allow adequate time for children to report their solutions/strategies and explain how they know their answer is correct? 7. How will the teacher ask for consensus in resolving differences between student explanations and look for clarification of student ideas?	4. Were students allowed to reflect on their thinking and verbalize their explanations before writing them down? 5. Can students clearly state what they know?

Student Teacher's Field Guide
for Planning and Teaching Mathematics Lessons
(continued)

	Planning	*Teaching*
Representations	8. Are materials available for students to use in explaining their ideas and solving the problem such as visuals, manipulatives, diagrams, charts, tables, calculators, etc? 9. What various ways will the important mathematical ideas in the lesson be represented?	6. Do students link words, visuals, number, and/or manipulatives to explain their ideas?
Connections	10. How will connections be made to student's prior knowledge? 11. Is a context provided for the task? 12. What type of closure is planned so that students can make connections to other mathematical ideas? To other real-world applications?	7. Did the teacher connect student's prior knowledge? 8. Was closure to the lesson provided which validated students' ideas and reviewed what students learned? 9. Did students understand the big ideas of the lesson?

Appendix Continued on Next Page

Supervisor's Field Guide for Observing Mathematics Lessons		
Did you observe the student teacher planning and implementing a lesson with:		
Problem Solving	Students actively engaged in solving a problem?	Notes on Problem Solving: • Problem solving means engaging in a task for which the solution is not known in advance (i.e., not practice) • Students should be building new knowledge through problem solving • Students rather than teachers are doing the mathematics
Explanations	Students making sense of the mathematics by presenting their solutions and explaining their reasoning?	Notes on Explanations: • Teacher accepts various methods to solve a problem • Students and teacher listen to, respond to, and question one another • Students are allowed to reflect on theirt hinking and verbalize their explanations before writing them down • Teacher asks for consensus in resolving differences and looks for clarification of student's ideas
Representations	Students and teachers using multiple ways to represent a solution?	Notes on Representations: • Pictures, words, numbers, models, symbols, concrete objects, tables, charts, diagrams, calculators, or technology are used • Students link words, pictures, numbers, for example, to explain their ideas
Connections	Teacher and students making connections ?	Notes on Connections: • Teacher sets the stage to use student's prior knowledge and provides a context for the lesson • Teacher and students connect mathematical ideas and apply ideas to other subject areas • Teachers allow adequate time to provide closure to the lesson

Appendix Continued on Next Page

Mathematics Lesson Reflection Grid

Name ________________________ Date _______

Provide specific examples from the mathematics lesson taught for each of the boxes in the grid. Feel free to change the spacing in the grid or continue your reflection on another sheet.

	Evidence of Success	*Missed Opportunities/Next Steps*
Problem Solving: Students actively engaged in problem solving		
Explanations: Students making sense of math by explaining reasoning, questioning ideas		
Representations: Multiple ways used to represent/ communicate ideas		
Connections: Mathematical connections made by teacher & students		