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The Social Construction of Mathematical Knowledge: Presented Problems in Mathematics Classrooms

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This study examined how mathematical problems are articulated, i.e., identified and defined, in the context of a fifth-grade lesson on equivalent fractions. Opportunities to participate in mathematical discourse and reasoning activities were closely related to the structure, organization, and content of classroom presented problems. In this lesson, the presented problem took the form of a concatenation of tasks. Each task in the series became the mathematical context that animated students' talk about solution methods. Classroom discourse limited to serial tasks constrained students' opportunities to develop relational knowledge about the properties and principles of equivalent fractions.

Does a child learn only to talk, or also to think? Does it learn the sense of multiplication before or after it learns multiplication?

Wittgenstein, Zettel, p. 324

INTRODUCTION

In traditional research into mathematics education, domain knowledge such as conceptual understandings of rational numbers is studied independent of the social context. The epistemological basis for this approach to the study of mathematics assumes a dichotomous relationship between the mind and the world and thus views cognition as an internal and individual process (von Glasersfeld, 1991). The cognitivist framing of mathematical knowledge production accounts for the valued and widely practiced tradition of conceptualizing mathematical problems as static products to be used either as problem-solving practice or as vehicles to assess children's knowledge and/or thinking processes (Kieren, 1985; Smith, 1995). From this perspective, mathematical problems reify the salient dimensions of a problem environment so that when the issue of context comes into the foreground it is framed as an individual's interpretation and use of contextual clues during mathematical problem-solving events (cf. Littlefield & Rieser, 1993). It follows, then, that research into mathematics education would separate teaching from learning since

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the contextual clues inherent in the social organization of classrooms are considered structurally independent from the variables they are to explain.

Presently, there is a sea change occurring in educational research in general and in mathematics research in particular. With increasing frequency, cognition is viewed as a "transactional" process (Dewey & Bently, 1949) between individuals and the social context (Saxe, 1991; Stone, 1996). A theoretical treatment of the relationship between context and cognition is found in the cultural-historical school of psychology developed by Vygotsky (1978) and elaborated in the works of Leont'ev (1981), and Luria (1976). From the cultural-historical view, individual cognition arises from participation in social practices in which both the child and the social *milieu* are active. From this view, learning and development occur as children's participation is transformed through their active involvement in culturally organized activities (Ochs, 1988; Rogoff, 1990, in press). Participation in routine activities provides the concrete situations in which cognitive processes are constructed and applied (Cole, forthcoming). However, Giddens (1984) argues that the relationship between patterns of activity and cultural practices are mutually constituted. Accordingly, it is reasonable to say that how one makes sense out of mathematical knowledge cannot be separated from an underlying structure of cultural practices and their history of meanings. This characterization of classroom culture suggests that practices and knowledge construction are constituted in the accomplishment of practical activity.

Since classroom cultures in the form of daily practices provide the medium in which children come to know and understand mathematics in a formal setting, the research in this article provides a structural analysis of how mathematical problems are articulated, i.e., how problems are defined and represented through vocal, nonvocal, and written language. Problem articulation is both more interesting and complex than a cursory glance would reveal. While the notion of problem articulation entails a definition and representation of a problem, any potentially problematic situation (e.g., $3/4 = x/12$) necessarily requires someone to view it as a problem, i.e., a goal framework. So, what may appear at first glance to be a static event, i.e., a statement of a problem, is more accurately viewed as the result of a dynamic and complex process of interaction in which students come to understand the meaning of mathematical problems. Thus, during problem articulation activities students take on a problematic situation as their own, understand just what is expected of them in relation to the situation, have access to resources for finding a solution, and opportunities to utilize these resources. The significant issue, then, is how participation in the situated practices of problem articulation provides access to resources and opportunities for students to develop mathematical understandings.

To investigate how problems become goal frameworks and create resources and opportunities for mathematical reasoning and knowledge production, this study investigates one type of problem articulation, presented problems. A presented problem is characteristic of classroom mathematical problems in which

the solution/s and procedures are already known to the teacher but not necessarily to the students. Presented problems are interactional achievements in which students come to see particular situations as tasks that need to be accomplished. The cognitive consequences of identifying and defining a problem during social interaction arise from an ensuing emergent framework used to interpret what constitutes a problem, what are important attributes of a problem, and how to solve problems. In addition to developing an understanding of the meaning of mathematical problems, the organization of a presented problem creates events in which students are encouraged to participate in activities such as explaining and justifying. For these reasons presented problems offer a richly textured site for the study of mathematical learning.

The presented problems selected for this study involve the property of equivalency in fractions or rational numbers in the form p/q where p and q are integers (Behr et al., 1992). The property of equivalency in fractions is simply the idea that there are multiple ways of representing the same number. This transitive relationship of equivalent fractions is often difficult for children to understand because of their previous experiences with natural numbers which have a distinct symbol for each number (Smith, 1995). Since equivalency in fractional numbers is the topic of the focal lesson in these data, an integral part of this data analysis is to determine to what extent students had opportunities to develop complex understandings about the properties of equivalency.

A detailed analysis of presented problems involving equivalent fractions was conducted for two significant reasons. First, the identification and representation of problems are considered to be important aspects of both problem solving and the development of expertise (Carpenter et al., 1993). Second, research into the domain of fractions is warranted since there is a general consensus that fractions are both a difficult topic for children to master and a topic for which many children and adults do not have competent understandings (Behr et al., 1983; Davydov & Tsvetkovich, 1991). Consequently, a better understanding of classroom social practices used for the teaching and learning of fractions may help us better organize instructional environments so that students' poor performances are remedied.

METHOD

Data Sampling

The analysis in this article focuses on one lesson from an American classroom. The data set is part of a corpus of ten fifth-grade lessons selected from an investigation funded by the National Science Foundation (NSF) on mathematics education in the United States and Japan. Classrooms in this NSF study are located in urban school districts of Japan and the United States and serve middle to upper middle class students. Although individual schools were

randomly selected, site administrators worked with the NSF research group to offer teachers the opportunity to participate in a study of mathematics. Thus, all teachers and students in the data sample were volunteers.

The data collection method in this study involved video taping lessons with two cameras. One camera focused on the teacher while another focused on the students. This two-camera technique rendered this classroom data set an excellent resource for studying how problems are interactively identified and represented. That is, by affording visual and auditory access to both teacher and students concurrently, it became possible to conduct a study that used discourse and conversation analytic methodologies.

Classroom discursive processes offer the most direct evidence possible about situated reasoning in relation to the social organization and content of mathematics lessons. For this reason, discourse and conversation analytic methodologies were used to conduct a detailed examination of how cognitive processes and products arise during the enactment of mathematical events (cf. Duranti, forthcoming; Levinson, 1983; Schegloff, 1991). Further, since presented problems are not necessarily the same for all participants (cf. Lave et al., 1984), it is the communicative processes of classroom mathematics, and more specifically, the cultural practice of collective problem solving that can be analyzed to determine how 'intellectual' activity is shaped by interactional resources and opportunities. To enhance the analysis and fully explore the relations of situated action, language, and mathematical content, a complementary methodology of video technology (i.e., analysis of individual video frames) was employed to provide a means of closely examining presented problems for both their non-verbal content (e.g., gestures, eye-gaze, body positioning) and their mathematical artifacts.

RESULTS

Lesson Overview: Finding Equivalent Fractions

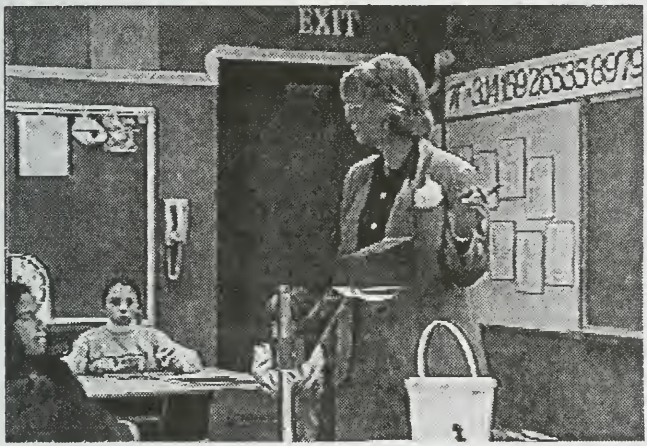
The following lesson is a fifth-grade introduction to the concept of equivalent fractions. The teacher in this study provided students with geoboards to empirically investigate solutions to a presented problem. In addition, students were expected to publicly display their solutions by going to the front of the classroom and drawing their results on an overhead using pre-made two-dimensional diagrams of geoboards. The sequential patterns in this lesson consisted of a recurring cycle of classwork interlaced with seatwork, i.e., small group work. Classwork segments, the focus of this study, were made up of a teacher-presented problem with multiple tasks and student-shared solutions.

Presented Problems: Organizing and Structuring Experience

Presented problems are initiated through multiple interactional sequences in which the meaning of a problem is realized over time. Thus, presented problems cannot be understood by simply invoking an internal understanding or mental representation but must be understood as a "special part, phase, or aspect, of...[the] experienced world" (Dewey, 1938, p. 67). In this way, presented problems become a social activity in which participation stimulates the co-production of a particular form of cultural knowledge, i.e., mathematics.

In what follows, I show how the structure and organization of presented problems are interrelated with the discourse and reasoning processes afforded in classroom mathematics practices. One aspect of presented problem activities is revealed in Example 1 in which the teacher, Mrs. Kim, initiates the instructional activity aimed at equivalent fractions.

Example 1: Teacher's Initiation of the Presented Problem



Mrs. Kim:	O:kay: if you can: right now let's look up here.	1
	((Pointing finger to chalkboard behind her.))	2
	(1.2)	3
	And lea:ve the geoboards for just a few minutes.	4
	(4.7)	5
	((Students are cleaning up their desks. Noise levels begin to drop.))	6

The above example demonstrates an interesting structural feature of classroom presented problems found in these data. Presented problems are events in which the interactional accomplishment of the activity minimally involves the co-management of joint attention. Co-attending to an event is accomplished during the initiation of the presented problem activity when the teacher marks what Goffman (1974) calls an attentional track. That is, by

requesting students to refocus their attention and reorient their eye gaze on the front of the classroom in this setting (lines 1-4), the teacher frames the activity as one in which important information about present and future events will be generated from a specific position in the classroom. In other words, the 'main story line' will arise from a particular spatial area and thus necessarily requires that all participants orient their attention to this space (Goffman, 1974; Kendon, 1990). In this way, the initial elicitation in lines 1 and 4 along with the teacher's gesture (i.e., pointing to the blackboard) not only help to organize students' attention spatially but also foregrounds future events. Moreover, the occurrence of multiple pauses (lines 3 and 5) in the teacher's production of utterances provides further evidence that this attention focusing request was important since some minimal attentional level had to be achieved and demonstrated by students before the activity would continue as part of the formal structure of the lesson.

After shifting attention to a specific area of the classroom, Mrs. Kim and the students co-participate in the "development of a social setting" for the presented problem (Stone, 1996). Social settings are a form of introduction that produce a spatial, temporal, and linguistic "bracketing" of presented problem events (Goffman, 1974). This bracketing contributes to an interpretive frame for participants to make sense out of mathematics problems. Social setting activities shape the organization of experience as presented problem activities unfold in time and space. In Example 2 below, the social setting emerges as Mrs. Kim constructs an explanation about a past event to explain why geoboards will be used to divide a geometric shape into equal parts.

Example 2: Social Setting as an Explanation for Past Activity

Mrs. Kim:	I brought in: (1.4) ↑six: >peanut butter sandwiches.<	8
	One for each table.	9
	(5.1)	10
	((Students continue to clear desks. Room noise level drops noticeably))	11
	I only had peanut butter at home. I didn't have anything else so it had to be	12
	peanut butter.	13
	(1.6)	14
	<u>U</u>sually we think (.) in terms of a piece of bread looking like a square.	15
	(2.7)	16
	((Holding up a geoboard))	

In this explanation, Mrs. Kim is linking a common, everyday item, i.e., a peanut butter sandwich, to the shape of a geoboard (lines 15-16). Since, in Mrs. Kim's view, the shapes of bread and geoboards are isomorphic, the geoboard will function as the mathematical environment for the presented problem. Reference to the sandwich occurs only in the initial statement of the presented problem. All the presented problems that follow are related to the geoboard. This teacher's use of an explanation to relate mathematical artifacts such as geoboards to the daily experiences of children is found in many of the classrooms in this data set. Further, explicit instruction or verbal explanation is one common way that teachers assist children in connecting mathematical models and real world

situations. However, in this setting, references to the similarity between sandwiches and geoboards fade after the initial few minutes of the lesson. Since neither the teacher nor the students made any future references to the geoboard as sandwiches, there were few structured opportunities for children to participate in collective reasoning activities that systematically connected geoboards with daily experiences.

To return to the presented problem, after identifying the mathematical environment as geoboards, Mrs. Kim explicitly states the mathematical task, i.e., divide the sandwich into halves (Example 3, lines 19-20 below). The statement of task is also combined with information about how speakers will be selected (line 24).

Example 3: Presented Problem Task

Mrs. Kim:	Our ta:sk to:day (.) is to divide: that sandwhic::h (0.9) into	19
	(.) halves.	20
	(0.8)	21
	How can you divide that sandwich into halves?	22
	(0.6)	23
	I'll remember I'll just call on you.	24
	(0.7)	25

By combining a mathematical environment with a task or an elicitation to act on that environment, the problem is presented. That is, the task of dividing the sandwich into halves transforms the mathematical environment into a condition that necessarily requires students to act upon it in some way. In other words, elicitations function in very powerful ways to organize the activity such that students fully expect to respond in some way to a mathematical environment.

In educational settings, there is and has historically been an asymmetrical relationship between students and teacher. This relationship is overtly configured in this setting when the teacher states that she will select or "call on" a student to provide an answer (line 24). The overall shape of this presented problem activity, then, organizes speaker selection as falling under the aegis of the teacher. Since responsibility for elicitations resides primarily in the teacher's purview, questioning and clarification activities tend to be initiated by the teacher and not the students. Further, it will be shown that the structure of presented problems in this classroom rendered differing solutions to problems as the object of inquiry for the teacher rather than the students. In this way the social organization of presented problems stimulated some forms of interaction and constrained others.

While the core of this presented problem is captured in the task in Example 3, the shaping of the presented problem in this setting continues to develop as the interaction continues. An example that characterizes this development is demonstrated in Example 4 when Mrs. Kim asks a student to share a solution.

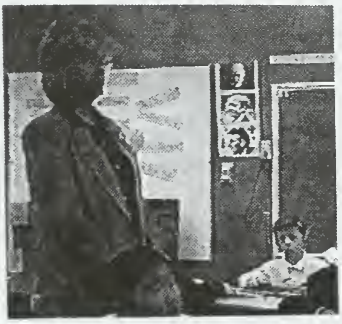
Example 4: Shaping of a Presented Problem

Mrs. Kim:	Would you come up to the board and show us one way we could divide er	26
	up to the overhead one way we can divide.	27
	(0.6)	28
	((*looking around the room.*))	29
	David.	30

The elicitation in lines 26 and 27 configures the presented problem activities in very important ways. Students now expect not only to have a solution to a problem but also to display the solution in an area of the room that has been marked previously as important. Another critical feature of the teacher's discourse is the use of "one way" to signal that solutions are not single correct answers but rather candidate solutions. Thus problems in this classroom are linguistically crafted as having multiple solutions rather than one single correct solution. This shaping of a problem creates an expectation about mathematical problems that potentially shifts the understanding of the presented problems from algorithmic procedures to a field of possibilities. These data suggest that when this exploration perspective on presented problems is an integral part of the activity then presented problems become a potential resource for probing mathematical solutions rather than a means to access a static body of knowledge. This exploration approach differs from what has been found in many United States classrooms in which single correct answers are the preferred response to an elicitation (cf. Voigt, 1989; Stone, 1994).

So far, I have shown that presented problems are initiated by activities that organize students' attention and provide background information for a problem. Further, the kernel activity of presenting a problem is characterized by a mathematical environment and a task. Nonetheless, the meaning of a presented problem continues to develop during social interaction. Examples 5 and 6 illustrate how the interactional shaping of a presented problem develops.

Example 5: Interactional Accomplishment of the Presented Problem

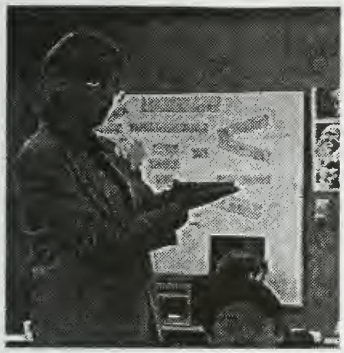


Mrs. Kim:	Jen:ni:fer do you have a↑nother way?	80
Jennifer:	((*Walks to the overhead and draws a diagonal line on the picture*	81
	of a geoboard as the teacher and students watch.))	82

Two significant features of this teacher's talk further shape and reshape the original activity of dividing a sandwich into halves. First, when asking a second student, Jennifer, if she has a solution, Mrs. Kim's elicitation again mirrors the idea of candidate solutions with the words, "do you have another way". This casting of a problem as having more than one solution method is a typical example of the teacher's persistent framing of problems as tools for exploration. Moreover, the linguistic resources Mrs. Kim uses to construct this particular view of problems also function as resources for students to interpret responses to mathematical problems as possibilities or candidate solutions. In this way, the meaning of presented problems continued to be shaped by ongoing activities, e.g., elicitations.

The nature of students' opportunities to use the mathematical discourse of this classroom is illuminated in Example 6 below.

Example 6: Opportunities for Explanations



Mrs. Kim:	↑Jennifer, why did you (.) why tell us	83
	why did you thin:k that's divided in half?	84
	(0.8)	85
Jennifer:	Well:: it's the same on the top and the	86
	bottom.	87
	(0.6)	88
Mrs. Kim:	Can you prove: that to us?	89
Jennifer:	Well uh if you fold it over then it's ( )	90
Mrs. Kim:	Oh:: if you: just folded it such as a piece	91
	of paper: it would match up. (.) all right.	92
	((Making a folding motion with her hands.	93
	Jennifer nodding her head.))	94

In this example, Mrs. Kim's elicitations created "slots" for explanation and justification activities (Antaki, 1994). That is, the preferred sequential response to the request for information "...tell us why you think that's divided in half?" is an explanation (Schegloff, 1991). When this elicitation is followed by "Can you prove that to us?", Jennifer produces a justification for her response. Of significance is that the "conditional relevance" of these particular requests makes

the student accountable for providing reasons and explanations (Schegloff, 1968). In this way the social organization of talk about problems created opportunities for students to provide reasons for their solutions. The activity, then, is more an exploration rather than a simple checking of answers. Inasmuch as the discourse practices in this classroom involve a language game that stimulates students to justify their solutions, these particular elicitations create very powerful expectations that invoke a particular relationship between mathematical content and modes of interaction. Accordingly, children are provided opportunities to display their mathematical knowledge. While the mathematical understandings demonstrated in these activities are not complex, i.e., showing how to fold or partition a shape into equal segments, the children's justifications can be considered informal forms of mathematical proofs (an essential element of a mathematical proof is an argument in which evidence for a valid conclusion is demonstrated). In this setting, children had opportunities to participate, however informally, in the mathematical practice of constructing proofs.

In this lesson, the core sequence of mathematical ideas involved relating a spatial representation of 1/2 on a geoboard to an equivalent spatial fraction, e.g., 2/4, 4/8, and so forth. In other words, students were expected to use their geoboards to investigate equivalency relationships through successive permutations of a similar task. Consequently, a presented problem was made up of a *series* of tasks or presented problem elements. Further, the final task element of the presented problem, i.e., "...prove to the person sitting either on your right or left. You need to prove to this person that 1/2 = 2/4" did not vary in any substantive way from the tasks that preceded it. Thus, the students arrive at an increased level of complexity through their participation in a progression of tasks which, in succession, offer only minor differences in terms of complexity or novelty.

In this setting, the structure of the presented problem involved requests to act repeatedly upon the same mathematical environment. When problem environments remain constant, there is essentially one presented problem developing out of a concatenation of tasks. For this reason, the articulation of this presented problem extended throughout this lesson. The organization of a problem into a series of tasks that function as problem elements not only organized mathematical content but also shaped the discourse practices in this classroom. The serial organization of tasks configured mathematical content in this lesson as pairs of fractions (e.g., 1/2 and 2/4) to be compared. The construction of these fractional parts became the basis for mathematical talk in this lesson. Thus, the organization of the lesson afforded particular types of mathematical reasoning. Since children's opportunities for participating in reasoning activities were influenced by the mathematical content, the form and organization of mathematical content can also be considered a structural resource that contributes to how mathematical communication unfolds.

The overall structure of the presented problem as a series of tasks, however, constrained the knowing and doing of mathematics in significant ways.

Although the mathematical content becomes increasingly complex (i.e., each task was a slightly more complicated permutation of the previous task) this content did not lead to any noticeable conversational reasoning about properties or principles of equivalency in fractions. Moreover, the stepwise sequence of problems structured students' strategies into patterned responses. As an example, developing an explanation of how to divide a rectangle into two equal portions is not fundamentally different from explaining how to divide the same shape into four equal portions. To the extent that repetitive procedures could be used to complete the collection of problem tasks, the structure of the presented problem confined children's mathematical reasoning to explanations about the procedures for breaking up a space and comparing two fractional parts. As a consequence, explanation/justification activities did not play a substantive part in relating each of the series of tasks to conceptual understandings of equivalent fractions. That is, children did not have opportunities to talk about or evaluate patterned relationships among equivalent fractions for one half during whole group activities.

In effect, the structure and organization of the mathematical activity in this lesson determined the focus of evaluative or metapragmatic language about mathematical content. Metapragmatic discourse is language that "signals" how practical activity is to be interpreted (Lucy, 1993). In mathematics, metapragmatic language entails, at least in part, a discussion of how mathematical content or patterns are related and further what this relationship means. Therefore, metapragmatic language is a form of reflection-in-talk about ongoing events in which participants take a perspective on practical activity. Furthermore, from a Bakhtinian (1981) viewpoint, taking a perspective on mathematical endeavors requires that children reflect on mathematical content to "recall, weigh and [analyze] other people's words, opinions, assertions, information" (p.338). In mathematics, this is a removed stance from which to draw iterative conclusions about patterned relationships that arise from mathematical activity. Since metapragmatic talk potentially redirects attention to the salient features of mathematical activity and thus organizes perception, important aspects of mathematical content and concepts can be highlighted.

However, in this data set the serial structure of the mathematical problem constrained metatalk to individual problem elements of the presented problem. Thus, while the elicitations of the teacher in these data did encourage students to explain and, thus, reflect on the relationships between separate sets of equivalent fractions like 1/2 and 4/8, these elicitations did not stimulate students to take a more removed perspective and consider the relationship of all of the problem elements constructed in this activity. In other words, the students did not explore the significance of equivalency by utilizing multiple examples of fractional numbers, e.g., 1/2, 2/4, 8/16, 32/64. The result is that students did not have structured opportunities to talk about and reflect on the significance of the relationships found among equivalent fractions. As a consequence, the social organization of this lesson did not capitalize on the structural resources of

mathematical content, i.e., recurring patterns. In this setting, then, the structure of the presented problem constrained how the discourse of pragmatic activity was "interanimated" with metapragmatic language (Bakhtin, 1981).

This study of presented problems suggests that the traditional approach of separating content knowledge (e.g., presented problems) from instructional practices provides only a partial picture of how mathematical knowledge is produced. The data in this study also suggest that whole-group activities in which problems are articulated involve a dialectical process of interaction between the complex organization of mathematical practices and individual actions within those practices. The structure of the presented problems organized the moment-to-moment activities of questioning, justifying, and explaining. Pragmatic forms of action, then, shaped mathematical cognition. For this reason, knowing and doing mathematics is "crafted" from participation in social practices, discourse processes, and mathematical content used in the service of problem solving (cf. Goodwin, 1994). As a result, the production of mathematical knowledge results not only from the domain topic under consideration, i.e., principles and properties of equivalent fractions, but also from the context of use and how that context is created and recreated during ongoing activity. Thus, Rogoff's (in press) metaphor of cognitive development as changing participation can be understood better by examining children's mathematical activities as they make use of the available resources of the classroom to think, talk, and do mathematics. Participation in classroom mathematical practices affords resources and opportunities for children to produce mathematical knowledge.

Certainly the enterprise of classroom mathematics instruction is motivated by larger concerns to educate children in very productive ways. Children's participation in the communicative and reasoning processes of mathematics is central to current reform policies in mathematics education (cf. National Council of Teachers of Mathematics [NCTM], 1989, 1991). Further, mathematical problems in school reform literature are viewed not as practice tasks but complex wholes having multiple solutions that provide a basis for talking and thinking (NCTM, 1989). It is significant, then, that Mrs. Kim's classroom evidenced an interesting blend of traditional practices in which mathematical problems often consist of a series of similar tasks with single correct answers and reform oriented practices that cast problems as complex entities with multiple solutions. In other words, in this classroom, traditional configurations of problems as serial tasks become the object of talk about multiple solutions. This combination of new and old practice may account, in part, for the constraints on students' opportunities to produce and communicate complex conceptual knowledge about equivalency and its properties. The implication is that learning about and creating reform-oriented classrooms is not an either-or proposition but rather a continuum that reflects a process of conceptual development. For this reason, I am suggesting that the metaphor of changing participation is not limited to a study of the learning and development of children

but also includes the learning and development of teachers. Coming to understand the pragmatic meanings of reform is not qualitatively different from developing understandings of mathematics; both involve conceptual, procedural, and social knowledge (cf. Fullan & Stiegelbauer, 1991).

APPENDIX: TRANSCRIPTION CONVENTIONS

Transcription conventions used in this paper were developed by Gail Jefferson for the analysis of conversational turn taking sequences (see Sacks, Schegloff, and Jefferson, 1974).

Symbol	Meaning
( )	Unclear speech
(( ))	Paralinguistic information about context
(.)	Untimed pauses
(2.1)	Pauses in seconds and tenths of seconds
[	Simultaneous start-ups or overlaps
=	Contiguous utterances
::	Extension of sound
↑ or ↓	Up or downward shifts in intonation
!	Animated tone
Underlined or bold words	Increased stressed
° hello °	Quiet talk in relation to surrounding speech

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