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Using Hypermedia Technology to Explore Connections Among Mathematics, Language, and Literacy in Teacher Education

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Expectations for teachers entering the profession embrace new visions of teaching and learning that require reforming—not just fitting into—existing teaching practices (Cochran-Smith, 1991; Liston & Zeichner, 1991). As teacher educators in mathematics and English language arts, we recognize that setting high standards for beginning teachers (National Council of Teachers of English [NCTE] & International Reading Association [IRA], 1996; National Council of Teachers of Mathematics [NCTM], 1991, 2000) requires pursuing high standards for our own practice. In Michigan State University's five-year teacher certification program, TE 401 (Learner Diversity and the Teaching of Subject Matter) is fourth in a sequence of five preinternship teacher education courses, and the first course that focuses more specifically on teaching subject matter (e.g., pedagogy, curriculum, and planning, how learners construct knowledge). Upon completion of their BA degree, teacher candidates participate in a year-long internship while taking four additional MA-level courses to receive teacher certification.

In our team teaching of an integrated version of this methods course focused on teaching and learning in mathematics and language arts, the three authors created various assignments and projects designed to promote an inquiring stance toward developing one's curriculum and classroom practices. We also wanted to provide a context for exploring connections among subject matters that lead to enhanced learning for all children. In one project, which was offered at the beginning of the course, teacher candidates worked in small groups to generate an inquiry question about discourse in mathematics and used hypermedia materials to explore various connections among mathematics, language and literacy. The project was intended to provide foundational experiences for our semester-long exploration of curriculum and methods in elementary mathematics and language arts and help our preservice teachers conceptualize literacy as foundational knowledge that is required for learning in the subject areas of the elementary school (Pearson, 2001).

The hypermedia environment consisted of an extensive set of multimedia materials that document teaching and learning in Deborah Ball's third-grade mathematics classroom where extended discourse about mathematical ideas and students' written work are central features (Lampert & Ball, 1998). We made available a subset of materials including videotapes and transcripts of consecutive lessons from the end of the school year in a unit about fractions, students' notebooks and quizzes, and the teacher's journal. These materials were catalogued and could be searched and accessed at each of the eight computer work stations in a teacher education classroom. In electronic notebooks, groups of teacher candidates recorded their own questions and ideas about their investigations. They could also cut and paste into the electronic notebook from any of the data sources, as well as create and enter "vidbits" from the video disks. These group notebooks became a written record of how a group's investigation unfolded over time, documenting both the data that a group examined and their emerging interpretations.

The unique features of this environment made it a potentially rich resource for an introductory methods course aimed at helping novices construct new visions of teaching and learning that they may not have experienced themselves. As teacher educators reform their practices through the use of new technologies, we must ask whether and how preservice teachers are learning from reconceptualized courses and alternative experiences (Houston & Clift, 1990). Therefore, we engaged in action research into the following question: *What happens when technology (hypermedia) is integrated into teacher education instruction to help teacher candidates explore connections among mathematics, language, and literacy?*

This article begins with a discussion of the theoretical framework that informed our course development and use of technology as a tool to explore subject matter connections. The next section describes our methods of inquiry. In the third section, the support provided throughout the hypermedia project and the remainder of the course is outlined. Then our findings from our study of course evaluations of four cohorts of prospective teachers (*n*=87) are discussed and the written work produced from one small group per cohort (*n*=13). This is followed by a detailed portrait of three prospective teachers' learning during the hypermedia project and throughout the remainder of the course to illustrate concretely how their learning developed over time. In the final section, the learning opportunities in the hypermedia environment, the structure and timing of the hypermedia project, and our current thinking about future use of the environment are discussed. Implications for teacher educators who are interested in using hypermedia technology as a learning tool for prospective teachers are also suggested.

THEORETICAL FRAMEWORK

Exploring Connections Across Subject Matters

Newer visions of using the five language modes (reading, writing, speaking, listening, viewing) to explore subject matter persist (Calkins, 1991; Griffiths & Clyne, 1994; Moline, 1995; Rosaen & Roth, 1995; Whitin & Wilde, 1992, 1995; Zemelman & Hyde, 1993), even though teachers have experienced a variety of difficulties in implementing these approaches over the years (Pearson, 1994). For instance, teachers may have considerable expertise in teaching in one subject matter area (e.g., science, mathematics, history), but limited knowledge in how to bring teaching strategies from another subject matter area (e.g., language arts) into their teaching in meaningful ways (Langer & Applebee, 1987). Moreover, even when teachers are given considerable support by their school districts to adopt new approaches such as writing workshop or literature-based reading instruction, some still merely imitate surface features of the practices without having a good understanding of the theoretical underpinnings which guide the practices (Spillane & Jennings, 1997). This may limit learners' opportunities to use language processes to explore ideas and concepts in rich and meaningful ways.

Additionally, even as teachers implement newer models of literacy instruction, there is wide variation in the extent to which they teach reading, writing, speaking, listening, and viewing as integrated processes, and even more variation in the extent to which teachers provide sufficient support for children to learn to use these processes effectively in subject matter contexts (Dudley-Marling & Searle, 1991; Lee & Lawson, 1996; Staab, 1992). Several of these difficulties may be related to the need for teachers to pay attention simultaneously to multiple issues as they develop curriculum: "validity within the disciplines, validity for the disciplines, validity beyond the disciplines, consideration to broader outcomes" (Jacobs, 1989, pp. 27-30). Learning to foster meaningful connections across the subject matters is especially complex for novices, who are just beginning to develop a practice within each subject matter area.

The Challenges and Potential of Using Technology

Additional complications arise for teacher educators who are also interested in helping novices understand and use technology for educational purposes. We know that to understand and model the use of technology as a "cognitive tool" (Reeves, 1996), teacher educators need to use technology as a learning tool themselves (National Council for Accreditation of Teacher Education [NCATE], 1997; Strudler, McKinney, & Jones, 1999; Willis & Mehlinger, 1996). Nevertheless, multiple challenges emerge when educators use technology as part of their own pedagogy, such as, "engaging students in authentic, challenging tasks, carrying out multidisciplinary projects over extended periods of time, having students take on differentiated roles in collaborative efforts, assessing performance, and most importantly, moving from teacher-centered instruction to student-centered learning" (Reeves, 1996, p. 75). As teacher educators become increasingly immersed in their own use of technology as a tool for "analyzing the world, accessing information, interpreting and organizing their personal knowledge, and representing what they know to others," they will be in a better position to provide such experiences for prospective teachers (Reeves, 1996, p. 74).

We reasoned that novices would need explicit support in understanding how learners use language processes to develop subject matter understandings prior to their taking on the challenge of developing more sophisticated and complex forms of integrated curriculum and teaching. Thus, we looked for naturally occurring situations where language processes (e.g., discussion, writing) play a central role in subject matter learning. Deborah Ball's third-grade mathematics classroom (made accessible through hypermedia) provided one example that could be studied closely. Two of us, Rosaen and Schram, participated in a professional teacher education study group in which we were able to use the hypermedia materials to frame and pursue questions related to discourse in mathematics (Heaton, 1995; Lampert & Ball, 1995) and therefore think about its potential for fostering preservice teacher learning. This was an opportunity to move beyond the typical practice in methods courses of examining single videotaped excerpts of classroom events with little, if any, additional contextual information. It was also a challenge to figure out how to integrate the use of this rich resource as a meaningful pedagogical tool.

A common use of hypermedia in teacher education involves teacher candidates working in predesigned environments to explore and respond to teaching events and issues, where developers of the materials have organized classroom data (e.g., edited video segments of classroom lessons) according to thematic or topical categories (e.g., teacher role, student role, environment). Additional data may include commentary from teachers and teacher educators about classroom events, or conceptually organized information bases that provide written material on topics such as assessment, management and teaching strategies (e.g., Abell, Cennamo, Anderson, & Bryan, 1996; Daniel, 1996; Hatfield, 1996; Goldman & Barron, 1990; Goldman, Barron, & Witherspoon, 1991; Lambdin, Duffy, & Moore, 1996).

The materials available to us, however, consisted of virtually "raw" data—long unedited video segments of classroom discussions in which children do most of the talking and the teacher takes on the role of facilitator, the teacher's journal as she wrote it at the time, and the children's written work both finished and unfinished. As such, we were free to construct curriculum and pedagogy that integrated the hypermedia materials into the conceptual frameworks that guided the content and methods of our course. Teacher candidates could have considerable autonomy in deciding what to look at and how to proceed with their inquiry. They could play an active role in their own learning. This inquiry-based approach appealed to us because it required high level thinking about highly contextualized problems of practice and the multidimensional nature of teaching (Lacey & Merseth, 1993; Lampert & Ball, 1998; Lampert, Heaton, & Ball, 1994; Spiro, Coulson, Feltovich, & Anderson, 1988).

Because the materials span an entire year, it was possible to study the classroom learning community and student learning over time. Moreover, the materials made it possible for instructors and teacher candidates to view classroom episodes together, creating common experiences and a shared context for discussion and debate. Teacher education students could develop research and observation skills that they could then use in actual classroom settings during field experiences. The layout of the computer lab—with group work stations and a central gathering area furnished with tables and chairs—accommodated both small group work and large group discussion of the materials, where technology could become an integral part of, not just a supplement to, our teacher education course. Nevertheless, we still faced pedagogical questions related to the nature of support needed by teacher candidates to use this technology for inquiry, optimal ways to integrate it into the content and methods of the course, and how to hold our preservice teachers accountable for their learning. In the course of offering the hypermedia project across four semesters, questions about what and how our teacher candidates were learning also emerged. Action research into our own teaching and our students' learning (Hubbard & Power, 1993; Oja & Smulyan, 1989; Stenhouse, 1975) provided an opportunity to examine these questions.

METHODS OF INQUIRY

Research Questions

We investigated the following questions to document the curriculum offered and the teacher candidates' interpretations and learning:

- What experiences and support were provided to enable teacher candidates to (a) use the technology with comfort and proficiency; and (b) explore connections across the subject matters?
- To what extent did the teacher candidates develop a comfort and proficiency in using the technology as a learning tool?
- To what extent did the technology enable teacher candidates to enrich their understanding and appreciation of connections across the two subject matters while maintaining the integrity of each discipline?

- To what extent did the use of technology to explore subject matter connections help teacher candidates adopt an inquiring stance toward teaching and learning in mathematics, language and literacy?

Data Sources, Research Subjects, and Data Analysis

Copies of written course work for four cohorts of preservice teachers were collected, including: (a) reflective writing about course and field experiences; (b) individual papers (philosophy statements; position statements); (c) written work for group projects (team planning projects); and (d) open-ended course evaluations. Each semester detailed records of our lesson plans and handouts that outlined expectations for course assignments were kept and notes were made about our own teaching to record impressions and insights as the course proceeded.

To investigate our first research question, we used our lesson plans and reflective writing to construct a detailed chronology of our teaching during and after the hypermedia project. We identified four "areas of investigation" that were introduced during the hypermedia project, which we continued to explore throughout the course: (a) using a common conceptual framework for studying mathematics and language arts as subject matter; (b) adopting three perspectives—self, teacher, and K-5 student—to study classroom teaching and learning; (c) engaging in planning as an inquiry process; and (d) developing and articulating a philosophy for teaching. These four areas captured our intended and enacted curriculum (Erickson, 1982). We also identified complementary "tools of inquiry" that were introduced and used throughout the course to support our preservice teachers in exploring the areas of investigation: (a) use of technology (hypermedia) to generate and pursue questions about teaching and learning; (b) ongoing reflective writing; (c) use of conceptual frameworks found in course readings to study and interpret classroom events; (d) engagement in learner-centered activities; and (e) analysis of classroom visitations.

The remaining three research questions were designed to learn more about preservice teachers' perceptions of course assignments and their learning. End-of-course evaluations asked teachers to rate, on a scale of 1 to 4, how helpful each major course assignment was in supporting their professional learning ("1" is least helpful" and 4 is "most helpful") and to provide comments to explain their overall rating. The evaluations allowed us to compare ratings of the hypermedia project with ratings of other course assignments.

We targeted one small group per cohort for detailed analysis of the individual and group written work generated in the course. Group size ranged from two members (Cohort 1) to three members (Cohort 2) to four members (Cohorts 3 and 4) for a total of 13 teacher candidates (1 male, 12 females). Groups were selected on the basis of whether each member of the group provided written consent to participate in the study, and whether the group represented the range of teacher candidates who were in the cohort generally, with respect to academic ability, interest in teaching and learning to teach and active participation in course activities and assignments.

The four "areas of investigation" that we identified from our lesson plan analysis emerged as useful categories to study what preservice teachers learned from engaging in the project and the extent to which that learning continued throughout the course (the actual curriculum as interpreted by our students as learners; Erickson, 1982). Following standards for qualitative methodology (Bogdan & Biklen, 1982; Erickson, 1986), patterns and themes within and across the data were sought as well as disconfirming evidence to test them. Patterns in the written work provided insights about the prospective teachers' developing understandings of connections across the two subject matters and questions the students generated. The extent to which they made connections among complementary course experiences (readings, reflective writing, in-class activities) throughout the course was also investigated. By using multiple data sources, we were able to "triangulate" or cross-check our inferences about the preservice teachers' developing understandings and insights (Gorden, 1986).

CREATING AN INQUIRY-ORIENTED PEDAGOGY TO EXPLORE CONNECTIONS

Areas of Investigation to Support the Learning Process

Designing an introductory integrated project for a methods course that focused on two subject matter areas pushed us to create cross-cutting frameworks, themes or goals, which became more refined as we worked together across the four semesters. We *introduced* various aspects of four "areas of investigation" during the hypermedia project and continued to explore them throughout the course.

Investigating subject matter connections with a common framework. One complication in finding a common framework for the two subject matter areas was that the study of mathematics and literature in schools may have some connections to the disciplines from which they originate (Bruner, 1960; Siskin, 1994), whereas the language arts are communication processes that are used to reason, discuss, think, express ideas, and so forth in any discipline and in every day situations (Pearson, 2001). Indeed, those who study in the field of English language arts have a history of trying to define the field and articulate its connections to the disciplines (Elbow, 1990). Many ideas expressed in the national standards (NCTE & IRA, 1996; NCTM, 1991, 2000) call for a heavier emphasis on using the processes that represent various "ways of knowing" (e.g., reasoning and problem solving in mathematics; responding to literature in English) that originated in the disciplines, while others emphasize cross-cutting reasoning processes that can take place in any discipline, such as creative and critical thinking.

One of our colleagues (Cantlon, 1994) wrote about how she assesses student progress in mathematics in terms of three types of outcomes: *content* (concepts, procedures, and connections), *processes* (problem solving, reasoning, and communication) and *attitude*s (mathematical dispositions) (NCTM, 1991). We adopted this framework to conceptualize and explore with our college students each subject matter and possible connections across the two. In the context of the hypermedia project, we explored a key area where language arts and mathematics connect: how *language processes* (speaking, listening, writing) and *attitudes* toward use of those processes, played a role in helping preservice teachers develop *mathematical content, processes*, and *attitudes*. In other words, looking at discourse in mathematics, and children's writing associated with that discourse, was an opportunity to understand how language is foundational to subject matter learning. Course readings provided background information about the three areas in the framework as well as key concepts that could be used to guide analysis of classroom events in the videotapes.

Adopting three perspectives to explore content, processes and attitudes. Teacher educators know that if the influence of prospective teachers' beliefs on their current learning is left unperceived or unexamined, teachers may merely imitate practices they have experienced rather than actively seek to construct new practices (Ball & McDiarmid, 1990; Feiman-Nemser & Buchmann, 1986; Grossman, 1990; Lortie, 1975). We introduced three perspectives when discussing interactions in Deborah Ball's classroom to help our preservice teachers examine their own beliefs and to build a framework for analyzing classroom experiences from multiple perspectives: (a) self as learner of mathematics and English language arts; (b) teacher's perspective; and (c) K-8 students' perspective. We continued to use these perspectives throughout the semester.

Developing and articulating a philosophy for teaching. At the completion of their investigation in the hypermedia lab, prospective teachers wrote an initial draft of guiding principles that could become part of their philosophy—an individual position statement on the teacher's role in helping children use oral language to explore mathematical ideas. This introduction to articulating and supporting their beliefs provided a record of their thinking that could be revisited and reexamined as the course progressed and as they wrote a philosophy statement at the end of the semester.

Engaging in planning as an inquiry process. We engaged our preservice teachers in lesson planning as an inquiry process where they explored a set of questions about instructional goals (content, processes, and attitudes); resources, tasks, and activities; assessment; students' prior knowledge and experiences; and their own knowledge. The three perspectives (self as learner, teacher's perspective, student perspective) were also represented in our planning questions. The planning framework questions paralleled closely the issues and questions that emerged during the hypermedia project as they explored Ball's teaching and journal entries and engaged in mathematical problem solving during class.

Tools of Inquiry for Developing and Pursuing an Inquiring Stance

Novices need to develop particular processes and attitudes in order to sustain the development of "best practice" across their teaching careers. We supported teacher candidates in using a complementary set of "tools of inquiry" to explore the four areas of investigation, thus beginning their career-long inquiry process.

Using technology to inquire about teaching and learning. We anticipated, correctly, that our preservice teachers would be unfamiliar with hypermedia as a learning tool, and therefore provided a brief introductory demonstration of the technology's capabilities. We viewed an introductory lesson or two from Ball's classroom on a large projector screen together and discussed the investigation into questions about discourse in mathematics they would soon begin. Then small groups were clustered at stations, viewing video clips of lessons, calling up transcripts of those lessons, reviewing Ball's journal, and viewing students' written work. We asked them to experiment with writing down their current thinking in a "group notebook" created on the computer, which would eventually become a record of the group's work and thinking throughout the project. Groups solved technology-related problems as they arose by drawing on their own knowledge of computers or asked us for our help. As the investigations got underway, we gradually introduced more specialized features available in the environment, such as how to "cut" and "paste" a vidbit (a short excerpt from the video disk) into their group notebook.

The Discourse in Mathematics Investigation assignment asked teacher candidates to work in small groups to develop a question related to discourse in mathematics that they could investigate together using the hypermedia materials. We explained that some questions might emphasize how teachers support children in developing oral language skills in the mathematics classroom, while others might emphasize mathematical reasoning as it is revealed through classroom talk. We provided seven sample questions that they could use as a model to construct their own question, or investigate directly.[1] Preservice teachers were asked to use an electronic group notebook to record their question (and any subsequent revisions), specific data examined with explanations as to what they were looking for, their thinking about the data, and a final entry describing their current thinking about their question. Upon completion of the four-week project (for which some class time was given and some out-of-class time was expected), the teacher candidates were asked to write individually a two-three page position statement in response to the following question: What is the teacher's role in helping students use oral language to explore mathematical ideas?

Several forms of support were critical during the investigation. First, we helped our preservice teachers frame and pursue questions that were possible to investigate with available data. Second, we met with groups to make suggestions about where to begin (e.g., directing them to a lesson that seemed especially relevant to their question) and how to proceed (e.g., encouraging consideration of Ball's journal entry for a given lesson to investigate her perspective). Third, we reminded them to record their thinking and discussions in the group notebook and to include examples (e.g., vidbits, student work, transcript excerpts) that would help us follow their thinking. Creating a written "intellectual history" of a group's interpretation of multiple classroom events was a new undertaking for most individuals and at times felt a bit risky. After all, they were exposing their "rough draft" thinking to their peers and instructors (Barnes, 1976). We assured them that we were looking for and expecting their thinking to change and evolve over time.

Using writing as a reflective tool. Throughout the semester we asked our preservice teachers to do reflective writing in an individual notebook (Calkins, 1991). It was a place to record ideas, impressions, questions and tentative hypotheses about teaching and learning in response to course readings, in-class activities, and their classroom participation. We provided feedback about their ideas and sometimes encouraged them to explain or illustrate their thinking more fully.

Using conceptual frameworks for analysis. We encouraged the prospective teachers to analyze, reflect upon, and ask questions about events they viewed in the video materials, rather than to form conclusions immediately. We also modeled these approaches during whole-class discussions and provided key readings that encouraged them to use concepts found in them to interpret the events. As each group's investigation proceeded, we encouraged the group to record key concepts and ideas from readings in their group notebooks and write about how those ideas could help them pursue their question. Individuals continued to write in their own notebooks and we asked them to share ideas with their hypermedia group that would contribute to their investigation.

Engagement in learner-centered activities. Our future teachers brought assumptions about the nature of mathematics and what they need to know to do mathematics, and these assumptions were one source of influence on how they perceived and interpreted the video materials. Some found it difficult to follow the mathematical reasoning embedded in the third-graders' discussions. Some wondered why Mrs. Ball didn't just tell the students "the answer" and move on. Others assumed that Mrs. Ball's third grade class was unique and concluded that "this kind of teaching" could not become typical in today's classrooms. Still others entered the course believing they could not even get the "right answer" to most mathematics problems, and therefore reasoned that the kind of mathematical reasoning and problem solving that took place in her classroom was beyond their reach. Thus, we engaged these preservice teachers in mathematical problem solving, reasoning, and communication in our own classroom. We stood back from these experiences and reflected upon implications for themselves as learners of mathematics and drew comparisons with what we were seeing in Mrs. Ball's classroom.

Analysis of classroom visitations. We emphasized that Ball's classroom was but one example of how the NCTM Standards might be enacted, and not "the answer" to effective mathematics teaching. We arranged to visit other classrooms (in person, through other videotapes, and through reading case studies) so we could discuss a range of approaches.

LEARNING ABOUT PROSPECTIVE TEACHER'S LEARNING

A brief report on what we learned from the analysis of students' end-of-course evaluations and our study of the written work (individual writing and group writing) of 13 teacher candidates will provide a context for the more detailed case of one group's learning.

Student Perceptions of the Discourse in Mathematics Hypermedia Project

Across four cohorts of preservice teachers (n=87), the hypermedia project received a rating of 3.2 (out of 4 possible), which is closest to the "most helpful" category. In written comments, several individuals (45%) said they appreciated the opportunity to see a concrete example of new ways of teaching mathematics that are consistent with NCTM Standards. A smaller portion (14%) explained that they liked having the opportunity to learn about and use a new form of technology. Some (16%), however, felt that too much time was spent on the project or identified problems getting to the lab to work with their group outside of class time. A smaller portion (9%) felt confused or undirected during the project. A larger portion (25%) also suggested ways the project should be modified (e.g., we should spend less time on the project; more class time should be provided; project should not be so open-ended).

A Closer Look at 13 Teacher Candidates' Use of Technology as a Learning Tool

Developing a working relationship in the group. We were struck, across the four cohorts, by how unremarkable learning to use this technology was. Their writing revealed no problems with the use of the technology itself. The menu-driven, user-friendly format of the hypermedia materials allowed each group to begin exploring the materials and focusing immediately on the content of their investigations.

Because the groups were formed based on mutual interest in a specific question, each group quickly began their investigations by thinking about how they could use information available in the environment to learn more. All groups were unfamiliar with the process of pursuing open-ended questions, forming hypotheses, seeking confirming and disconfirming evidence, and therefore sought and made use of our help as their investigations proceeded. Each group came up with its own approach to working at their computer station. Some groups met together in the lab outside of the class time, while others went to the lab individually or in pairs and wrote notes to the others in their electronic group notebooks.

Changing views of teaching and learning mathematics. All 13 teacher candidates entered the course with traditional views of teaching and learning mathematics, based on their prior schooling experiences. All 13 had opportunities to begin to develop alternative views, mostly by noting contrasts between their own schooling experiences and those of the third grade children in Ball's classroom and examples they read about in the NCTM Teaching Standards (1991). Some of them merely raised questions at that point in time, noting that the third-grade classroom looked and felt very different from their own experiences, and also explained that they were unsure about whether they agreed with various aspects of Mrs. Ball's practice. Some became very excited about the possibilities this new way of teaching opened up for learning mathematics. Several remarked on how their own (mostly negative) attitudes toward learning mathematics might have been different if they had experienced this kind of mathematics learning. All 13 began to think about how their own histories of learning to get right answers limited their exploration of mathematical content and processes, and saw how those experiences influenced their attitudes toward learning mathematics. All noted that the discourse in the classroom was dramatically different from their own experiences and commented on the complexities of facilitating such discourse. Thus, their self-as-learner perspective became a tool for comparison and contrast.

As the course progressed, their understandings of the subject matter frameworks—the role language processes play in helping students develop mathematical content, processes and attitudes—became more complex. We saw progress in all 13 teacher candidates' use of concrete examples, although five who began the course as less proficient writers still needed more work in that area even by the end of the course.

The extent to which each group paid attention to the subject matter framework (content, processes, attitude) during the hypermedia investigation varied according to the question they chose to investigate. For instance, the Cohort 1 group explored the question: Who is responsible for the series of ideas (train of thought) that leads to a conjecture? This investigation required careful study of classroom talk to look at how the mathematical concepts developed and how mathematical processes (reasoning, making conjectures, use of evidence) shaped students' understanding over time. As their investigation proceeded, this group became interested in how teachers and students can share authority for knowing in the classroom.

By contrast, the Cohort 3 group investigated how a teacher builds confidence and respect among students so they will feel comfortable presenting their ideas and speaking in class. This question focused their attention primarily on teacher behaviors such as how well Ball listened to students' ideas, how she created a safe environment for sharing, how she encouraged students to talk and ask questions, and the extent to which positive responses contributed to children's feelings of confidence.

The Cohort 4 group studied one student's participation and sense making. In addition to looking closely at the child's understanding of the concept of fractions, they noted his attitude (e.g., becoming frustrated with others' lack of understanding) and how that shaped his level of effort and his participation. This group observed that the child's ability to verbalize his understanding did not always match understandings that showed up in his written work.

Developing an inquiring stance. An inquiring stance toward teaching and learning developed in the course of all four groups' investigations. All groups needed considerable assurances from us during class that there was no "right answer" to their questions, and that their role was to explore their question as best they could, given the materials available. We explained that we were more interested in the "journey" of their investigation, in the quality of the questions they asked and the kinds of evidence they considered, than we were in definitive conclusions. In their final group notebook entries, each group not only reported tentative conclusions, but areas of uncertainty and additional questions they would pursue if they had more time.

By the very nature of the project's structure, each group began with a general question to investigate. These general questions were then refined as the groups used the course readings and their own insights to frame more particular questions. It became a frequent pattern for groups to form a conjecture about something they viewed on videotape, view the segment again, and follow up by seeing whether Ball's journal (teacher's perspective) and a child's written work (student perspective) provided additional evidence that was consistent with their interpretation. By the end of the project each group generated additional questions they were interested in investigating. We saw an increased curiosity about what they initially took to be "typical" classroom events, and an increased appreciation for the complexity of classroom life.

A CLOSER LOOK AT ONE GROUP'S INVESTIGATION

A more detailed portrait of the learning of three preservice teachers from Cohort 2 is provided to help make concrete the generalizations previously discussed. Angela, Helen, and David (pseudonyms) did not know each other before they took the course. They formed their group based on a common interest in one of the sample questions we provided. All three participated actively in the class activities and in their small group and each one brought different experiences and strengths to the group.

Angela was an extremely bright and capable teacher candidate who demonstrated a particularly strong ability to analyze and integrate course readings and experiences. She entered the course assuming that learning mathematics meant finding "a straightforward, single correct answer"

(Individual Notebook 1/10). She noted, at the end of the course, how her thinking had changed, “I have definitely ‘evolved’ in my thinking about mathematics...I no longer, for example, see mathematics as something straightforward...I want to become a facilitator of students’ class discussions (Final Notebook Entry).

Helen was also a strong and motivated teacher candidate who read carefully. She consistently took time to compare and contrast her own experiences as a mathematics learner with what she saw in Ball’s classroom and other examples found in course readings and activities. She frequently noted strong contrasts, since mathematics “provided me with years of frustration” which contributed to the “low self concept I have within me when I face math” (Individual Notebook 1/10). By the end of the course, Helen’s ideas about her own and her students’ learning changed: “The discoveries I have made in [the course] have made me realize that math can be a wonderful and interesting subject if you are given the direction and the time to explore!” (Planning Project).

David brought different strengths to the course. Although he seemed to understand course readings and concepts without difficulty, he was less consistent in keeping up with assigned readings and reflective writing and relied more on his in-class learning. He felt confident as a mathematics learner, and emphasized how active participation contributed to his learning. Although Angela and Helen tended to reflect upon and analyze ideas and experiences, David seemed more inclined to simply engage in them and absorb what he was able to learn on the spot. As the course progressed, he became more aware of the need for reflection and expression of his thoughts. As he put it, “My favorite days of class are when we are given a problem and have to solve it and give an explanation...I think the thing I really need help with is language. How do I convey my thoughts in a way that is clearly understandable as I often fumble over my words” (Individual Notebook, 2/27).

Getting the investigation started. As part of a class activity, we used Gee’s (1990) concepts of *learning* (learning through explicit teaching) and *acquisition* (learning through immersion) to think about a lesson we viewed together. That day Mrs. Ball explicitly taught the conventional mathematical language “numerator” and “denominator” to the children, which took place several weeks after they had been working with fractions and using the every day language of “top number” and “bottom number.” This seemed like an interesting example of a teacher facilitating *acquisition*—immersion in using concepts—prior to *learning*—explicit teaching of conventional language. We read and discussed Ball's journal entry, noting her thinking about the use of mathematical language (to whom it is helpful or not).

Over two days of working together in the lab, the group drafted and then revised their question to read: *When working with her third graders on fractions, how does Mrs. Ball elicit acquisition to occur before learning?* Across the four weeks spent on the project, the group viewed and studied closely three lessons and Mrs. Ball's journal associated with those lessons. They also selected one third grader, Cassandra, whose interactions were prominent in the second lesson, to study more closely. They investigated whether or not Cassandra understood the concept of dividing cookies into equal parts to share with family members, and the extent to which opportunities for Cassandra to "learn" and "acquire" (Gee, 1990) the concept resulted in understanding. They also paid attention to when and how Cassandra was able to move from using a round to a square object to represent equal parts.

Investigating Discourse in Mathematics Using a Common Framework

As described earlier, we investigated whether or not, and how this group focused on the common framework we used to talk about language arts and mathematics in the course.

Exploring mathematical content. With respect to mathematical content, Angela, Helen and David decided to track Cassandra's progress in developing her understanding of the concept of equal parts. They viewed a lesson in which Cassandra explained to the class how she obtained her answer to the second part of this problem (2b): *2a. I have one dozen small cookies. If I want to share them equally with my family, how many would each person get? How do you know? 2b. How would this work out in your family—how many cookies would each person get? How do you know?* After studying the video clip and accompanying transcript, the group concluded, "At this point, she definitely understands to divide the cookies into five parts, but has not yet grasped that those five parts must be equal" (Group Notebook, 1/25). They also noted that Mrs. Ball reminded Cassandra to use rectangular cookies to help her represent equal parts. The group found that they agreed with Mrs. Ball’s assessment in her journal of Cassandra’s understanding: “As evidenced by Cassandra’s dialogue in the vidbit, her circle representations of a cookie divided into five parts, and Ball’s analysis in her journal, Cassandra appears to understand how to divide the 12 cookies, but to not understand the concept of dividing things into equal parts.” They noted that although Cassandra obtained the correct answer, her division of the round representation did not show each cookie divided into equal parts.

The group continued to explore Cassandra’s understanding of equal parts as they looked at how she represented money. This time they noted that she did use equal parts, but that her language did not reflect an understanding: “After discovering Cassandra’s representation of quarters (in reference to dividing up a dollar) in Mrs. Ball’s journal, we noticed that instead of putting .25, .25, .25, and .25 she put .25, .50, .75, and 1.00. It seems that she understands to increase each piece by 25 cents (and thus create equal parts), but her language doesn’t appear to reflect the equal parts.” They were unable to find conclusive evidence in the video that Cassandra understood the concept of equal parts.

Exploring key math and language arts connections. Concurrent with working in the lab with their group and engaging in class activities, several of their individual notebook entries contained reference to course readings and Ball’s facilitation of *language processes* to explore mathematical ideas. All three group members found concrete examples of how language processes played a central role in helping children explore mathematical ideas. For example, David explained,

> Going over the strategies for listening helped me realize that Mrs. Ball incorporates each one into her classroom in one form or another. Strategy #1 involves forming a picture in your mind. This is apparent when students write on the board showing the class how they perceive it. Strategy #2 is putting information into groups. This is done with conjectures and relating things to things done previously. Things that they might have written down in their notebooks. Asking questions is strategy #3...All of these ways of comprehensive listening are needed to get "the big picture," or the ideas behind each lesson. (Individual Notebook, 1/23)

The group shared a history of having fairly traditional experiences in learning to get the “right answer” in math. Their work in the hypermedia environment provided an indepth and expanded view of what engaging in mathematical subject matter can entail. It helped them think about how engaging in *mathematical processes* (problem-solving, reasoning, and communication) are important ways to develop *mathematical content* (concepts, procedures, and connections), and to explore the role language processes play in those experiences. Angela explained, after reading about Cantlon’s (1994) approaches to assessing content, processes, and attitudes that, like Ball, Cantlon used speaking, listening, and writing to learn about student’s mathematical thinking processes. Helen remarked that Cantlon’s approach to assessment was “just as thorough as Mrs. Ball,” and delineated the many tools that gave Cantlon a view of children’s thinking: notebook, quizzes, worksheets, videos, discussions, and journal entries. Helen noted, however, that she had not seen enough of Ball’s work to determine whether or not she used the same variety of approaches.

This group’s focus on understanding the roles *acquisition* and *learning* play in Ball’s classroom helped them make connections between mathematical processes and content. Angela, for example, applied these two concepts to Ball’s classroom to explain how students were first immersed in working with mathematical ideas through problem solving and reasoning and communicating before Ball provided explicit instruction about the use of more conventional mathematical language:

> She does not focus on rules, nor does she emphasize drills. Rather, she has her students use their problem-solving ability to solve “real world” fraction problems, working through the problems as a class. In this way she promotes the acquisition of fraction concepts; as the children work through the problems identifying patterns, drawing tentative conclusions and making conjectures, they acquire the basic—yet fundamental (and *meaningful*)—ideas. (Individual Notebook, 1/31, emphasis in original)

She went on to relate what her group was learning about Cassandra’s learning through their work in the hypermedia lab.

All three group members, in their end-of-project individual position statements, identified fostering open communication about mathematical ideas in a comfortable environment as a major part of the teacher's role. They understood that without comfort and safety, positive attitudes toward engaging in mathematical processes cannot be promoted. The group explained, "Mrs. Ball is like a facilitator of the mathematical discourse: she doesn't outright tell the students they're right or wrong; rather, she keeps them on track, gently nudging them, and providing suggestions" (Group Notebook, 2/1).

Adopting Three Perspectives to Make Sense of Discourse in Mathematics

During the introductory weeks of the course, Angela, Helen and David were encountering (in Ball's classroom, in classroom visits, and through course readings) and experiencing (in our teacher education classroom) mathematics teaching and learning that contrasted with their own experiences in school. These contrasting images helped them examine their own beliefs from three perspectives: (a) themselves as learners; (b) the teacher's role in facilitating understanding of mathematical content, their engagement in mathematical processes and fostering of attitudes; and (c) children's learning in those areas. For instance, Helen explained how her own learning of mathematics contrasted with a classroom example she read about in the NCTM Teaching Standards (1991). She was beginning to see how her own experiences shaped her view of mathematics as a discipline. As the course progressed, David wrote that his "favorite" part of the class was to solve problems and share explanations (Individual Notebook, 2/27), which was an approach to learning math he did not experience in his own schooling. All three began to see how their prior experiences influenced how they thought about teaching and learning mathematics.

As we have already illustrated, the group focused quite specifically on tracking the learner's perspective, Cassandra's understanding of the concept of equal parts. They drew upon what Cassandra said during class, what Ball wrote about in her journal and Cassandra's written work to understand the student perspective. As they tracked her thinking, they also tried to understand her use of representations. Helen, after reading an article about how teachers base their planning for instruction on children's thinking (Rathmell, 1994), appreciated that the group could investigate Ball's planning in her journal entries and "... our group can see the development of the thinking and reasoning of the children that Rathmell is talking about and then see it progress" (Individual Notebook, 1/25). David also noted that as the teacher pays attention to children's thinking for planning, "The teacher doesn't tell them how to do it as much as the teacher gently guides the students' independent thought in the right direction" (Individual Notebook, 1/25).

Here we see the advantage of having available extensive documentation of Ball's teaching over time, and her thinking about her teaching. The materials provided opportunities to learn to "observe psychologically" in a classroom (Dewey, 1904) to understand a child's thinking and the teacher's thinking in relation to the child's participation. This group focused on Cassandra's thinking and making inferences about what their understanding of the student perspective means for the teacher's role. In their final group notebook entry, they tried to characterize how Mrs. Ball uses children's thinking to plan for and assess student understanding: "Through looking at the journals, Mrs. Ball is able to assess what the children have acquired and learned, and she is able to tailor the next day's lesson according to what is not yet understood. By looking at each students' notebooks over a course of several days or even weeks, Mrs. Ball can assess what each student has learned."

Learning to Develop an Inquiring Stance Through the Use of Technology

An important part of adopting an inquiring stance is to develop the capacity to analyze, reflect upon and ask questions about classroom events, the teacher's reasons for her actions, and student thinking (Dewey, 1904). As Schon (1983, 1987) reminded us, naming and framing problems and issues is just as important for the reflective practitioner as trying to solve them. Helen, early in the project, wrote about her initial reactions to exploring the video materials and explained her developing appreciation of the complexity of classroom life:

> It is amazing to me that when you explore a 5 min. or 10 min. segment such as this one you find out how complicated it really is! Before reading this article and talking in our class I would view this video clip as nothing other than a regular classroom lesson. But now I know how complex and rich it really is. Wow! (Individual Notebook, 1/23)

It seems that having access to a teacher's daily practice made her more inclined to wonder "what else" they could consider before coming to conclusions.

Angela also began to think about what kinds of questions the video materials raised: "I wonder whether any of the videos capture the dialogue in one of these groups of students discussing a math problem. It would be interesting to examine" (1/25). David noted, "I've thought about inviting students to participate and directing questions, but I didn't think about the need to decrease teacher evaluation" (Individual Notebook, 1/25). Likewise, Helen appreciated how further learning helped her get a more complex view of teaching: "I tell you what, the more I read and learn I become very excited to teach. However, I also realize how complex teaching really is. It makes me a little nervous" (Individual Notebook, 1/23). Helen's "nervousness" may have come from her awareness that she had more questions than answers.

The group members also showed an increasing appreciation for how difficult it was to draw conclusions from their investigations. The final group notebook entry emphasized their uncertainty at drawing definitive conclusions:

> We tried to follow Cassandra's progress through looking at her journals, looking at Mrs. Ball's journals and viewing classroom sessions. If we had more time, we would look through more students' journals and trace their learning progress, because after looking through all of Cassandra's journal entries, we did not obtain enough evidence to draw conclusions about what Cassandra has acquired and/or learned. (Group Notebook, 2/1)

Yet they also thought of other areas they could try to study, showing that their hypermedia investigation fostered curiosity beyond their group's initial question: "It would be interesting to map out each student's progress with the fractions unit...it would also be intriguing to tally up the different ways which the students use to visually represent fraction problems..." (2/1). They framed some new questions that would be interesting to investigate, such as: the relationship between acquisition and learning; comparing Mrs. Ball's method of encouraging acquisition of concepts to more traditional approaches of teaching rules for concepts; and considering the different ways in which students verbally communicate their reasoning for the fraction problems. These questions not only indicated a growing curiosity, but an expanded view of how the hypermedia materials could support their continuing study.

Using technology as a cognitive tool. The hypermedia materials became a "cognitive tool" (Reeves, 1996) for this group to ask and pursue meaningful questions. We wondered about the extent to which they felt comfortable with its use. Angela gave the hypermedia project a 4 rating (the highest possible) and explained, "Examining D. Ball's research was extremely beneficial to my integrating of course ideas about new math teaching strategies, including establishing a forum for math discourse." She went on to add that the *set of experiences* offered in the course was beneficial: "Viewing/discussing videotapes, using hypermedia materials, whole class discussions, small group tasks and activities.... these activities engaged my peers and me." Helen also gave the project a 4 rating and offered this comment: "Mrs. Ball's classroom was interesting to observe because I had never been exposed to math instruction like that before. The project helped me to look even further." David, however, gave a 3 rating because it was "confusing at first," but he added that he understood it better as the project went along. Compared with other course projects, David said he got the "least" out of it. But a comment in his philosophy statement is puzzling:

> If I had to pick one thing that moved me the most in this direction [more open learning environment] it had to be the hypermedia investigation that we did. Seeing those children make such deep connections was simply astounding. Not only can you determine where they are, you can also tailor your lesson plan to touch on areas that they may need help in or figure out which direction you should head in next. Having open discussion in the classroom creates another form of assessment from which I as a teacher can work with.

At this point, we can only speculate that while the content offered in the materials helped David get new images of mathematics teaching and learning, the open-ended structure of the project itself seemed confusing to David and may have caused some discomfort. If, in his mind, the project's purpose or processes were unclear, it makes sense that he would describe the project as "least" helpful compared with other projects that looked more like the kinds of assignments he was used to doing.

Elaborating and Synthesizing Learning Throughout the Semester

Because we viewed the preservice teachers' learning during the group investigations as just beginning, we also analyzed their written work throughout the course to get a view of how the group's thinking changed over time.

Pulling ideas together in a position statement. At the close of the group investigation, we asked the prospective teachers to each write an individual position statement on the teacher's role in helping children use oral language to explore mathematical ideas. All three group members drew upon video excerpts, course readings, and course experiences to illustrate their ideas. For all three, the teacher plays an active role in the mathematics classroom. In David's words, the teacher is "responsible" for making things happen. Creating a safe environment that promotes discussion is essential. Angela referred to this as "fearless exploration" while Helen emphasized children's comfort in discussing ideas (like sharing of cookies) that are familiar and to which they can relate. Discussion was viewed as a central means for sharing and examining ideas. As Helen explained, "...teachers must ask students particular questions (like ones with no wrong answers) or use common experiences when making up problems." David illustrated how the teacher is a guide in response to student thinking, carefully planning when and how to teach mathematical language to describe ideas.

Angela no longer viewed the teacher's role as helping children work individually to get the right answer. Helen was willing to put aside her years of frustration as a mathematics learner as she began to see how teachers can help children make connections within and across areas of mathematical study. David understood his past success with seeing one sample problem and quickly moving to solve several more just like it, but also began to see that the teacher can do much more than present examples of how to solve problems for students to imitate.

Deepening understandings over time. Examination of the written work that Angela, Helen, and David generated throughout the remainder of the course revealed that all three developed more complex views of the role language processes play in helping children develop mathematical content, processes, and attitudes. Angela wrote about her frustration in her field placement classroom when she encountered management problems while trying to foster a rich mathematics discussion. Helen was faced, impromptu, with the opportunity to read a children's book to first-graders and discuss the mathematical content with them. She wrote about her feelings of surprise that she actually could think of questions to stimulate a discussion. David wrote about another type of difficulty, that of making sure all children are included, and his awareness of the teacher's responsibility to help children establish appropriate norms for participation.

There was an increasing complexity in these three teacher candidates' understanding of mathematical content, processes, and attitudes. For example, Helen connected mathematical content with mathematical reasoning: "...I definitely believe that part of the math curriculum for elementary school should include ways of teaching why...A problem should not be solved by just using a formula. A student needs to understand why that formula works and what other ways or formulas could possibly work" (2/13). Angela brought up yet another issue, when and how computation should become part of the mathematics curriculum: "Teaching computation first and then applying those skills to problem situations is backwards, as teaching children to read or write music before having them 'sing, listen, and move their bodies to the sound of music'" (2/13). David wrote about Cassandra's lack of understanding of equal parts to argue that understanding is more important than getting the right answer:

> In the investigation in mathematics discourse [it] showed me how important it is for students to have an intimate knowledge of the material, that is they must understand it backwards and forwards, inside and out. If they don't they are very likely to misunderstand concepts, like Cassandra does in Mrs. Ball's class when working on defining fractions on the board. Cassandra knows the answer but she is still not quite sure how she got it. (2/1)

There was also more discussion about children's attitudes toward mathematics. After a visit to a mathematics class both Angela and Helen commented on the children's ownership of ideas and attitude of confidence. Angela also added, "Until I observed this class and interacted with a few of the kids as they worked on the math question, I did not fully believe how excited and engaged elementary students could become about math. Students at several tables debated ideas back and forth..." (4/19). Although she saw children engaged in mathematics discussions on videotape, interacting with them in person was a more convincing experience.

˜Angela, Helen, and David continued to raise issues related to adopting the three perspectives of self as a learner of mathematics, teacher and K-5 student. Angela wanted to know more about the teacher's role in discussions: "At what point in math discourse with students should a teacher jump in with info. to get them on the right track? How nondirective should a teacher be?" (2/13). Moreover, she expressed concern about what the teacher should do when incorrect procedures are used, and worried about whether there is time in a crowded curriculum to work through incorrect procedures (2/27). David had a different concern about how to teach students to create their own strategies, and how to link those strategies to different areas. Further, he thought about what he personally brings as strengths and weaknesses as a teacher and shared, "I think the thing I really need help with is language. How do I convey my thoughts in a way that is clearly understandable as I often seem to fumble over my words. I know that the kids will come to many of these ideas on their own. I guess my real question is how do you nurture these thoughts and/or bring them out" (2/27). Helen raised questions about how teachers can apply ideas about fostering discourse with first graders and commented that she had not witnessed much discussion of mathematical ideas in her field placement classroom among first graders. All three demonstrated an inquiring stance as they tried to make connections among readings, course experiences and their interactions in classrooms.

A prominent theme in Helen's reflections across the semester was the contrast between her own mathematical learning experiences and the newer ways of teaching mathematics. Near the end of the course, she made explicit her understanding that with a different approach to teaching mathematics, she might have been a different (and more successful) learner explicit (4/16). Helen came to realize that she could follow the advice in the mathematics standards (NCTM, 1991) to draw upon one of her strengths, her love of literature, to look at math differently and to approach teaching mathematics in a way that promotes her own and her students' interests.

Pulling thoughts together in a philosophy statement. Initial ideas about the teacher's role became more elaborated and better illustrated in their end-of-semester philosophy statements about teaching mathematics. For example, Angela explained her understanding of constructivist learning of mathematics as problem solving, communication, and reasoning processes. She used the word "facilitator" to characterize the teacher's role in the learning community, and assigned the role of "problem solver" to the children. Angela clarified that open communication is fostered when the teacher remains neutral while asking children to agree or disagree with conjectures that are put forth. Moreover, Angela pointed out that the use of journals in Ball's classroom provided an additional mode of communication. The aspects of the teacher's role that were discussed earlier in the semester were more integrated, interconnected, and concrete in her philosophy statement.

David's philosophy statement continued to assign a guiding role to the teacher, that of facilitator of student learning. However, he was able to articulate how this could happen more specifically in three ways. First, he emphasized the social nature of learning, linking it to constructivism. More importantly, David was able to explain more concretely the impact social interaction has on children's mathematical learning: "If students tie what they are learning into what they already know, they can develop mathematical structures that are more complex, abstract, and powerful than the ones that they currently possess. This enables them to become increasingly capable of solving a wide variety of meaningful problems." Finally, David articulated more specifically the teacher's responsibilities in the learning process: be a facilitator, create problems that engage students and can be solved in a variety of ways, and let students take the lead in completing tasks.

THE USE OF TECHNOLOGY AS A LEARNING TOOL

This study of 13 teacher candidates' learning from four cohorts provides convincing evidence that they gained important exposure to reform-based teaching in mathematics. That exposure helped them begin to re-think and re-imagine what it means, in an elementary context, to teach and learn mathematics, and the role discourse can play in that process. Nevertheless, we know that not all of our preservice teachers' learning was as powerful as that of these groups. For instance, some groups were less focused as they developed and pursued their investigation questions, and therefore seemed to experience a series of "false starts" before they were able to proceed systematically. Other groups had less experience with technology in general. We are curious about how these variations in focus affected what different groups learned from the project or how their learning continued throughout the semester. However, our research methods did not include audio recording of interactions at the computer stations, which might have told us more than we were able to learn by analyzing written work.

We have additional questions about how different groups' exploration of the four areas of investigation across different contexts influenced their learning. We know, for example, that for some preservice teachers, initial exposure to Deborah Ball's classroom had a profound effect on their thinking from the onset of the course. One prospective teacher reported, for example, that it was especially helpful to begin the course with the hypermedia investigation because, "...It helped me see the value of environment and teacher's role." For others the hypermedia project itself did not have a strong impact, but in-class work with open-ended mathematics problems that supported a new kind of mathematical discourse made a big difference for them. Others felt that they only understood more about the purpose of the project in hindsight, or that their learning would have been enhanced if their group had been able to work longer on the project. Some individuals who were less successful in synthesizing their ideas in their individual position statements were highly successful in other parts of the course. Further study is needed to provide insights into ways in which different areas of investigation in different contexts have the potential to influence different groups' learning.

Learning Opportunities in the Hypermedia Environment

Earlier we discussed the importance of supporting novices to develop their capacity to analyze, reflect upon, and ask questions about teaching and learning, for those qualities are needed to adopt an inquiring stance toward their practice and to become reflective practitioners (Schon, 1983, 1987). Our study has taught us that the hypermedia environment provided opportunities for teacher candidates to engage in conversations that, for many, are very different from the kinds of discussions they were used to having in school. Through the inquiry process, they engaged in many activities that became part of their ongoing conversation during the early weeks of the course: framing problems and questions; generating conjectures; seeking evidence; formulating questions; making arguments; playing out their ideas; and revising their thinking. That is, they engaged in "exploratory" open-ended talk and writing that allowed them to use communication processes as tools for learning rather than merely a means to produce right answers (Barnes, 1976). This way of talking and writing represents new "ways of knowing" that are advocated in the NCTM (1991, 2000) and NCTE/IRA (1996) standards (Lampert, Heaton, & Ball, 1994), and represents how language is fundamental to subject matter learning (Pearson, 2001). By recording many aspects of their thinking and talking in written form through the use of the individual and group notebooks and more formal writing assignments, preservice teachers had a way to “think on paper” (Calkins, 1991, p. 67), document their intellectual development, and revisit and revise their ideas. In that sense, they were experiencing the kind of teaching and learning that is advocated in the standards.

The hypermedia environment also provided a context for teacher candidates to learn to take more responsibility and ownership for their learning. Groups were in charge of deciding which question to pursue, how to proceed, and which aspects of their “rough draft” thinking to record in their notebooks. This kind of work required active engagement and self-direction. Teachers must develop those qualities in order to continue learning from their practice across their careers. Moreover, the work took place in a collaborative group context, which gave novices experience—with support—in working within a community of practice where problems were ill defined and approaches to addressing them must be constructed by professionals (Lieberman & Miller, 1990).

A hypermedia environment seems especially suited to fostering exploratory conversations and close collaboration with peers. Novices explored rich, concrete examples of one teacher’s reform-oriented teaching. Instead of hearing about such teaching, they watched it happen. Instead of relying on one person’s memory to report fairly vague details, they viewed particular conversations around specific mathematical ideas. Instead of watching classroom teaching by themselves as single observers in a classroom, they viewed common concrete examples in the company of their colleagues, which promoted the exchange of insights and ideas. Instead of having to figure out what to notice and how to make sense of classroom life on their own, they first supported one another in a common environment and thus got more solid preparation for their own classroom participation. Instead of only seeing a small slice of one teacher’s practice, they had access to multiple aspects over time.

Insights about the Structure and Timing of the Hypermedia Project

Like all teachers, we encountered a range of learners across four semesters. For this range of learners, we had an ambitious agenda that included an introduction to learning in at least three broad areas: (a) to engage in teaching practices as defined by the national standards in mathematics and English language arts; (b) to reflect and collaborate in a professional community of practice; and (c) to engage actively in inquiry about teaching and learning. Some of our learners brought at least some prior experience with doing open-ended, self-paced projects with loosely-defined tasks. Others found that experience to be difficult, confusing, and sometimes frustrating. Some of our learners brought with them fairly well developed capacities for analytic thinking, reflective writing, and critical reading. Others needed our support in learning to develop those capacities. Some novice teachers were able learners in mathematics and their confidence about themselves as learners enabled them to take risks with mathematical ideas during in-class discussions. More frequently, our preservice teachers entered the course with little success as mathematics learners and therefore had little confidence in their ability to explore mathematical ideas or engage in reasoning and problem solving. Some entered the course with a willingness to share their emerging thinking because they encountered taking such risks in the past and met with success. Others had either not experienced that kind of risk-taking, or did not trust that they could take such risks in the course until they knew us better. Some teacher candidates had engaged in collaborative work with colleagues and possessed the interpersonal and organizational skills to be successful. Others disliked learning in collaborative contexts. Some simply had little experience in that area and therefore felt the need for more support and direction than their peers. We saw many of these variations as we got to know each learner.

Two questions grow out of these observations. One question has to do with the timing of when we offer the hypermedia project: Is a highly complex project that takes place in a new technological environment the most appropriate context to begin to address our ambitious goals with our range of learners? What would we gain or lose if we singled out particular areas—such as learning to work on collaborative tasks, or engaging in mathematical problem solving in new ways, or working on analytic and reflective writing—first, and then led up to our work in the hypermedia environment? We certainly could gain a simplicity of focus and therefore be in a better position to provide support to our teacher candidates as they develop the many capacities needed to work successfully in the hypermedia environment. We could single out particular areas and support them systematically over time and lead up to working in the hypermedia environment.

Still, the strengths of working in the environment early in the course may lie in the fact that preservice teachers are confronted with materials and tasks that make their world complex—just like the world of teaching they are about to enter (Spiro, Coulson, Feltovich, & Anderson, 1988). We might reason, then, that such a complex situation is exactly the kind of authentic context that will help them learn to engage in reflective conversation and writing to make sense of teaching as a complex activity. In addition, we have noticed that although some groups struggled with collaboration as the project proceeded, this gave us a ripe opportunity to make such problems explicit and support them as they confronted problems associated with learning to collaborate. Indeed, several groups in each cohort continued to work together throughout the course, which indicates that they valued the relationships they established during the early weeks. We also question whether "saving" video materials for analysis until after our candidates are already working actively in their field placement classrooms might make the video materials seem less rich than their first-hand interactions with actual children in classrooms. If we waited to use the materials, we could lose the opportunity to carefully prepare our prospective teachers to observe psychologically and consider classroom events from multiple perspectives.

A second question we continue to think about has to do with the use of these unique materials: What are alternative ways to engage future teachers in exploring teaching and learning in the hypermedia environment? Perhaps we could ask them to engage in various tasks and discussions in the hypermedia environment without framing it as an inquiry "project" that has a beginning, middle, and end. In that way, framing of problems and issues, searching for evidence and so on could take place in the hypermedia lab throughout, rather than just at the beginning, of the course. We might be in a stronger position to help *all* prospective teachers make the connections our stronger groups seemed to be able to make on their own. In making this choice we might give up, however, the opportunity for prospective teachers to make their own choices regarding what to study, and how to proceed; they may miss opportunities to develop ownership of their investigations.

Another issue we are thinking about is assessment. In our version of the project, teacher candidates were held accountable for their participation and learning in three ways: their actual participation in the lab, the group notebook, and the individual position paper they wrote at the end of the project. There may be other, more effective ways for us to assess and evaluate their participation and learning that would capture more fully the rich interactions that the students experienced. Many struggled, for instance, with what to write in the group notebook, and we acknowledged that we struggled too with defining exactly what "genre" of writing the group notebook required. We defined it as a record of their thinking, a record of the "journey" they took as they worked with the materials in the environment. We emphasized that we were looking for evidence of their asking questions, posing problems, considering possibilities, and testing hypotheses. The closest example of writing in that "genre" that our preservice teachers may have experienced is reflective journal writing. However, in the case of the group notebook, groups struggled with how to write as a group, because writing is traditionally a solitary activity. They encountered problems with whether every member was contributing and therefore deserved credit for the content of the notebook. They also confronted decisions about what to include in the group notebook and how to capture and represent to us their hard intellectual work and the lively dialogues that took place around the computer screen. These were not struggles they already learned to face during individual journal writing. The individual position paper was one way in which individuals moved from "rough draft" to "latest draft" thinking and was a place where they could synthesize and pull together their learning thus far. We are still searching for other ways in which groups could help us stay in touch with what they are doing and learning, both so we can use that information for our ongoing teaching and so the reward structure in the course acknowledges each person's contributions.

Still another question is related to our own involvement in the investigations as they proceed. As their teachers, we wonder what is appropriate access to (and support of) our students' "rough draft" thinking. To what extent or for what time period might they simply be free to explore and "mess around" with ideas *without* having a teacher looking over their shoulders? What if we simply made ourselves available for support, as needed, and relied on them to identify times when they need contact with us? We experimented with various ways to handle that issue with varying success. So far, our experience has shown us that there are times when those who are new to conducting inquiry are not aware that they are losing focus in their inquiry. Other times, they may be unaware of a particular lesson or piece of student's work that will help them pursue their question. Some groups tend to assume they are "lost" or "off track" without confirmation and encouragement from us that what they have been doing is, in fact, inquiry. Just as teachers struggle with when to join a small group's conversation about a mathematics problem or when to initiate a writing conference, we are still working on finding an appropriate balance between interacting to support our preservice teachers and leaving them to work out problems and issues on their own.

Implications for Teacher Educators' Design and Use of Hypermedia Environments

What might teacher educators learn from our specific example of using hypermedia as a tool for exploring teaching and learning? We cannot emphasize enough how important our own use of the same technology with our professional teacher education study group was in helping us design, carry out, and revise this project. Time and again, we have found ourselves reflecting on how we used technology as a learning tool for ourselves (Reeves, 1996). Reflections included looking at how we used our group notebook; how we learned to use the technology itself; what kinds of conversations we had; what interactions occurred around the computer screen that did not get included in our group notebook; and what other experiences seemed to influence our thinking over time as our investigation proceeded. We used these insights to make decisions about structuring and revising the project over time. We also have come to appreciate the revisions we have made in the course over time. These revisions have helped us more fully integrate the hypermedia project into the course. The better we were able to provide a complementary set of course experiences—where course readings, in-class activities, classroom observation and participation, use of other video materials, and so on, are highly interconnected—the more sense the project seemed to make to our candidates. That means that the use of technology, such as spending time in a hypermedia environment, must be designed to fit within the overall course content and structure.

We are presently thinking about ways that new hypermedia materials might be designed and used in other subject matters, because any set of artifacts from classroom teaching will have gaps, inconsistencies, and incomplete information (Ball & Lampert, 1999). In designing hypermedia environments, teacher educators need to consider what background knowledge is needed about a teacher's curriculum and instruction to interpret classroom examples, and what additional artifacts (students' reflective or narrative writing, copies of instructional materials), use of participation structures (e.g., group work that probes student thinking), or documentation (e.g., student interviews) may be useful in making sense of students' understanding. Moreover, we wonder how a "living and growing" environment that expands over time in response to users' questions and insights might be constructed (Rosaen, 2002).

We conclude by offering three key questions teacher educators might ask when thinking about whether and how their preservice teachers can benefit from spending time in a hypermedia environment: (a) What potential do the materials offer for generating rich conversation, inquiry, and reflection? (b) What support do teachers need to realize that potential? and (c) How can preservice teachers be held accountable for their participation and learning in ways that enhance their learning? We will continue to explore these questions as we proceed with our teaching and action research.

References

Abell, S., Cennamo, K., Anderson, M., & Bryan, L. (1996). Integrated media classroom cases in elementary science teacher education. *Journal of Computers in Mathematics and Science Teaching, 15*, 137-151.

Ball, D.L., & Lampert, M. (1999). Multiples of evidence, time, and perspective: Revising the study of teaching and learning. In E. C. Lagermann & L. S. Shulman (Eds.), *Issues in education research: Problems and possibilities*, (pp. 381-398). San Francisco: Jossey-Bass.

Ball, D.L., & McDiarmid, G.W. (1990). The subject matter preparation of teachers. In W.R. Houston (Ed.), *Handbook of research on teacher education*, (pp. 437-449). New York: Macmillan.

Barnes, D. (1976). *From communication to curriculum*. London: Penguin Books.

Bogdan, R.C., & Biklen, S.F. (1982). *Qualitative research for education: An introduction to theory and methods.* Boston, MA: Allyn & Bacon.

Bruner, J. (1960). *The process of education*. Cambridge, MA: Harvard University Press.

Calkins, L. (1991). *Living between the lines.* Portsmouth, NH: Heinemann.

Cantlon, D. (1994). Toward authentic assessment: Two case studies. In P. Schram (Ed.), *Nurturing the freedom to wonder: Vignettes from elementary mathematics classrooms, (Monograph No. 25*, pp. 93-119). Michigan Council of Teachers of English.

Cochran-Smith, M. (1991). Learning to teach against the grain. *Harvard Educational Review, 61*, 279-310.

Daniel, P. (1996). Helping beginning teachers link theory and practice: An interactive multimedia environment for mathematics and science teacher preparation. *Journal of Teacher Education*, *47*, 197-204.

Dewey, J. (1904/1965). The relation of theory to practice in education. In R.D. Archambault (Ed.), *John Dewey on education: Selected writings*, (pp. 313-338). Chicago: University of Chicago Press.

Dudley-Marling, C., & Searle, D. (1991). *When students have time to talk: Creating contexts for learning language*. Portsmouth, NH: Heinemann.

Elbow, P. (1990). *What is English?* New York: Modern Language Association of America.

Erickson, F. (1982). Taught cognitive learning in its immediate environments: A neglected topic in anthropology of education. *Anthropology and Education Quarterly, 13,* 149-180.

Erickson, F. (1986). Qualitative methods in research on teaching. In M. Wittrock (Ed.), *Handbook of research on teaching*, (3rd ed., pp. 119-161). New York: Macmillan.

Feiman-Nemser, S., & Buchmann, M. (1986). The pitfalls of experience in teacher preparation. In J.D. Raths & L.G. Katz (Eds.), *Advances in teacher education*, (Vol. 2, pp. 61-73). New York: Ablex.

Gee, J. (1990). *Social linguistics and literacies: Ideology in discourses*. New York: Falmer Press.

Goldman, E., & Barron, L. (1990). Using hypermedia to improve the preparation of elementary teachers. *Journal of Teacher Education, 41*, 21-31.

Goldman, E., Barron, L., & Witherspoon, M. (1991). Hypermedia cases in teacher education: A context for understanding research on the teaching and learning of mathematics. *Action in Teacher Education, 13,* 28-36.

Gorden, R.L. (1986). *Interviewing: Strategy, techniques, tactics*, (4th ed.), Homewood, IL: Dorsey.

Griffiths, R., & Clyne, M. (1994). *Language in the mathematics classroom: Talking, representing, recording*. Portsmouth, NH.

Grossman, P. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Hatfield, M. (1996). Using multimedia in preservice teacher education. *Journal of Teacher Education*, *47*, 223-228.

Heaton, R. (1995). Thinking together about teaching teachers. *Changing Minds, 11*, 24-28. East Lansing, MI: Educational Extension Service, Michigan State University.

Houston, W.R., & Clift, R.T. (1990). The potential for research contributions to reflective practice. In R.T. Clift, W.R. Houston, & M.C. Pugach (Eds.), *Encouraging reflective practice in education: An analysis of issues and programs*, (pp. 208-222). New York: Teachers College Press.

Hubbard, R., & Power, B. (1993). *The art of classroom inquiry: A handbook for teacher-researchers*. Portsmouth, NH: Heinemann.

Jacobs, H. (1989). The growing need for interdisciplinary curriculum content. In H. Jacobs (Ed.), *Interdisciplinary curriculum: Design and implementation*. Alexandria, VA: Association for Supervision and Curriculum Development.

Lacey, C., & Merseth, K. (1993). Cases, hypermedia, and computer networks: Three curricular innovations for teacher education. *Journal of Curriculum Studies, 25*, 543-551.

Lambdin, D., Duffy, T., & Moore, J. (1996). *A hypermedia system to aid in preservice teacher education: Instructional design and evaluation*. (ERIC Document Reproduction Service No. 397 808)

Lampert, M., & Ball, D.L. (1995). *Aligning teacher education with contemporary K-12 reform visions*. Paper presented to the National Commission on Teaching and America's Future, New York.

Lampert, M., & Ball, D. (1998). *Teaching multimedia: Investigations of real practice,* New York: Teachers College Press.

Lampert, M., Heaton, R., & Ball, D. (1994). Using technology to support a new pedagogy of mathematics in teacher education. *Journal of Special Education Technology, 12*, 276-289.

Langer, J.A., & Applebee, A.N. (1987). *How writing shapes thinking: A study of teaching and learning*. Urbana, IL: National Council of Teachers of English.

Lee, C., & Lawson, C. (1996). Numeracy through literacy. *Educational Action Research, 4*, 59-72.

Lieberman, A., & Miller, L. (1990). Teacher development in professional practice schools. *Teachers College Record, 92*, 105-122.

Liston, D.P., & Zeichner, K.M. (1991). *Teacher education and the social conditions of schooling*. New York: Routledge.

Lortie, D. (1975). *Schoolteacher: A sociological study*. Chicago, IL: University of Chicago Press.

Moline, S. (1995). *I see what you mean: Children at work with visual information*. York, Maine: Stenhouse.

National Council for Accreditation of Teacher Education. (1997). *Technology and the new professional teacher: Preparing for the 21st century classroom.* Washington DC: Author.

National Council of Teachers of English and International Reading Association. (1996). *Standards for the English language arts*. Urbana, IL: Author.

National Council of Teachers of Mathematics (NCTM) (1991). *Professional standards for teaching mathematics*. Reston, VA: Author.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics*. Reston, VA: Author.

Oja, S., & Smulyan, L. (1989). *Collaborative action research: A developmental approach.* New York: Falmer Press.

Pearson, D.P. (1994). Integrated language arts: Sources of controversy and seeds of consensus. In L. Morrow, J. Smith, & L. Wilkinson (Eds.), *Integrated language arts* (pp. 11-31). Boston: Allyn & Bacon.

Pearson., D.P. (2001). Learning to teach reading: The status of the knowledge base. In C. M. Roller (Ed.), *Learning to teach reading: Setting the research agenda,* pp. 4-19. Newark, DE: International Reading Association.

Rathmell, E.C. (1994). Planning for instruction involves focusing on children's thinking. *Arithmetic Teacher, 41*, 290-291.
Reeves, T.C. (1996). Technology in teacher education: From electronic tutor to cognitive tool. *Action in Teacher Education, 17*, 74-78.
Rosaen, C.L. (2002). Designing and using hypermedia materials to investigate language use in a culturally diverse classroom. *Journal of Educational Multimedia and Hypermedia, 11*, 155-175.
Rosaen, C.L., & Roth, K.J. (1995). Similarities and contrasts between writing during a writers' workshop and writing in science: Examining the teacher's role. In J. Brophy (Ed.), *Advances in research on teaching, (Vol. 5*, pp. 291-354). Greenwich, CT: JAI Press.
Schon, D. (1983). *The reflective practitioner*. New York: Basic Books.
Schon, D. (1987). *Educating the reflective practitioner*. San Francisco: Jossey-Bass.
Siskin, L.S. (1994). *Realms of knowledge: Academic departments in secondary schools*. Washington, DC: The Falmer Press.
Spillane, J.P., & Jennings, N.E. (1997). Aligned instructional policy and ambitious pedagogy: Exploring instructional reform from the classroom perspective. *Teachers College Record*, *98*, 449-481.
Spiro, R.J., Coulson, R.L., Feltovich, P.J., & Anderson, D.K. (1988). Cognitive flexibility theory: Advanced knowledge acquisition in ill-structured domains. In *Proceedings of the 10th annual conference of the Cognitive Science Society,* 375-383. Hillsdale, NJ: Erlbaum.
Staab, C. (1992). *Oral language for today's classroom*. Markham, Ontario: Pippin.
Stenhouse, L. (1975). *An introduction to curriculum research and development*. Portsmouth, NH: Heinemann.
Strudler, N.B., McKinney, M.O., & Jones, W.P. (1999). First-year teachers' use of technology: Preparation, expectations and realities. *Journal of Technology and Teacher Education, 7*, 115-129.
Whitin, D.J., & Wilde, S. (1992). *Read any good math lately?* Portsmouth, NH: Heinemann.
Whitin, D.J., & Wilde, S. (1995). *It's the story that counts*. Portsmouth, NH: Heinemann.
Willis, J., & Mehlinger, H. (1996). Information technology and teacher education. In J. Sikula, T.J. Buttery, & E. Guyton (Eds.), *Handbook on research in teacher education,* (pp. 978-1029). New York: Simon and Schuster MacMillan.
Zemelman, S., Daniels, H., & Hyde, A. (1993). *Best practice: New standards for teaching and learning in America's schools*. Portsmouth, NH: Heinemann.

Note

1. The following are examples of questions provided: How does the teacher help students *acquire* and *learn* mathematical discourse and what is the relative balance given to supporting learning and acquisition?; What is included in developing a mathematical argument in this classroom and how does discourse enter into the process?; What speaking and listening skills are needed to participate in mathematical discourse in this classroom and how does the teacher help the students develop these skills?. We encouraged exploration of the children's written work as a way to understand their thinking, but did not require the topic of writing to be included in their question.

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