Running Head: USING EYETRACKING TO COMPARE REACTIONS TO VIDEO

Using Eyetracking Technology to Compare Professionals' and Novices' Reactions to a Videotaped Teaching Episode

Randolph A. Philipp, Judith T. Sowder, Tricia Valeski, and Rimma Livyant

San Diego State University

Preparation of this paper was supported by a grant from the National Science Foundation (NSF) (REC-9979902). The views expressed are those of the authors and do not necessarily reflect the views of NSF.

Using Eyetracking Technology
to Compare Professionals' and Novices' Reactions
to a Videotaped Teaching Episode

Abstract

Eyetracking technology and individual interviews were used to investigate differences among the ways prospective elementary school teachers, practicing teachers, and mathematics educators observed and analyzed videotape of a researcher and a 5th-grade student engaged in a teaching episode. Results indicate that, among these three groups, mathematics educators attend most closely to the student, teachers to the interviewer, and prospective teachers to the mathematical content. Although the mathematics educators provided deep, detailed analyses of the episode, their cognitive-activity measures were lowest of the three groups; teachers exhibited the highest levels of cognitive activity. Prospective teachers attended more to problem presentation than to the student's solution; the opposite was true for teachers. Implications for videotape production and use for teacher development and teacher enhancement are included.

Using Eyetracking Technology to Compare Professionals' and Novices' Reactions to a Videotaped Teaching Episode

Videotapes are widely used in the preparation of prospective elementary school teachers and in the professional development of practicing teachers because they can provide rich contexts for considering issues of learning and teaching. Some of the many ways videotapes are used by mathematics educators to support teacher development and enhancement include consideration of individual children’s mathematical thinking, analysis of teachers' decision making during instruction, and reconsideration of the important mathematical concepts under investigation. Although videotapes are widely used, little research is available to guide mathematics educators in determining effective ways to incorporate the use of videotapes in teacher development and enhancement. At a more basic level, we know little about what draws an individual's attention while viewing videotapes or how one’s background and training affect the sophistication with which one interprets video. The purpose of this study was to address these issues by investigating differences among three groups--prospective elementary school teachers, practicing teachers, and mathematics educators--while they viewed a videotape of a researcher and a fifth-grade student engaged in a mathematics-teaching episode. In the methodology we used, reactions of participants were gauged though analysis of point-of-gaze and level of cognitive activity, which were measured and recorded with sophisticated eyetracking technology. Additional data were collected through interviews of the participants. The study was part of a larger project designed to help prospective elementary school teachers better understand the depth of knowledge necessary for teaching elementary school mathematics and was intended to inform the development of an early field experience that would meet this aim. Two areas of research were considered particularly relevant to this study. Each is summarized only to the extent that it was useful in interpreting the results of the study.

Expert-Novice Research

Early studies contrasting expert and novice reasoning (e.g., Chi, Feltovitch, & Glaser, 1981, Larkin, McDermott, Simon, & Simon, 1980) indicated that experts are more likely than novices to focus on relevant problem features that lead them to qualitatively better conclusions. Experts have access to a large body of organized knowledge that can be quickly accessed and used to guide problem interpretation and solution. In a major study of the qualities exhibited by experts, Dreyfus and Dreyfus (1986) outlined five stages of development of expertise: Novices are relatively inflexible in their reasoning; advanced beginners have experiences that allow them to build cases that complement their book knowledge; competent performers can articulate goals and find means to achieve them; proficient performers recognize similarities among situations and are more holistic in their approaches to finding solutions; and experts share this holistic approach by responding effortlessly and appropriately to the situation encountered. Experts have quick access to a large body of organized knowledge that can be used to guide problem interpretation and solution.

In a summary of expert-novice distinctions in teaching mathematics, Livingston and Borko (1990, also Borko & Livingston, 1989) noted that teaching has characteristics of expertise found in other domains; that is, expert and novice mathematics teachers differ in their perceptions, information processing, knowledge structures, and decision making. Indeed, in their own comparison of review lessons of expert and novice teachers, they found that explanations of expert teachers were conceptually linked and less procedural. Novice teachers spent time coming to understand the content themselves instead of in thinking about how to make the content more comprehensible to students.

Stages in teachers' reactions to instructional settings have also been described in the literature. For example, in a study of what expert, advanced beginners, and novice teachers attended to during three simultaneous videotapes of a junior high school science class, Saber, Cushing, and Berliner (1991) found classroom experience to be a critical factor differentiating reactions of expert and beginning or novice teachers. Experts were better able to integrate visual and auditory stimuli to understand and interpret what was happening in the classroom. In one example of stages of expertise, the researchers found that novices tended to focus on student behavior but offered no solutions to problem behavior; advanced beginners attempted to offer solutions, but their solutions were less insightful than those of experts, who instead focused on student behavior in the context of teacher behavior. We mention this example because we were also interested in the differences in focus of individuals from each of our three groups while they viewed a selected videotape.

Eyetracking Technology

While each participant watched a videotape, her point-of-gaze was tracked using the state-of-the-art Eye-Link system. With this system, both eyes were tracked at 250 Hz, recording the exact pixel coordinate of each observation. The coordinate data were used to plot the scanning patterns of participants while they watched the video. The data collected for our study revealed not only the paths but also the percentage of time that individuals spent observing each of the three major screen locations: an interviewer, a student interviewee, and the artifacts created on the work area during the interview.

Index of cognitive activity. In addition to tracking what participants watched on a screen, we incorporated into our study a novel means for measuring cognitive activity, developed by Marshall (1998). According to Marshall, past attempts to measure cognitive activity have focused on such approaches as measuring galvanic skin response, measuring pulse rate, and interviewing individuals in the act of processing and relying on their self-reports of difficulty (Marshall, personal communication, February, 19, 2002). However, a large body of research has now shown that “the pupil dilates on presentation of cognitive or affective stimuli; pupil dilation occurs with effortful information processing in many areas; . . [and] the degree of dilation varies by individual and task” (Marshall, 1998, p. 2). Researchers measuring pupil responses to determine cognitive-activity level have tended to focus on individual acts of perception, for example, how the pupil reacts when one views the letter A (Marshall, personal communication, February, 19, 2002). By adjusting the threshold level of the instrument, Marshall has chosen to focus on larger variations in pupil activity so that she can increase the grain size of analysis from the effects of viewing an individual letter to the effects of viewing more complex phenomena. In studies (Marshall, 2001; Marshall, Davis, & Knust, 2001) of U.S. Naval Commanding Officers engaged in tactical decision-making simulations, creating anagrams, or automobile-driving simulation while counting backwards by 3s from 100, Marshall has found that she consistently measures cognitive activity, and that the level of cognitive activity is related to the complexity of the situation. For example, when Naval Commanding Officers, faced with a perceived threat, argued about how best to handle the situation, their cognitive-activity levels increased with the escalation of their argument. Or, when the number of letters in an anagram was increased from three (e.g., make all the words you can in 15 s with the letters in the word *eat*), the cognitive-activity levels of participants increased until they were given a word that was apparently too long for them to consider; at that point, the cognitive-activity levels dropped because the participants reportedly gave up. When participants counted backward by 3s while driving a simulated vehicle, their measures of cognitive activity increased just before they crashed their simulated vehicles. Although we recognize that Marshall's cutting-edge measure of cognitive activity is a measure in search of a well-defined construct, we incorporated this measure into our study as one additional piece of information. When used in conjunction with point-of-gaze data, individual interviews, and stimulated recall, we hope that the measure of cognitive activity will help us better understand how experts, teachers, and prospective teachers process a videoclip of a student interview.

Method

Participants

The participants, all female, were prospective elementary school teachers, practicing teachers, and mathematics educators.

Four prospective teachers (PTs) intending to teach in elementary school participated as novices. The first (PT1) was a high school senior seeking admission to a program leading to a credential program for elementary school teachers. She was completing an Advanced Placement course in calculus. The other three were completing the first of four content courses designed for future elementary school teachers. The focus of this course, called *Number and Number Sense*, was on developing future teachers' understanding of whole and rational numbers and arithmetic operations. PT2 and PT3 were completing their first year of university course work; PT4 was a psychology senior who had decided to become an elementary school teacher.

The four elementary school teachers (T1, T2, T3, and T4) were experienced teachers who were known to project staff because of their active roles in various professional development activities in mathematics. All had been observed teaching mathematics and were considered by project staff to be at least competent teachers. These teachers had taught elementary school between 8 and 24 years, primarily in Grades 4 and 5. T1 had also taught methods courses in mathematics for elementary teachers, and T2 was a coordinator of mathematics for a local school district. Using the Dreyfus and Dreyfus categories, we considered these teachers to be proficient performers.

The remaining two professionals were mathematics education professors at our university. We considered them to be experts in analyzing mathematical teaching and learning episodes. Neither had had involvement in this project beyond this experiment.

Procedure

A videotape of a fifth grader being interviewed by one of our project researchers (R) was shown to each of the 10 participants. Before watching the video in a viewing room, each participant was fitted with equipment used to track point-of-gaze and level of cognitive activity during viewing and each underwent full testing for accuracy of the measures. A staff member of the eyetracking team remained in the room in case equipment needed adjusting. The room adjoining the viewing studio had a one-way mirror, and another member of the eyetracking team coordinated activities with the staff person in the viewing room. At the end of each session, we were given a copy of the video on which a white dot moved across the video showing the participant's point of focus at each moment during the experiment. The individual then was taken to another room where she viewed the video again; this time the white dot showed the tracking of her eye movements. During this second viewing, a researcher from our project team interviewed the participant regarding her reactions to the videotape. At specific times, and also whenever the participant requested, the tape was paused to allow for conversation. A specific 2 min of the video, referred to here as *the critical segment,* was shown again after the full videotape had been shown, and participants were asked to focus more carefully on their own eye movements and tell, if they could, why they had watched a particular part of the screen.

By showing a videotape of a single child interviewed by a researcher, we isolated that to which the participants attended. Furthermore, we interviewed the participants individually to assess what each was thinking rather than to study their reactions during a conversation. This study is an assessment of how mathematics educators, teachers, and prospective teachers viewed a single, staged, learning episode, but it does not indicate how a videoclip might be used to conduct a conversation with a group of prospective teachers, teachers, or researchers.

Each interview was audiotaped and transcribed. The transcriptions were used for this report.

The Videotape

The videotape selected for this experiment was a 40-min interview of a fifth-grade girl. The girl, Terry, was from a middle-class-neighborhood magnet school with communications as its focus. The teacher had selected Terry as someone with “average mathematical ability,” and the girl and her parents had agreed to the interview and to the use of the videotape for project purposes. The girl was poised, pleasant, and cooperative. She appeared to be quite comfortable with the interviewer and the videotaping process. The interview was taped in a studio; two cameras were used so that the final version of the video had a split screen. The top of the screen showed the interviewer (R) and the girl; the bottom half of the screen, called the "work area," showed everything the interviewer and interviewee saw and did on the table—the paper work throughout and the manipulatives used in the third part of the interview. The tape was edited to 22 min for the purpose of the eyetracking experiment. The following is a description of the edited version of the interview.

The videotape had been created to provide viewers opportunities to consider the effectiveness of procedural versus conceptual mathematics lessons, and it was comprised of three parts: an assessment of Terry's fraction knowledge, a procedural lesson, and a conceptual lesson. These three parts are summarized here with some of the questions and answers from each part. In the first part, Terry was asked to circle the larger fraction in a pair or to place an equal sign between two fractions if they were equal. Her knowledge of fractions appeared to be quite weak. For example, when asked to compare 1/7 and 2/7, she chose 1/7 as larger and said that "usually you go down to the smallest number to get the biggest number." When asked to compare 1/2 and 3/10, she chose 1/2 as larger because "I could change the bottom number one more digit and it would be 1." (Fractions were always written by R vertically with a horizontal line between the numerator and denominator.) When asked to find 1/2 plus 1/3, she changed the problem to vertical form (writing 1/3 below 1/2), paused, and said, "Two fifths. This one is complicated, and I'm putting down the number I think could be right." After stating that she knew what improper fractions are, Terry was asked to write 13/6 as a mixed number; she wrote 1 3/6.

In the second part of the interview, R gave an explicit, procedurally oriented lesson on changing mixed numbers (e.g., 5 2/3) to improper fractions (e.g., 17/3) and vice versa. R presented the rule: "Multiply 5 times 3 and add 2"; Terry calculated 17. "And what will the denominator be?" Terry paused, and R told her it would be 3. When then asked to write 4 5/6 as an improper fractions, she paused, used her fingers to count, and finally said, "Twenty-nine sixths. I multiplied 4 times 6, 24, then added 5, equal to 29; 6 is the denominator." She then successfully (albeit slowly) changed 15/2 to 7 1/2. At the end of the procedural segment, R again briefly assessed Terry's understanding. When asked to close her eyes and answer, “Is 1/2 plus 1/2 more than, equal to, or less than a whole?” she responded that “it is less than a whole, because 1/2 is less than a whole number.”

The third part of the interview was a conceptually based lesson during which R used pattern blocks[1] to develop Terry’s understanding of fractions. R placed a yellow hexagon on the work area and told Terry that it represented one whole. She was asked to make a whole using red blocks (trapezoids). She placed two red trapezoids together, long base to long base, but was unsure whether this representation was the “same” as a hexagon until R turned the trapezoids slightly so that they were oriented like the hexagon (see Figure 1). R asked her what she would call the red piece, and she said, “One half.” She then identified the blue piece as one third and the green piece as one sixth, in each case first fitting the pieces together to form a hexagon (see Figure 2). She called the blue piece one third "because it is a whole cut into three pieces” and wrote 1/3 beneath the blue piece, then 1/2 below the red piece and 1/6 below the green piece. Asked for one third, she laid down one blue piece; asked for two thirds, she laid down two blue pieces, asked for three thirds, she was unsure, and R helped her to see it as one whole, 3/3. He then placed three blue blocks together to form a hexagon, and a fourth blue next to the hexagon. After a pause, Terry identified this representation as one and one third. Asked to write this amount as an improper fraction, she decided that it could not be done. (Note that she did not relate this lesson to the previous procedural lesson.) R asked how many thirds she saw, and she then wrote 4/3. After other similar activities, she was asked to make a whole using blocks of different sizes. This task began the critical 2-min segment (actually 2 min and 9 s) identified, at the request of the eyetracking staff, for in-depth analysis of the eye movement of each of the 10 participants.

[1]Pattern blocks are wooden blocks of related shapes. A yellow hexagon can be covered by two red trapezoids, three blue rhombuses, or six green equilateral triangles. The blocks are used in many elementary school classrooms (and in classes for prospective teachers) to assist in the development of understanding of fractions and their relations.

When Terry was asked to make a whole using blocks of different sizes, she used one red, one green, and one blue to form a hexagon (one whole). When asked to write an equation for what she had produced, she wrote, "1/6 + 1/2 + 1/3 = 1." She [T] was asked by R to explain what she had done, as though she were explaining it to a third grader:

T: I took a one-sixth block, then a one-half block, then a one-third block. I put them together. I asked, "Would they be a whole?" And so it equals 1.

R: Look at the three fractions. Which is smallest?

T: One half, because if you change one half just one more digit, it'd be one whole.

R: Now if you look at the blocks, which fraction is the smallest?

T: If I didn't know fractions, I'd say one sixth is the smallest.

R: Okay, act like you don't know fractions. Which is smallest?

T: One sixth.

R: And which is biggest?

T: One-half.

R: And in between?

T: One-third.

At the end of the session R again asked Terry to close her eyes and tell whether 1/2 plus 1/2 was bigger than a whole, equal to a whole, or less than a whole. Terry said it would be less, then she paused, self-corrected, and said, "Oh, it's equal to a whole." Finally R asked the same question about 1/2 plus 1/3, and Terry again responded, with her eyes closed, that it was "less than a whole; you would need a sixth."

Place Figures 1 and 2 about here.

The Eyetracking Information Gathered

In addition to the videotape showing point-of-gaze for each participant, used in the interview immediately after the eyetracking episode, we were later provided with the following data, together with detailed explanations and opportunities to clarify with the eyetracking personnel the meaning of each type of data.

1. Data for the 2-min critical interval were reported for each of five segments (25–30 s in duration). Data for each interval for each participant were converted into gaze traces (25–30 s per page of output); a different color was used to indicate movement during each 5-s interval. Figure 3 is a gaze trace for one of the prospective teachers for one 30-s interval. The upper-right part of the screen showed Terry, and the upper left showed R. The work space was shown in the bottom half of the screen. Interpretation of the figure is difficult for the reader, because the movements are shown in shades of gray instead of in the original colors. However, this figure clearly shows that during this interval the individual was looking at the work space for much of the time.

Place Figure 3 about here.

----

2. We also received, for each of the five 25–30 s intervals during the 2-min critical interval, graphs (see Figures 4, 5, and 6) indicating the relative amounts of time each group watched the interviewer, the child being interviewed, and the work space. Note that each graph in these figures has been scaled to show the comparison across the three groups' attention to each component of the video (child, interviewer, work area).

Place Figures 4, 5, and 6 about here.

----

3. The pupil-dilation information provided estimates of the cognitive activity of the participant while she watched the video. Using her (Marshall, 1998) proprietary techniques, Marshall derived estimates of each participant's level of cognitive activity throughout the watching of the video. The level of cognitive activity was indicative of the complexity of the situation for the viewer. For each individual we received a graph showing the person's cognitive-activity level for each 30-s interval during the full 22-min video observation. (See in Figures 7, 8, and 9 graphs indicating averages of levels of cognitive activity for each group. These graphs are discussed later.) The vertical scale is a measure of cognitive activity (categorized as low, medium, or high) during the 30-s interval. In addition, averages were calculated and graphed for each of the three groups and for the entire group. The horizontal scale is in number-of-30-s-intervals in the entire video.

Place Figures 7, 8, and 9 about here.

To make sense of these data, we then divided the entire video into 30-s intervals and documented what was happening in the interview during each interval. Table 1 provides an example of this type of documentation.

Place Table 1 about here.

----

4. We charted the level of cognitive function for each participant during each 30-s interval and then used these data to determine the cognitive-activity-level comparison of the three groups over the entire video. Figure 10 shows these comparative data.

Place Figure 10 about here.

The results are described in two sections. The first deals with the interviews of participants while each watched the video that had been made during the individual's first viewing of the video. The videos were identical except for the moving white spot that indicated where the individual was looking at all times during the first viewing of the video. The second section deals with what we found from our study of the eyetracking data.

Interviews During the Second Viewing of the Video

Each participant watched the entire video twice and the 2-min critical episode three times. During the first viewing, each participant watched the entire interview while her point-of-gaze was tracked and recorded on a copy of the video. After watching the video, each participant met with an interviewer who gathered some information about the participant and allowed the participant to provide initial reactions to the videotape. During the second viewing, the participant and interviewer watched the copy of the video that showed the white dot tracking the participant's point-of-gaze throughout her initial viewing of the video. We asked the same questions of each participant. The participant was encouraged to comment on the video at any time, and we paused the video for comments. After each major section of the videotaped interview, we stopped the tape and asked for the participant's reaction. Then the 2-min critical episode earlier selected for special data collection was shown again, and participants were asked to comment particularly about their points-of-gaze in terms of what they remembered thinking about at the time. In this section we consider the participants' reactions to the video.

Initial Reactions to the Videotape

This first section reports comments made by participants immediately after their first viewing but before beginning their second viewing, at which time the participants rewatched the video with the interviewer.

Mathematics educators. Both mathematics educators (MEs) made initial comments on the structure of the interview, on expectations, and on technological aspects of the videotape. For example, ME1, when preparing to be eyetracked, asked for what she was expected to watch. She said, “I usually think about why I’m watching a videotape. Is it because I want to learn to be a better interviewer? Is it because I want to learn about kids’ strategies?” (Interviewer: "But you weren’t given any directions, so did you set a purpose for yourself?") “No, but when I don’t have a purpose, I’m most intrigued by the kids’ strategies and what they understand. But in the back of my mind, I’m ready to listen to the interviewer and say, ‘That’s a good question.’” ME2, for whom technology is an area of expertise, was particularly interested in the technological aspects. She commented that the “editing was actually quite well done except for one part where there was a division left on the screen” and that she liked the split-screen technique.

Teachers (Ts). When T1 was asked for her first reaction, it was “Let me have that kid;” then later, “I didn’t see her knowledge, her real understanding, conceptual understanding, much beyond that of a first grader. And she clung to her previous beliefs unless she was pushed….a lot of damage with procedural understanding and definitions.” But the teachers were very aware of the conceptual problems children have with fractions. They tried to understand Terry’s thinking, but sometimes found it difficult to follow. When asked whether there were any surprises, T3 said that she was surprised that Terry, at the end of the interview, continued to say that two halves were less than a whole and that at the end she still, at one point, said that 1/6 was the biggest fraction, given blocks representing 1/2, 1/3, and 1/6.

All teachers commented on Terry’s confidence and poise. T2 thought that her being so confident in her misconceptions was frightening: “She spoke like a very confident child, and she’s obviously had much success in her schooling. You could just tell by the way she articulated her responses to R’s requests.” T3 was less certain that she was confident but noted that she was comfortable working with an adult.

Prospective teachers. The prospective teachers had few comments to make after their first viewing of the videotape. One mentioned Terry’s confidence: “Even when she didn’t know what she was doing, she was like, okay, and like, write something down. She never was like, ‘I don’t know.’ You know?” Another said, “I really liked her thinking. If I hadn’t known the answers beforehand, . . . I think her thought processes were really clear, but sometimes I didn’t think she. . . . She was just going off what was already given to her.”

Summary of initial reactions

The responses of members within each of the three groups, mathematics educators, teachers, and prospective teachers, reflected the participants' knowledge bases, experiences, and responsibilities. Mathematics educators, for whom one-on-one, in-depth interviews of children are common, immediately focused upon the purposes and structure of the interview. Teachers and prospective teachers did not question the purposes, possibly because considering an in-depth, one-on-one interview about a child’s thinking about mathematics was not a common situation, and so they had little prior experience from which to draw. This difference in experience with the interview setting is relevant to the data on the respective group's cognitive functioning.

Teachers come with expertise different from other participants; teachers understand children. However, this understanding often does not relate specifically to children’s understanding of mathematics. Teachers made comments about Terry’s demeanor. They understood that Terry, although confused about fractions, was an intelligent and articulate child. The teachers were, though, a bit confused about how Terry was thinking.

The prospective teachers came with little expertise with which to interpret this learning episode, and their initial comments were very general.

Reactions to Assessment Section

Mathematics educators. The mathematics educators were not surprised by Terry’s poor performance, but they realized that her knowledge of fractions was very weak, considering that she was in fifth grade.

> [Terry] did not have a very strong understanding about fractions. She has misconceptions. The basic one is probably that all fractions are less than a whole. Whenever she tried to understand anything about fractions, it's through some procedural way of changing numbers to make it closer to 1. She doesn't understand what she is doing. She has no imagery for fractional quantities. (ME1)

ME2 wondered why Terry thought that 1/7 was more than 2/7 "'because you can get it closer to 1?'. . . [For Terry] it's just a conglomeration of four numbers."

From their own experiences, they thought that their own students (prospective teachers) would find some of the questions unfair. "[My prospective teachers] often pick up on the nuances of the interviewer's questions, and say, 'That was a trick question' or 'she didn't understand' and 'it's not the student's fault'" (ME1).

Teachers. For the most part, the teachers were not surprised by Terry's responses to the assessment questions. They thought that Terry should know more about fractions than she did but that the errors she made were typical. For example, T3 said that children "tend to choose the fraction that has the larger number in the denominator as the larger—they see bigger numbers; they automatically think greater value." But Terry's responses to some comparisons, such as "I could change the bottom number one more digit and it would be 1," stymied the teachers. T1 said, "Maybe she had some idea that 1 over 1 was another way to say *whole*, but I couldn't make sense of her explanation. She hung onto the idea of the 1. That was one solid idea that she had." Other teachers also commented on this point. T3 said, "She had all this rhetoric that she was quoting back to him about 'one digit less makes it a whole number,' and so she'd obviously heard instruction things before and didn't have a clue as to how they were related."

Teachers also noted that some of the ways that R wrote on the paper could have been confusing. For example, T4 commented, "There's a lot of numbers on that paper, and the wrong answer—that's right next to where you're showing her how to do the problem. I would have either crossed out some of those wrong answers or gotten a clean sheet of paper, so that she didn't have so many other things to focus on."

Prospective teachers. All appeared to be at least somewhat surprised by how weak Terry's knowledge of fractions was, but they were careful not to fault her. PT1 said, "It looked like she had not learned it yet, but considering if she had not learned that, she was doing pretty good." PT2's reaction was similar: "She may have been introduced to it, but not enough to remember." Some of their comments reflected their own limited knowledge of teaching and learning, such as this comment from PT4: "I was thinking that if she knew what a mixed number and improper fraction were, she'd have some little clue on how to do it. They teach it to you and if you know it, then you basically know how to do it too."

Summary of reactions to assessment section

The mathematics educators provided detailed comments about Terry's understanding during the assessment stage. They could make sense of Terry's thinking, and they were able to see the world that Terry was seeing. The teachers had some insights into Terry's thinking, but these insights were not as sophisticated as the mathematics educators'. Their interpretations of Terry's comments tended to be more literal than the mathematics educators' interpretations, most likely because the teachers had no way to make sense of some of what Terry said and did. They also focused more on what Terry was *doing* whereas the mathematics educators seemed to focus on what Terry was *thinking*. The teachers commented on the relationship between what the interviewer did and what Terry did, indicating that for them a major focus was on the teaching aspects of the episode.

The prospective teachers again were in no position to provide detailed comments on Terry's actions. The prospective teachers, like the mathematics educators, did not comment on the instruction, but unlike the mathematics educators, who commented extensively about the learning, the prospective teachers had little to offer about the session. They showed their naiveté about teaching and learning when they expressed the view that Terry's failure to understand some aspect of fractions must result from her not having been exposed to that content. This view is one mathematics educators and teachers almost never assume, because they have seen many cases of children who have made little or no sense of what their teachers thought that they had taught.

Reactions to Procedural Lesson

Mathematics educators. ME2 thought that the interview demonstrated the chasm between what teachers think they are teaching and what is being learned. Children like Terry learn that mathematics is a set of rules completely separated from any real-world application. “[The interview] reinforces the notion that just because we teach a procedure doesn’t mean students understood it or could repeat it." ME1 explained that she found value in the fact that the interview showed that Terry easily adopted the procedures "without a clue as to what they meant" and that she held on to her misconceptions, as was indicated in her answers. She thought that placing this procedural-lesson segment in the interview was “a smart thing” to do.

Teachers. Teachers hypothesized about the kind of teaching Terry had experienced. T1 said

> It’s probably the kind of teaching that she’s had, what she’s comfortable with. And it seems that she’s still operating on the numbers but not with any sense making to it, and the evidence for that is when she called it "seven twos" instead of seven halves, and that’s what she’s comfortable with. She’s confident. You do things to numbers and change them around, but they’re only fractions because that little line is there.

The teachers realized that Terry needed something concrete to help her understand fractions as quantities: “At some point here I was thinking, 'We need to get the manipulatives out, because she needs to visualize what halves and sixths and things are. She needs to go all the way back to the beginning of what is a half'” (T3). Both T2 and T3 commented on her lack of sense making.

Prospective teachers. Some of these interviewees indicated that they had particular ways of doing things that made understanding Terry’s thinking difficult for them. For example, PT3 said, “I’m trying to figure out why she would choose one half, because I’m so used to, well, I was converting it to decimals, like three tenths was point three and one half was point five." There was also a tendency on the part of these four to excuse Terry for her weak knowledge base. PT4 said, "I don't remember what I knew about fractions in the fifth grade. I don't think I knew much about fractions then. I was impressed with her." And at another time, "She made pretty good guesses for not knowing what she was doing." "I probably noticed her slowness with some of the numbers. It maybe would have been better if she had written out the process as she was going along. Write down the 3 times 4 plus the 5 over the 6" (PT1).

Summary of reactions to procedural lesson

The mathematics educators noted many connections among teaching, learning, and mathematics. They observed that the view reflected in the procedural section was of mathematics as procedures unrelated to the real world. They observed that Terry learned the conversion procedure without making sense of it, and they drew connections to what they have seen in some classrooms.

The teachers commented almost exclusively on the teaching and implications for teaching. They hypothesized about the kind of teaching Terry had received in the past. They noted that Terry needed a different kind of instruction to help her, and they suggested what that instruction might be. In contrast, the prospective teachers focused almost entirely on the learning by placing themselves in the position of the learner. They talked about how they thought about the tasks, and they noted how viewing the tasks from their own points of view made following Terry's thinking difficult.

Reactions to Conceptual Lesson

Mathematics educators. ME2 recognized that Terry's knowledge was still very fragile at the end of the lesson and thought that Terry was beginning to feel some conflict: "In fact, she called it 'I'm pretending whether I know fractions or whether I don't.' That is how she handles the conflict. Obviously she's recognizing that her old way failed her." ME1 did not think that this lesson helped Terry see any connection between the blocks used in the conceptual lesson and the procedures from the earlier lesson.

All participants were asked whether R should have explicitly linked the request, made in this section, to change 4/3 to an improper fraction with what he had taught in the procedural lesson. Neither mathematics educator thought that such a link would have been appropriate. ME1 said

> In terms of helping her, I don't think I would have gone back to the procedural way because that would have confused things even more. . . . I'm not convinced that she really understands how the symbols relate to this—how the improper fractions relate to this. I think by having her follow a procedure, it would stop her from making sense of all this, which is what she's sort of starting to do here. I think it would have been too soon.

ME2's response was similar in that she did not think that Terry yet really understood the connection between improper fractions and mixed numbers:

> He doesn't push her to really justify. Again, she almost looks surprised when he says, 'Are these the same?' I still don't think that she thinks that an improper fraction and mixed number have to, quote unquote, be the same, or have a common reference [unit] that they both describe.

These educators also commented on the use of manipulatives. ME1 noted the limitations of using pattern blocks to represent fractions:

> When I think about using the pattern blocks like that, I'm also aware of the limitations in terms of the fractions that aren't represented and wonder how that transfers. . . . I wonder if it would play a limiting role later on whereas here, it clearly played an enabling role to help her understand some of these things. . . . But I'm not convinced about what she really understands about fractions in terms of relating them to a whole other than a hexagon.

ME2 reflected similarly about the blocks:

> Obviously working with the manipulatives can reinforce the ideas, but they can be a completely different world. There's another world, which is really a quantitative understanding . . . looking at the fractions as a top number and a bottom number as opposed to a quantity that represents a part of a whole. . . . [If giving] names to the blocks is becoming the quantitative descriptions of the blocks to be then linked to the procedure, it's got to be done carefully. I mean, this is a big gripe I have with transfer studies. They say, 'Oh well, it didn't transfer.' Well, of course not, if you don't make the link [clear].

The mathematics educators commented on R's questioning. ME1 explained why she liked the way R phrased his question "Can we write that [sum of unit fractions] as 2/6 + 2/3 = 1?":

> By phrasing it that way, I think it allowed her to explain why she thought that was an okay thing to do. It's impressive to see her thinking of these pieces in her head now when he asks her to close her eyes and visualize it, which she wasn't doing before.

Teachers. Teachers were dismayed that even after her work with pattern blocks, Terry still responded initially that 1/2 plus 1/2 was less than 1. "She wasn't convinced even though they had done all that work [with blocks]. Then when prompted to push forward, to visualize the pieces, she's got something to grab onto, but that one experience wasn't enough to undo the damage" (T1). They were also surprised that she had difficulty naming three thirds and four thirds, after successfully naming one third and two thirds. They could see that she was struggling to accommodate the new and contradictory information she was being exposed to. T2 said, "She has all her misconceptions now, and she's really struggling because R's really shifted her paradigm a little bit, but she's still not there yet. She's really in disequilibrium. She's not too sure what's going on."

When asked, none of the teachers thought that when Terry was unable to change 4/3 to a mixed number, R should have reminded her about the rules she had learned in the previous lesson on converting improper fractions to mixed numbers. Their responses to this question were reflected in T1's response: “That’s the problem—that she’s had only procedural instruction—so I would want her to put that completely aside and just be visualizing . . . . She’s still too tenuous to throw the procedure back in.” The teachers recognized small incidents as telling. For example, both T1 and T2 noticed that Terry saw that two red trapezoids had the same shape as one yellow hexagon only after R had silently turned the red blocks so that the orientation was the same for the yellow block and the red blocks (see Figure 1). One of these teachers also noticed that Terry said *six* instead of *sixth,* that she was calling the green piece *one over six*, not *one-sixth*. T4 noticed that Terry never used the word *equal,* even though R used the word and equality was a key concept in understanding fractions.

Prospective teachers. When asked for comments on the conceptual lesson, the prospective teachers had little to say. One (PT3) said

> I think the blocks helped her to visualize and really understand, because when you asked her a half and a half, her first instinct was to say that this was not equal to a whole, but when she thought about it and could re-see in her mind the blocks, she understood it.

She later said, “I think it was good that you allowed her to see things first, and you didn’t contradict her and tell her, ‘No that was wrong,’ and [you] let her see it for herself."

Prospective teachers responded differently from mathematics educators and teachers to the question about returning to the conversion procedure taught in the procedural lesson when Terry could not convert 4/3 to a mixed number in the conceptual lesson. PT1 thought that R should probably have referred to the procedure, "because you’re not always going to have those blocks with you, so you have to learn how to write it down on paper and show your work or else you have to learn how to do it mentally.” PT3 noticed this lack of association without being asked:

PT3: I thought it was kind of funny, because you asked her to convert into an improper fraction, and she seemingly had learned that in an earlier segment of the video. . . . She couldn’t remember how to do it because she was trying to think of it in terms of the blocks and not the formula.

I: Do you think it would have been better if R had asked her to use the procedure she had learned earlier?

PT3: Probably, so she could see an association with how it’s all related to fractions. . . . It’s not like "because you’re working with blocks, this is how you do it."

PT4 thought that R should have helped T draw connections between this conceptual lesson and the previous procedural lesson.

Summary of reactions to the conceptual lesson

Again, the mathematics educators provided highly nuanced and detailed descriptions of this session. They recognized both the benefits and the limitations of using the manipulatives. They thought that Terry had made few connections and that her understanding was still fragile. They also noted more probing questions the interviewer might have posed at some points in the lessons.

Like the mathematics educators, the teachers noted that Terry had yet to make many connections and thought that to connect the procedural lesson to the conceptual lesson would be a mistake. However, they expected more than the mathematics educators expected from Terry by the end of the interview and were disappointed by how little Terry learned from the conceptual lesson. The teachers also focused on fine details about the instruction, pointing out, for example, how the interviewer placed the blocks.

The prospective teachers again were at a loss to make much sense of the session. They made general comments about the blocks' helping Terry. They thought that the interviewer would have helped Terry by making explicit the connection between the conceptual and procedural lessons, a connection that both the mathematics educators and the teachers thought would only have created more confusion for Terry.

We also asked participants to compare the procedural and conceptual lessons. Whereas the mathematics educators and the teachers spoke elaborately of the differences, the prospective teachers' responses showed that they saw differences, but only in vague ways. PT3 said, "[The last lesson] was more conceptual, I guess, visual. The other one was more math, as long as you knew how to do your math." PT2's response was similar: "Part 2 [the procedural lesson] was kind of like more information, like putting pictures into words. Part 3 was more conceptual, and it taught her how to grasp the numbers."

Point-of-Gaze Information From Critical 2 Minutes

Overall, the participants had little to say about their points-of-gaze while they watched the video. ME2 remarked (while Terry was working on 1/2 + 1/3), "I'm watching. . . . Is she using her fingers? I find myself [while rewatching] looking at the same place I did then [when being eyetracked]. It's kind of funny." T4 did not talk about her eye movement during the critical 2-min interview, but she earlier had remarked, "I move my eyes a lot. Is that typical? I didn't realize I was moving my eyes so much." Prospective teachers reacted, as one would expect, from their particular backgrounds and vantage points. PT1, who had not yet begun a university program, had fewer reference points from which to consider the actions of the student and the interviewer. The other prospective teachers often referred to what they had learned or were learning in their mathematics content classes and how that content related to the video they had watched.

What We Learned From the Eyetracking Data

The point-of-gaze information for the special 2-min segment showed that all participants watched the work area most (see Figure 6), watched the student less (see Figure 5), and watched the researcher least (see Figure 4) during that segment. This result highlights the major role the pattern blocks played during the interaction between the researcher and Terry. However, important differences emerged during further analysis of the eyetracking data. Although for all three groups, the researcher was the least watched element of the video, the teachers viewed the researcher twice as much as the MEs and about 25% more than the PSTs. This result confirms the interview data that show that the teachers were most interested in thinking about the instruction in the videoclip and in instructional issues generally. During the special 2-min segment, the researchers watched the student one third of the time, 40% more time than the teachers watched her and 70% more time than the PSTs watched her. This result confirms the finding from the interview data: The researchers were most interested in understanding how the student was thinking.

The prospective teachers spent 60%–75% of their initial viewing time looking at the work area. All four prospective teachers looked at the work area (and sometimes at R or Terry) during nearly every 5-s interval of this time period. They seemed to spend much of their time mentally deciding the answers to the problems posed to Terry so that they would know whether she was solving them correctly: “I think during this time I was probably trying to answer the questions in my head . . . and trying to see if it would match hers” (PT3). We conjecture that the PSTs' need to work each problem for themselves and their inability to work the problems quickly partially explain their focus on the work area.

Differences in Cognitive-Activity Levels

Levels of cognitive activity varied during observation of the videos, both within and among members of each group, as indicated on the cognitive-activity-level graphs developed by the eyetracking staff (see Figures 7, 8, and 9 for grouped data). We briefly describe the data on individuals then compare group reactions to a particular set of problems posed and Terry’s responses to the problems.

Mathematics educators. Both mathematics educators registered low cognitive-activity levels throughout the video.

Teachers. At the time of the eyetracking-data collection, we learned that one teacher (T2) had a detached retina, and we thus do not use her data. T1’s index of cognitive activity ranged from low to moderate; T3's was moderate to high; and T4's level was mostly in the low range, with some moderate activity in the last half of the viewing.

Prospective teachers. PT1's level of cognitive activity was in the low range during most of the interview, with highest peaks (in the moderate range) during the critical 2-min interval. PT2's cognitive activity registered consistently in the moderate range, with five of the forty-four 30-s periods in the high range and four in the low range. PT3 registered in the low range during most of the interview viewing, reaching a moderate level nine times during the forty-four 30-s intervals. PT4 alternated somewhat between low and moderate levels. The graphs for PT2, PT3, and PT4 did not show differences for the critical 2-min interval.

Comparing the Groups

The eyetracking staff produced a graph comparing the levels of cognitive activity across groups (see Figure 10). The three groups had significantly different levels of cognitive functioning, $F(2, 43) = 106.05$, $p < .05$, and each group's level was significantly different from the levels of the other two groups. The mathematics educators registered the lowest cognitive-activity levels, followed by the prospective teachers, with the teachers registering the highest levels of the three groups. Upon reflection, and after analyzing interview protocols, we speculate that the mathematics educators had the lowest cognitive-activity levels because they found little, if anything, surprising or complex in the interview. Both had undertaken many such interviews themselves and had viewed many interviews similar to this one. Terry's responses, although for the most part not indicative of all fifth-grade students, were similar to other responses they had witnessed. The teachers, however, have little opportunity to see one-on-one interviews with children. Also, they have developed expectations built on their own experiences. Each of the teachers has a strong interest in mathematics learning and thus found this video interview interesting, causing each to reflect on what she was seeing while viewing the interview for the first time. The prospective teachers lacked knowledge needed to interpret the interaction in the interview. They did, however, appear to attend to the problems being given to Terry, working them out so that they could make sense of her responses.

To investigate further our hypothesized explanation for the groups' relative activity levels, we studied a series of the problems posed to Terry. We were interested in cases in which a problem (e.g., 1/2 + 1/3) was posed in one 30-s interval and the response spanned the following one or two 30-s intervals. In analyzing these cases, we could consider differences in cognitive functioning for the problem posed and the problem solved. Using these criteria, we found one such problem sequence in the assessment portion of the video, four sequences in the procedural-instruction portion, and three in the more conceptually oriented instruction during which R used pattern blocks to help Terry visualize the relative sizes of the unit fractions being used. In this analysis, we were interested not in the degree of cognitive activity but in whether the level of activity increased, decreased, or stayed the same. To analyze change in activity level during the sequence, we used graphs of average cognitive-activity level of the teachers and of the prospective teachers (see Figures 8 and 9). Because few changes were noted for the mathematics educators, we analyzed the data only for teachers and prospective teachers. In Table 2 we describe the eight problem segments and indicate whether the teachers' and prospective teachers' levels of cognitive functioning increased (positive slope), decreased (negative slope), or remained the same (zero slope) from the posing of the problem in one segment to the response in the following one or two segments. Two responses spanned two 30-s intervals; in these cases two changes of slope are indicated. In the cases in which the response occurred in one 30-s interval, one change in slope is indicated. We then compared the slopes for the two groups.

Place Table 2 about here.

Generally speaking, in problems from Parts 1 and 2 of the video, the cognitive-activity levels of prospective teachers increased when they attended to solving the problem. After they had solved the problem, their levels decreased, indicating that they were not attending as much to the child's response as to the problem posed. For example, the prospective teachers' level of cognitive activity in Intervals 9–11 and 21–23 increased between the first two intervals, indicating that they were cognitively engaged in the problems. But between the last two intervals, their cognitive-functioning measures decreased, indicating that they were less engaged in the child's answer. The cognitive-activity measures for the teachers show a different pattern. The teachers were more engaged in the child's solution than in the problem posed. This finding is particularly evident in the two segments that span three 30-s intervals each, Intervals 9–11 and 19–21.

The changes in cognitive-activity levels of teachers and of prospective teachers were similar for the problems in Part 3. The pattern-blocks representation facilitated visualization of these problems, and we speculate that the prospective teachers did not need to work at solving the problems for themselves. Thus, once the problem had been posed, their cognitive-activity levels decreased. However, the cognitive activity of the teachers also decreased between problem posing and problem response. This surprising result may have occurred because to the teachers these responses were not as unusual or surprising as were the responses in the first four problems. Another possible explanation is that the degree of cognitive activity, measured by this index, is related to the complexity of the task (Marshall, personal communication, February 2002). That is, for the prospective teachers, the problems presented were more complex than the students' responses, whereas the opposite was true for the teachers.

We realize that the data shown in Table 2 are not refined; slopes are indicated only as positive, negative, or unchanged. No values are attached to slopes. However, these data provide one more support for the hypothesis that the prospective teachers were more attentive to the problems introduced by the researcher than to the responses provided by Terry.

Summary and Discussion

The university mathematics educators acted in ways one would expect experts to act. They responded effortlessly to the interview situation, as is evident in the cognitive-activity graphs of each individual and in the composite graphs of the two individuals. Nothing in the video interview surprised them; their levels of cognitive functioning remained in the low range throughout. They agreed that the procedural lesson should confirm, for most viewers, the ineffectiveness of this type of instruction. Both were aware of the limitations of the pattern blocks as an instructional aid. Both commented on the interviewer’s skill at questioning. The attention of one of these experts was at times drawn to the technological aspects of the experiment and to the smoothness of the editing. The other mathematics educator was a more experienced interviewer, and her point-of-gaze data showed that she focused almost all her attention on Terry. She commented that she was most interested in Terry’s responses, both verbal and nonverbal. During our discussions of these data, we realized that having the interviewer on the screen may have been an unnecessary distraction to the teachers and prospective teachers, who spent considerably more time than the mathematics educators spent looking at R. On the basis of this information, we decided to exclude the interviewer from videoclips when we want viewers to focus on the content and the child. However, we note that to understand the context of a learning episode, at times prospective teachers and teachers may benefit from seeing both the interviewer and the child, and we urge those producing videos to consider the different purposes for videotapes before deciding whether to show the interviewer.

The teachers' cognitive-activity measures, which were primarily in the moderate range, were considerably higher than those of the professional mathematics educators. Only one teacher's graph (not shown here) showed cognitive-activity measures in the moderate to high ranges. On the one hand, we think that this finding supports the position that viewing interviews may be a rich experience for mathematics educators, but it may not be a particularly complex task for them. On the other hand, we think that teachers find the activity more challenging, and they may need additional support to help them refocus their attention toward the child’s thinking. The levels of the PSTs’ measures of cognitive activity were between the MEs' and the teachers' levels, but their focus was on aspects of the learning episode different from the foci of the other two groups. We conclude that for people, such as prospective teaches, who have no experience either studying learning episodes or teaching students, viewing videoclips may initially be only as complex as the mathematical challenge provided to the viewer.

As shown in their interviews, the teachers realized what an average fifth grader should know about fractions. They recognized Terry’s answers as typical responses of a student with poor understanding of fractions, and they tried to understand the underlying misconceptions Terry had, knowing that those misconceptions would need to be overcome for Terry to progress. But they expected the work with the pattern blocks to be more effective than it was. Realizing that the procedural lesson was focused on Terry's following rules she did not understand, the teachers all recognized the futility of expecting work in that lesson to be useful to Terry during the conceptual lesson, They were attentive to language, such as Terry’s reference to a green block as one *six* instead of one *sixth.*

We considered the teachers to be experts, but in a way different from the professional mathematics educators. The teachers’ access to their own knowledge of the mathematics underlying R’s questions, their interest in Terry’s responses (compared to the prospective teachers' greater interest in the problems posed than in responses), and their abilities to understand and interpret the various parts of the interview were qualitatively different from those of the prospective teachers.

The prospective teachers did express some surprise at Terry’s lack of understanding of fractions, but they thought that she had probably not yet learned about fractions. They had their own ways of solving the problems posed to Terry and consequently found her answers hard to follow. They noticed that in the procedural lesson Terry had been taught to convert mixed numbers to improper fractions but that Terry did not use this knowledge later in the interview, and they wondered why. They suggested that R should have helped Terry make this connection, contrary to what the teachers said about this issue. The three prospective teachers who had had experience using pattern blocks preferred the conceptual lesson and thought that it would be helpful for other prospective teachers to see this part of the lesson. The fourth preferred the procedural lesson.

Thus, the reactions of the prospective teachers were, in most respects, quite different from those of the teachers. The prospective teachers could accurately be classified as novices. As in the Livingstone and Borko study (1990), they had different knowledge structures and processed information differently. They spent a large percentage of their viewing time looking at the work area, and even when they looked at the interviewer or the child, their observations seemed to be designed to support their understanding of the mathematical content of the questions instead of to focus on Terry's verbal and nonverbal behavior.

What did we learn from this study? The data from this study have led us to believe that there are experiences we can provide for prospective teachers to help them refine their knowledge of what children know, change their expectations of what children should be able to do, and enhance their abilities to observe and make sense of children's responses to mathematics problems. Thus a major implication from this study is that we must pay careful attention to how we use videos with prospective teachers. For them to benefit from viewing a video in the manner intended, particular care must be given to the selection of the video and to the preparation for the viewing. The prospective teachers in this study initially focused almost exclusively on solving the mathematics problems themselves; thus if we want them to focus on the children's thinking about the mathematics problems, we must first provide them opportunities to work through the mathematics. For example, before showing prospective teachers a videotape of fourth-grade children generalizing a formula for the sum of the first n natural numbers, we should first ask them to work through the activity so that might better understand the children's reasoning in the video.

However, simply solving the mathematics problem in a video may not be sufficient preparation if the child's solution in the video does not model a prospective teacher's thinking; thus we might need to help prospective teachers anticipate the kinds of solutions children might provide. For example, most prospective teachers know how to solve the problem "How many cars are needed to transport 20 children on a field trip if each car could hold 4 children?" but few are prepared to pay attention to whether a child thinks of this problem as quotitive division (How many groups can be formed if we split the 20 into groups of size 4?) or a partitive division problem (What is the size of each group if we split the 20 into 4 equal groups?). We need also to pay attention to the tools used in a video, so that, for example, before showing prospective teachers a video of a child using a hundreds chart, we would acquaint them with the hundreds chart and even help them consider ways the chart might be used. These considerations are guiding our ongoing work with prospective teachers in this project.

Do these results apply to teachers as well? Not exactly. We recognize that the teachers' reactions to the video interview were heavily influenced by their many years of experience in the classroom, working with students like Terry. They had knowledge of the mathematics appropriate for this grade level, and they had expectations that helped them evaluate Terry's mathematical knowledge. We think that teachers, like prospective teachers, should have opportunities to work through the mathematics before they view a videoclip. Although for teachers to approach videoclips of learning episodes from their points of view as teachers is natural, we believe that redirecting their attention toward deeper issues of children's mathematical learning is advantageous. Because teachers might need help in identifying and understanding some of these issues, we make two suggestions. First, we suggest that excluding the interviewer from the videoclip is important for teachers, perhaps even more important than for PSTs. Second, we suggest asking teachers who are watching videoclips questions to redirect their attention from what the interviewer should do to how the child might be thinking.

We have come to believe that preparing for, watching, and discussing videos that illustrate students' thinking can change the knowledge structures of prospective teachers and practicing teachers, the manner in which they process and interpret student answers, and the ways they make decisions about what next steps should be taken. Such activities may help PSTs move, in the words of Saber et al. (1991), from being novices to being advanced beginners and thus more likely to succeed in teaching and to take less time becoming experts. Furthermore, although this process may appear, at first glance, contrary to how teachers perceive their roles, we believe that in the long run, focusing upon children's mathematical thinking cannot help but be beneficial to both teachers and prospective teachers.

References

Chi, M., Feltovitch, P., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science, 5,* 121–152.

Borko, H., & Livingston, C. (1989). Cognition and improvisation: Differences in mathematics instruction by expert and novice teachers. *American Educational Research Journal, 26,* 473–498.

Dreyfus, H. L., & Dreyfus, S. E. (1986). *Mind over machine.* New York: The Free Press.

Larkin, J., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Expert and novice performance in solving physics problems. *Science,* New Series, *208*, (4450), 1335-1342.

Livingston, C., & Borko, H. (1990). High school mathematics review lessons: Expert-novice distinctions. *Journal for Research in Mathematics Education, 21,* 372-387.

Marshall, S. P. (1998). *Cognitive workload and point of gaze: A re-analysis of the DSS directed-question data.* Technical Report CERF 98-03. San Diego: Cognitive Ergonomics Research Facility, San Diego State University.

Mulligan, J. B. (1997). Image processing for improved eyetracking accuracy. *Behavior Research Methods, Instruments, & Computers, 29,* 54-65.

Sabers, D. S., Cushing, K. S., & Berliner, D. C. (1991). Differences among teachers in a task characterized by simultaneity, multidimensionality, and immediacy. *American Educational Research Journal, 28,* 63–88.

Sternberg, R. J. (1999). *Cognitive Psychology*. Fort Worth: Harcourt Brace.

Table 1

Example of Event Data for a 2.5-Min Segment (in 30-s Periods)

Time (minutes)	Period	Video events
17:30-18:00	36	R asks T to write the amount for five reds, four of which are placed together to show two wholes; she writes 2 1/2. Asked to write this number as an improper fraction, she writes 5/2. She explains, "There are five pieces, all halves, so I made the bottom number half."
18:00-18:30	37	T is asked to make a whole using pieces of different sizes. She uses one red, one green, and one blue to make a whole
18:30-19:00	38	R asks T whether she can write an equation for the event in Period 37. She writes 1/6 + 1/2 + 1/3 = 1. He asks her to explain her answer to him as though he were a third grader.
19:00-19:30	39	Terry says, "I took 1 sixth block, then 1 half block, then 1 third block. I put them together. I ask, 'Would they be a whole?' and so it equals 1."
19:30-20:00	40	R asks T to look at the three fractions and asks, "Which is smallest?" She says, "One half, because if you change one half just one more digit, it'd be one whole." He asks which is smallest "if you didn't know fractions?" Terry says, "I'd probably say one sixth" is smallest.

Table 2

Cognitive-Activity-Index-Slope Changes From One Segment to Another, for a Set of Problems Given to Terry

Section of video	Segment number and content	Cognitive-activity-index slope	
		PTs	Ts
Part 1: Assessment	9. Asked to find $\frac{1}{2} + \frac{1}{3}$		
	10. Rewrite to vertical form, writes $\frac{2}{3}$	+	--
	11. "Complicated" when questioned about answer	--	+
Part 2: Procedural instruction	11. Given $5\frac{2}{3}$; change to improper fraction		
	12. Pauses, writes $5\frac{3}{2}$	+	+
	17. Asked to convert $4\frac{5}{6}$ to improper fraction		
	18. Correctly follows procedure, writes $\frac{29}{6}$	+	+
	19. Asked to change $3\frac{1}{2}$ to improper fraction		
	20. Writes $\frac{7}{2}$. Explains that denominator is important	0	--
	21. "Important one times other then add one"	--	+
	22. Is $\frac{1}{2} + \frac{1}{2}$ more than, less than, or equal to 1?		

	23. "Less than whole because $\frac{1}{2}$ is less than a whole number.	+	--
Part 3: Instruction using pattern blocks	24. Using reds, make a whole		
	25. Terry does so, after R aligns the tops of the whole made of reds and the yellow whole horizontally	--	--
	38. Asked to write an equation for one green and one red plus one blue makes a whole		
	39. T. writes $\frac{1}{6} + \frac{1}{2} + \frac{1}{3} = 1$	--	--
	42. Shown 2 greens, 2 blues; says $\frac{1}{6} + \frac{1}{6} + \frac{1}{3} + \frac{1}{3} = 1$. Is asked which fraction is the smallest		
	43 "One sixth"	--	--

Figure Captions

Figure 1. The interviewer's movement of blocks to establish sameness.

Figure 2. Terry's placement of blue blocks and green blocks to show congruence with the yellow hexagon, the whole.

Figure 3. Example of eye movements of a prospective teacher during a 30-s interval. Terry is shown on the upper-right of the screen, R on the upper-left, and the work area across the bottom half of the screen.

Figure 4. Average percentage of time, during each interval in the 2-min critical period, participants watched the researcher.

Figure 5. Average percentage of time, during each interval in the 2-min critical period, participants watched the student, Terry.

Figure 6. Average percentage of time, during each interval in the 2-min critical period, participants watched the work area.

Figure 7. Mathematics educators' average cognitive-activity measures, plotted in 30-s intervals, with the critical 2-min interval shaded.

Figure 8. Teachers' average cognitive-activity measures, plotted in 30-s intervals, with the critical 2-min interval shaded.

Figure 9. Prospective teachers' average cognitive-activity measures, plotted in 30-s intervals, with the critical 2-min interval shaded.

Figure 10. Comparison of the cognitive-activity measures of the three groups during the entire video.

Figure 1. The interviewer's movement of blocks to establish sameness.

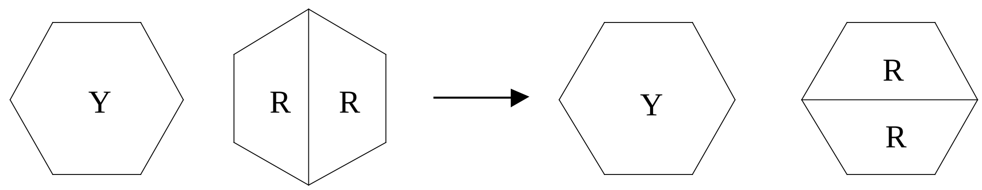

Figure 2. Terry's placement of blue blocks and green blocks to show congruence with the yellow hexagon, the whole.

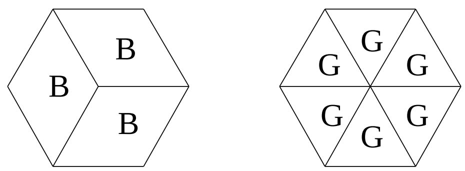

Figure 3. Example of eye movements of a prospective teacher during a 30-s interval. Terry is shown on the upper-right of the screen, R on the upper-left, and the work area across the bottom half of the scre

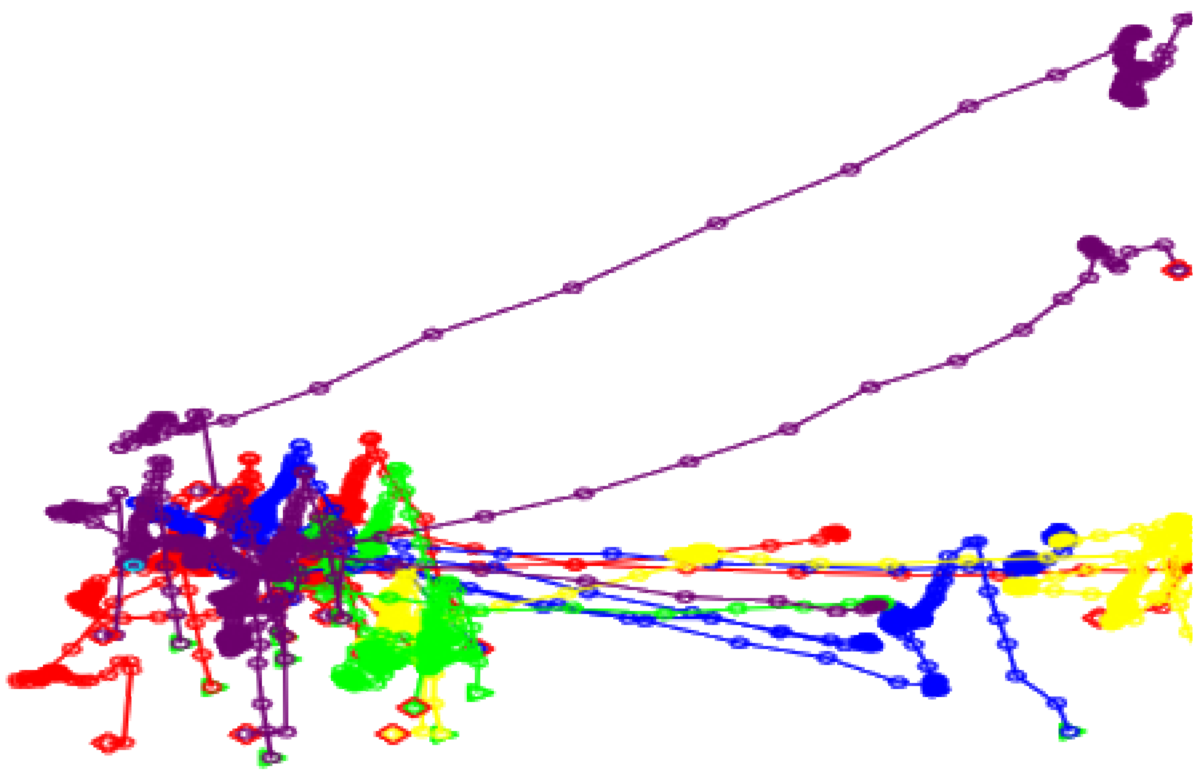

Figure 4. Average percentage of time, during each interval in the 2-min critical period, participants watched the researcher.

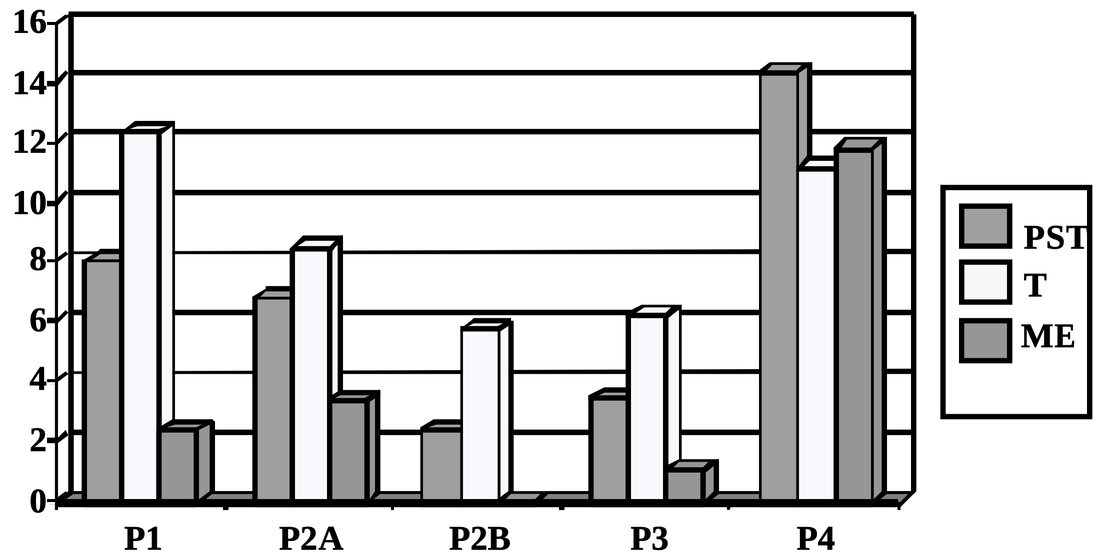

Figure 5. Average percentage of time, during each interval in the 2-min critical period, participants watched the student, Terry.

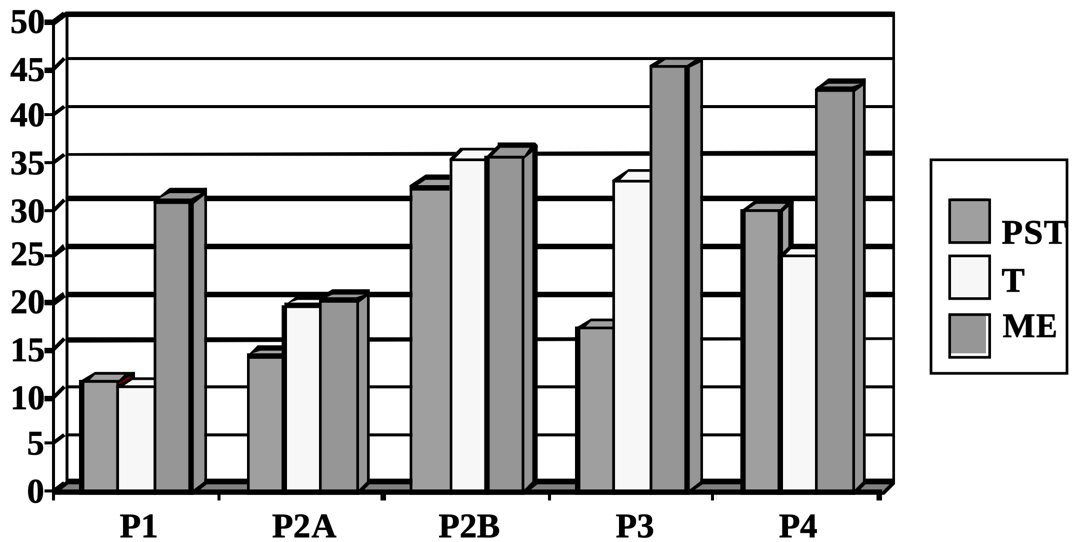

Figure 6. Average percentage of time, during each interval in the 2-min critical period, participants watched the work area.

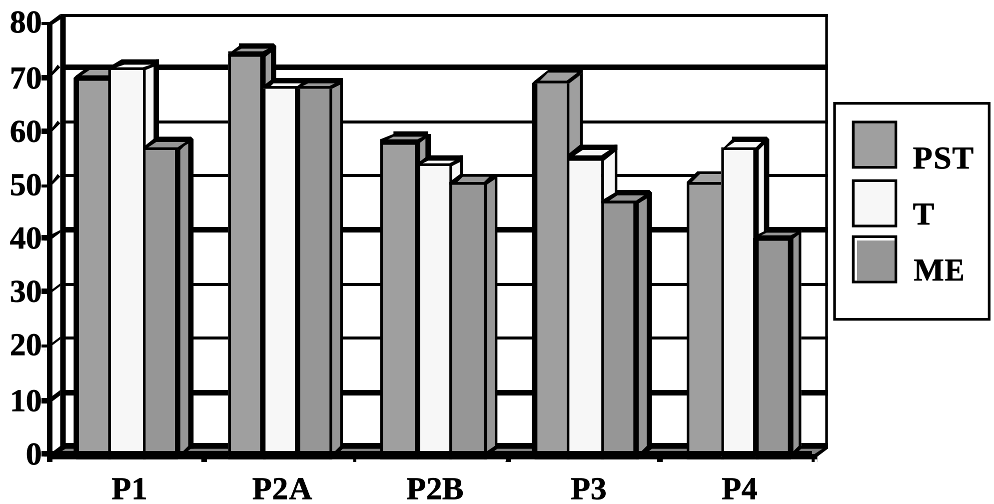

Figure 7. Mathematics educators' average cognitive-activity measures, plotted in 30-second intervals, with the critical interval shaded.

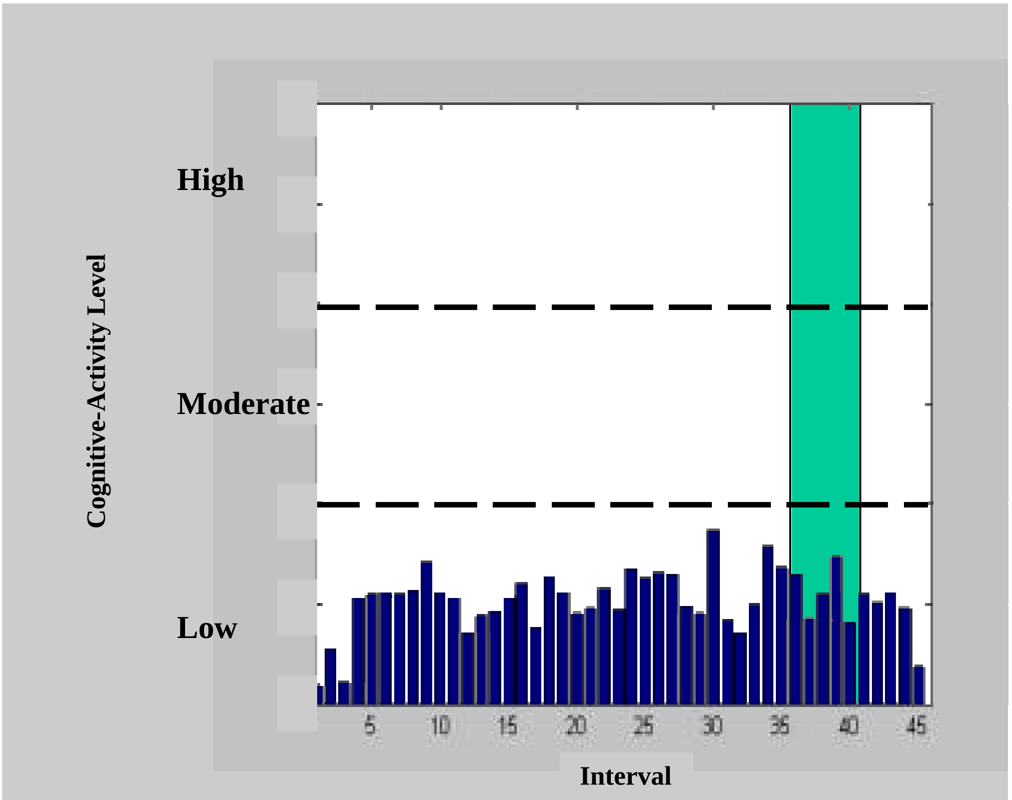

Figure 8. Teachers' average cognitive-activity measures, plotted in 30-second intervals, with the critical interval shaded.

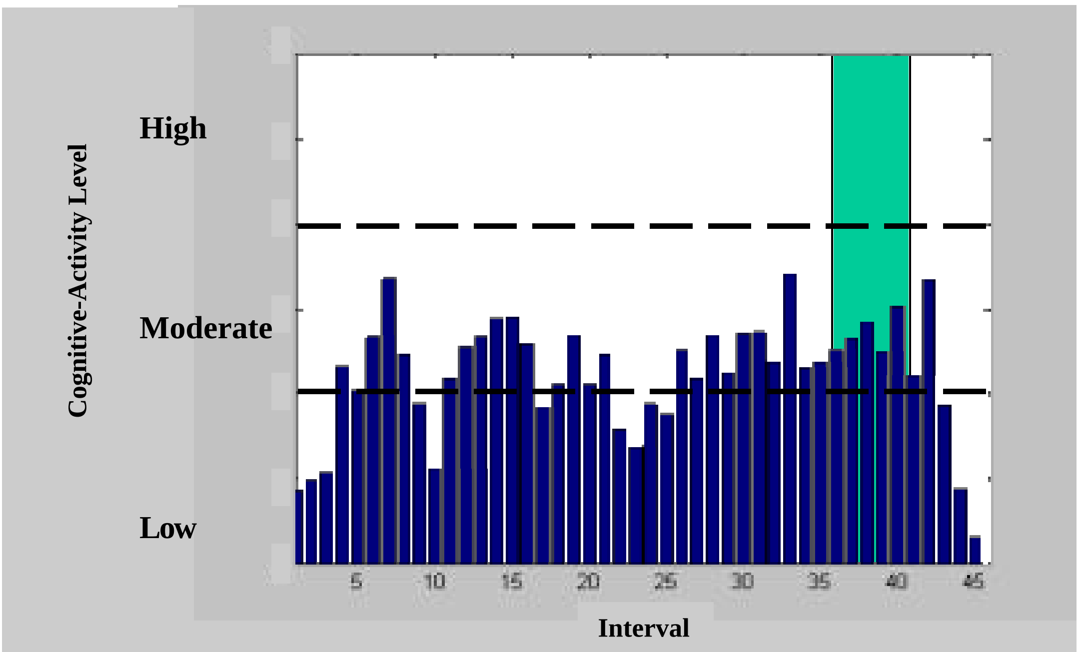

Figure 9. Prospective teachers' average cognitive-activity measures, plotted in 30-second intervals, with the critical interval shaded.

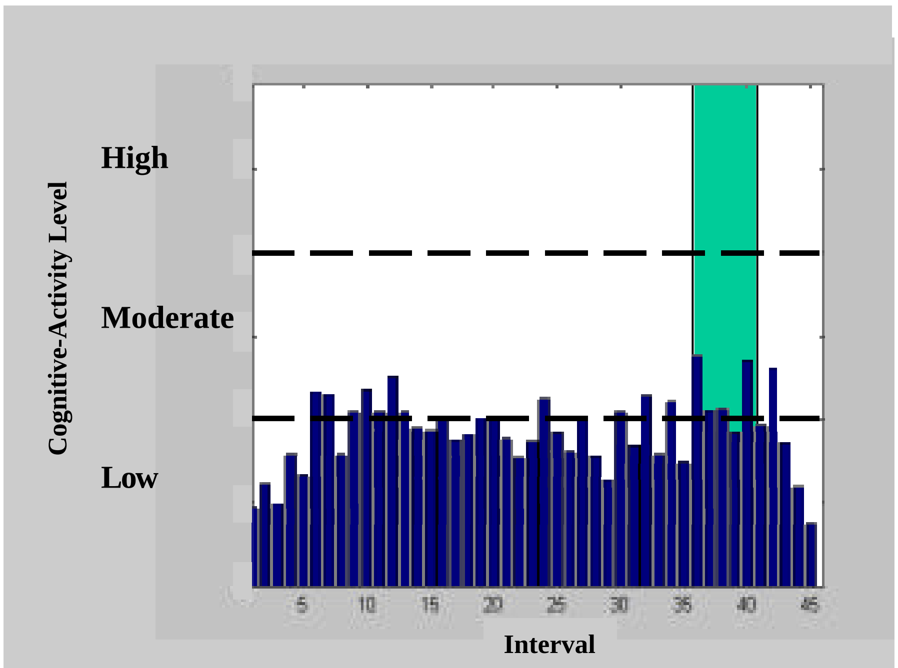

Figure 10. Comparison of the cognitive-activity measures of the three groups during the entire video.