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Regulation of Teacher Elicitations and the Impact on Student Participation and Cognition

Mitchell J. Nathan and Suyeon Kim

Studies of classroom interactions have generated wide interest in how teacher-student and peer-to-peer discourse promotes students' active participation and provides the pedagogical scaffolds that allow students to engage in sophisticated mathematical reasoning and critical reflection (Cobb, Wood, & Yackel, 1993; Hatano & Inagaki, 1991). Yet we have limited understanding of how teachers regulate student participation in classroom discussions and how this regulation affects students' conceptual reasoning. Advancing this understanding will increase our knowledge of the nature of language use in educational settings and also contribute to our theoretical understanding of the relation between communication and collaborative learning (Baker, 2007).

Instruction, particularly the form of instruction known as *scaffolding*, can be viewed as communication (Alibali & Nathan, 2007). Scaffolding emphasizes the socially mediated nature of knowledge and learning (Bruner, 1975; Vygotsky, 1978). With scaffolding, a more knowledgeable "other"—such as a teacher, parent, or more experienced peer—provides temporary support for learners so they can participate in more advanced reasoning and behavior than they are capable of performing on their own. The supports offered by the teacher then gradually fade away to allow for ever-increasing learner autonomy. This approach draws directly on Vygotsky's (1987) sociocultural theory of cognition, specifically, his *general genetic law of cultural development*, which states that any cognitive function that develops appears first in the social realm (through interpersonal interactions such as scaffolding and modeling) and then in the psychological realm, as internalized by the child.

Interest in how classroom discourse scaffolds students' participation and reasoning follows on the heels of recent education reforms, which recognize classroom interaction and discourse as an effective way to perform instruction, conduct knowledge assessment, and facilitate learning in the content areas (e.g., National Council of Teachers of Mathematics [NCTM], 2000; National Research Council, 2000, 2005). Classroom communication is acknowledged as a powerful mediator for complex cognitive behavior, including building meaning, reflecting on one's understanding, and co-constructing new ideas. Instructional conversation (e.g., Tharp & Gallimore, 1997) plays an important role in discourse-oriented classrooms because it helps scaffold students' access to higher levels of cognitive processing. Teachers orchestrate this discourse by drawing students into a social interaction.

This mediating role of communication is made especially evident in mathematics education research. By now a substantial number of studies have looked at classroom discourse to better understand how teachers stimulate students' participation and engagement, and scaffold students' construction of mathematical knowledge (e.g., Cobb, 1995; Cobb et al., 1993; Hufferd-Ackles, Fuson, & Sherin, 2004). However, the effect of teachers' elicitations on students' learning is still not well understood. Studies have shown both encouraging (e.g., Nystrand, Wu, Gamoran, Zeiser, & Long, 2003) and disappointing results (e.g., Ryan, 1974). For example, Hatano and Inagaki (1991) showed how students developed better mathematical understanding through defending and justifying their mathematical ideas using discourse. Some studies (e.g., Nathan & Knuth, 2003; Rittenhouse, 1998) have shown how much teachers struggle in their role as facilitators within discourse-based learning environments. Further studies of these interactive processes can yield important insights into how the teacher elicits students' participation in academically oriented ways of talking and thinking (Cobb, 2000; Cobb & Bowers, 1999; Williams & Baxter, 1996).

This study sought to deepen our understanding of how teacher invitations for students to participate in classroom discussions occur, and how they lead students to exhibit higher order reasoning. We investigated how one teacher regulated classroom discourse by modifying his elicitations—through questions, pauses, and various provocative responses—in order to influence students' engagement with a beginning algebra unit. We chose this particular classroom because we had prior quantitative evidence that the implementation of this instructional unit led to statistically reliable gains in students' algebraic reasoning (Nathan, Stephens, Masarik, Alibali, & Koedinger, 2002).

In the course of this investigation we set out to describe the elicitation techniques the teacher used in this classroom setting and document how the various techniques generated opportunities for students to participate in the mathematical discussion. We also examined how regulation of teacher-generated elicitations provided a form of scaffolding for students that allowed them to engage in higher levels of mathematical reasoning than they exhibited on their own. We used as our conceptual framework Vygotskian sociocultural theory and discourse analytic methods to describe classroom instruction and participation. This research deepens our understanding of how "observable classroom discourse affects the unobservable thinking" of students (Cazden, 1988).

Mediation of Classroom Discourse

Sociocultural theory asserts that mental processes are mediated by semiotic tools, such as objects (e.g., mathematical manipulatives like construction cubes), diagrams, formal systems of notation, and, most notably, language. These semiotic tools serve a mediational role by structuring interlocutors' mental activities and transforming inter-personal (i.e., social) actions to intra-personal (psychological) processes (Vygotsky, 1978; Wertsch, 1991, 1998; Wertsch & Toma, 1995). Activity with these tools, such as participation in certain forms of discourse, enables the internalization of socially constructed mental activities that emerge later as advancements in learners' cognitive development (Werstch, 1995).

In a similar vein, Gal'perin (1969) demonstrated that the materialization and verbalization that occur with physical learning materials—actual tools and objects—mediate learners' cognitive processing and, as a consequence, facilitate their internalization of the concepts that are directly related to the physical activity. Within Gal'perin's framework, Talyzina (1981) found that the verbalization stage is indispensable for learners' development of higher order thinking. Through verbal externalization learners organize their thoughts into verbalizable units and articulate their own hypotheses. This leads them to reflect on and critically examine their underlying knowledge and can lead learners to eventually restructure their understanding (Nathan, Eilam, & Kim, in press; Slobin, 1996; Swain, 2000; Wells, 2000).

Education reformers, particularly in the mathematics community, have recently attempted to implement some of the principles of socially mediated learning that emerge from classroom interaction (Ball, 1996; Cobb, 1995; Cobb et al., 2001; Cobb et al., 1993; Cognition and Technology Group at Vanderbilt, 1997; Lehrer et al., 2002; Lantolf, 2000; Wertsch, 1991, 1994, 1998). This current initiative focuses on the essential role teachers play in facilitating classroom discourse by scaffolding students to verbalize their ideas and critically evaluate the ideas of others (Nathan & Knuth, 2003).

Elicitation Techniques, Participation, and Cognitive Processing

Walsh and Sattes (2005) viewed teacher elicitations as an essential type of classroom discourse because they invite students' participation in a learning community and promote their cognitive development. Instructional conversation also allows the teacher to assay students' underlying level of knowledge and to adjust the instruction to meet a student's emerging understanding (Tharp & Gallimore, 1997). A number of researchers have focused on teachers' questioning techniques during instructional conversation. For example, Saunders and Goldenberg (1999) argued that teacher's various elicitation questions are important in instructional conversations because the questions can promote more complex and extended expression as well as facilitate learner engagement. Elicitation questions also invite students' responses, which provide them with opportunities for reflection and conceptual restructuring.

The logic underlying teacher elicitation questions and student responses is tied to the notion of a *conditionally relevant* response as a type of *adjacency pair* (Heritage, 1984; Schegloff & Sacks, 1973) where the question part elicits a relevant response. However, Mehan's (1979) ethnographic analyses of classrooms found some deviations from the adjacency pair structure, such as the absence of student responses immediately following a teacher's question. In such deviations, systematic sequences may be inserted until an answer to the question from a previous turn arises. This form of expanded participation structure effectively drives the teacher to communicate with students as a co-participant in the interaction, and allows participants to co-construct a mutual understanding (i.e., intersubjectivity), structure learning opportunities, and advance the conceptual understanding needed to enable formation of complex cognitive skills (Donato, 2000; Nathan et al., in press; Takahashi, Austin, & Morimoto, 2000). In this way, participation in classroom discourse provides opportunities for learners to be active members in a learning community (Tharp & Gallimore, 1991; Wertsch, 1991, 1994).

Interactional Scaffolding

Teacher elicitations function as a form of scaffolding (McCormick & Donato, 2000). Cazden (1988) argued that classroom instruction should be organized around the scaffolding modes such as *W-H* elicitation questions (why, where, who, what, and how) for probing the next piece of information. Through scaffolding, learners internalize knowledge that they co-construct with experts (Bruner, 1984; Wertsch, 1979). Cued use of W-H questions can promote internalization of publicly displayed knowledge and forms of dialogic interaction as external classroom interactions are overtly shifted to internal mental processing. In addition to internalization, scaffolding through elicitation questions can assist learners so they outperform their autonomous competence within their *zone of proximal development* (ZPD). As defined by

Vygotsky (1978), ZPD is metaphorically taken as “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (p. 86). More specifically, Scollon (1976) identified this instructional support as *interactional scaffolding* because teacher elicitations draw out students’ self-directed solutions and their metaprocess-level justifications.

Classroom interactions and instructional conversations often include teacher elicitations, which, when effective, generate more information, increased participation, and greater conceptual development from students (Cazden, 1988; Mehan, 1979; Nystrand et al., 1997). Teacher elicitations, in the form of questions and responses, can be viewed as occurring at different cognitive levels that reflect the ensuing demands they place upon the interlocutor. Several scholars have charted hierarchical systems that reflect the various levels of cognitive complexity. Bloom (1956, 1987), for example, proposed six levels of complexity within the cognitive domain: recall of prior knowledge; comprehension as exhibited by restating and reorganization; application of knowledge to new situations; analysis of knowledge into its constituent parts; synthesis of disparate knowledge to form ideas and solutions or make predictions; and evaluation of the quality and validity of ideas.

From this perspective, Mehan (1979) and Bloom (1987) highlighted how various types of elicitation techniques, based on different levels of cognitive complexity, reveal students’ deeper understanding and guide them toward higher level cognitive activities. More recently, Nystrand and his colleagues (1997), Kawanaka and Stiger (1999), and Wells and Arauz (2006) proposed alternative schemes that similarly distinguish between lower and higher levels of cognitive functioning in response to questions or task demands. Across all these systems, lower level cognitive questions are defined as those that require only recognition or the ability to recall factual information. In contrast, as the level goes up, the activities require higher order thinking skills, such as deeper forms of comprehension, interpretation beyond given information, metacognitive monitoring, reflection, and justification.

The most influential categorization system for teacher elicitations was offered by Mehan (1979), who identified four types. In order of increasing cognitive complexity, they are: choice, product, process, and metaprocess elicitations. *Choice elicitation* (*CE*) asks students to agree or disagree with what the teacher said in the previous turn and so merely depends on students’ recognition of correct information or guessing. *Product elicitation* (*PE*) invites students to provide factual knowledge, such as a name or a place, which they must generate from long-term memory. *Process elicitation* (*PRE*) asks students to provide opinions or interpretations. *Metaprocess elicitation* (*ME*) asks students to connect their responses with the intentions of a teacher’s elicitation by providing, for example, the justification supporting their reasoning.

Higher order questions generally challenge the student to provide additional information and engage in deeper understanding and reflection, and ultimately promote greater conceptual development. Verplaetse (2000) claimed that when students succeed in acknowledging (CE) or recalling (PE) knowledge at the factual level, teachers often move to a higher level of questioning, like a metaprocess elicitation (e.g., “How do you know that?”). This has the potential to expand the interaction with students and further explore their thinking. By regulating the level of the elicitation, teachers can use discourse participation as a way to scaffold students' higher order thinking (Yip, 2004).

Purpose of the Study and Research Questions

We assert that teachers exhibit even more sophisticated forms of regulation than those found in earlier studies (e.g., Verplaetse, 2000) and that teachers may adjust the cognitive complexity of their elicitations in response to students' incorrect and partially correct responses as well as to their successes. That is, teachers may move both up and down the hierarchy in their efforts to promote engagement and learning.

The main purpose of this study is to examine how one teacher used discourse in his classroom to engage students and promote their participation in higher levels of mathematical thinking. Traditional forms of mathematics instruction tend to focus on getting the answer correct and recalling facts and procedures, but often leave students unengaged and unprepared for complex and novel problem solving (National Research Council, 2000). The aim of contemporary mathematics education reform is to make a "shift from learning mathematics as accumulated facts and procedures to learning mathematics as an integrated set of intellectual tools for making sense of mathematical situations" (NCTM, 1991). Student repair of trouble sources is not enough. Students are now being directed to engage in extended, complex reasoning that often involves collaboration, and to go beyond getting an answer "correct" by also verbalizing their reasoning processes and their understanding of the underlying concepts. Students in this context must communicate their mathematical ideas and listen and critically evaluate the ideas expressed by others. The teacher's role in these settings then expands to include the role of facilitator of students' mathematical participation. We show here how the teacher traverses a hierarchy of elicitation forms in order to foster participation at various levels of discourse. From this detailed case, we posit that teachers, in their efforts to promote higher order reasoning in the classroom, can be highly responsive to students' demonstrated needs, using classroom talk to both assay student knowledge and promote its advancement. We posed two research questions to guide this investigation: (a) How does the teacher regulate his use of elicitation prompts as a reaction to students' responses? (b) How do teacher elicitations provide the interactional scaffolding needed to help students shift from lower to higher order forms of reasoning?

Method

Participants

Participants were students in a middle school mathematics classroom in the western United States. The participants included 1 male mathematics teacher and 24 middle/upper-middle-class students in a combined seventh-/eighth-grade class. The teacher had 10 years of experience teaching in elementary and middle school settings. The 9-week curricular unit under investigation focused on entry-level algebra. In this current analysis, we focused specifically on a multiday lesson that used tables, graphs, words, and mathematical expressions and equations to represent numerical patterns of growth exhibited with cubes of various sizes.

Data Collection

Four 45-minute sessions in the beginning algebra unit were videotaped. One researcher ran a video camera from a tripod, while a second researcher took field notes in order to document any events the videotaping might miss. The teacher typically stood in the front of the class, and the students sat in individual desks arranged in a half-circle along the edge of the classroom.

The particular unit was developed as part of an experimental intervention aimed at improving students' algebraic learning by bridging from their initial solution strategies and representations to more formal methods for representing quantitative patterns and solving problems (Nathan et al., 2002). The four algebra class sessions in this study were structured with three main curricular goals: (a) naming the parts of the 4 x 4x 4 cube, such as side length, corners, edges, faces, hidden blocks, and total volume, (b) identifying and recording the growth of linear and nonlinear patterns of the various parts as students built larger cubes using construction blocks, and (c) mathematically representing the patterns of growth using words, graphs, tables, and algebraic expressions that would allow students to form abstractions of the patterns and generalize the growth behavior for hypothetical cubes of different sizes.

Data Analysis

This is a descriptive, classroom-centered study. To investigate the classroom interactions, we transcribed the verbal and nonverbal actions such as changes in voice pitch, use of hand gestures, object use, writing and drawing, and so on. To understand the nature of the classroom discourse, we used three analytic methods to identify the elements of interactions. First, we drew on Gee's (2005) approach for segmenting the transcripts in stanzas, based on important events, actions or states. Next, we identified the teacher's utterances by the different types of elicitation techniques exhibited, taking context and responses into account. Student responses were coded as correct, incorrect, or partially correct replies to the currently active elicitation. In the final analytic step, we applied a coding scheme to assign a cognitive level (described below) to each teacher elicitation.

In our data, we coded as elicitations teacher's turns that invited the *next* turn from a speaker. These types of teacher elicitations are based on Mehan's (1979) framework and involve increasing cognitive complexity from the respondent. In addition, we drew from Bloom's (1987) taxonomy, Nystrand and his colleagues' (2003) cognitive levels, and the coding scheme used by Webb and his colleagues (2006) that distinguished between the simplest and the most complex behaviors. We synthesized these schemes into four ever-increasing cognitive levels (see Criteria and Examples of Four Levels of Cognitive Domains, below): (a) yes/no decision (Level I, CE), (b) factual knowledge (Level II, PE), (c) explanation and interpretation (Level III, PRE), and (d) evaluation or justification (Level IV, ME). While CEs may serve many roles, such as confirmation checks, the cognitive demands for making a legitimate response are quite low. For example the correct answer to a CE can be arrived at by guessing or giving confirmation (e.g., Koshik, 2005), but an appropriate response to an ME ("How did you arrive at that answer?") cannot be guessed at.

Following our scheme, as the cognitive level goes up, the mental processing expected to address the teacher elicitation gets more complex. For each level of cognitive complexity we provide examples from our corpus below (for a key to Jeffersonian notation, see Appendix B):

Criteria and Examples of Four Levels of Cognitive Domains

Level I: Choice elicitation (CE)

Criteria: Asking the respondent to produce a yes/no response or select among a fixed set of alternatives.

Example:

1. S: Well, there's <u>three</u> different sides of top (0.3) but they both share one.
2. →T: Ok↑a::↓y. so, it's a shared side?
3. S: Yeah.

Level II: Product elicitation (PE)

Criteria: Asking respondents to recall or describe factual mathematical knowledge or information.

Example:

1 →T: What shape is it? ((Teacher holds up a 4 x 4 x 4 cube composed of
2 wooden blocks)
3 Ss: Cube.

Level III: Process elicitation (PRE)

Criteria: Asking students to explain or give opinions. It produces new information from the respondent.

Example:

1. →T: If we wanted to look at some different cubes, how
2. would we identify other cubes we would consider?
3. S: Number of like the pieces of tape. If it has like... like Cathy has it up,

4. if it has like three: intercept, edge, and face. Two pieces of tape: it's
5. edge and face, and one piece of tape: it's a face, just a plain face. Zero,
6. it's a hidden.

Level IV: Metaprocess elicitation

Criteria: Asking the respondents to justify their own reasoning or make connections to ideas from the previous turns. It produces comments about old information from the respondent.

Example:

1. →T: You said subtract two then you said cube it. Why are you cubing
2. what you have left?
3. S: Because they're ah, they're, it's not just one row. There's... if we have
4. a side length of five, then there's um (2.7) there's three (3.0) ah, three,
5. three top ones (1.4) no, I don't know.
6. T: You're on the right track
7. S:[There's..
8. →T: Anyone] what to (.) go ahead keep going.
9. S: There's three rows of three. So it goes three, three and then three. And
10. then there'd be another row behind that one and another row behind
11. that one.

We assume that the main reason elicitations lead to responses is that recipients have an *intrinsic motivation* for speaking whereby the current elicitation serves as an active stimulus for turn taking from listeners (e.g., adjacency pairs). Elicitation prompts forcefully and successfully draw out students' responses because they are conditionally relevant turns (Sacks, Schegloff, & Jefferson, 1974). Furthermore, the unique aspects of the formal classroom setting provide important constraints on the nature of the interactions, since the onus for managing classroom talk and turn taking is directed by the teacher. As McHoul (1978) notes: "only teachers can direct speakership in any creative way" (p. 188). The format of a classroom has no need for conversational techniques to obtain turns of multiple units, since the classroom uses a "heavily preallocated system" in which "local management" of turn taking is solely the sphere of teachers (p. 209).

Our basic unit of analysis is teacher utterance. Codes for each cognitive level were assigned to each utterance. For the coding of cognitive levels, we went beyond the surface structure of each elicitation and examined the content and function of each utterance within its sequence, following researchers like Drummond and Hopper (1993) and Nystrand and his colleagues (2003). Methods like conversation analysis consider the diverse functions that tokens play within sequences. For example, a prolonged utterance by the teacher could serve as an elicitation, inviting recipients to complete the teacher's current turn (Koshik, 2002). Another example of our functional analysis is evident when the teacher asked students to recall mathematical facts that were dealt with in a previous lesson (e.g., "Why do you square the number that we formulated last time? Do you remember?"). Here, the teacher's elicitation question was coded as a PE (see above) because the purpose of the elicitation in this context was to invite students to recite knowledge that they had already learned. Interrater reliability for coding the levels of cognitive complexity was 94.44% (Cohen's kappa = .94).

Findings

Analysis of our corpus revealed 551 teacher elicitations organized into 38 stanzas during the four sessions of the mathematics lesson. We briefly summarize several interesting patterns in these data before we delve into the specific classroom dynamics (see Table 1). First, the teacher used a variety of elicitation formats, which we organized into five categories (along with their relative frequencies): (a) questions (68.8%), (b) provocative statements (21%), (c) utterances that were intentionally prolonged by the teacher (3%), (d) use of a student's name (2.4%), and (e) requests to do something (4%). Examples of each type of format can be found in Appendix A.

Table 1
The Frequency (and Percentage) of Each Form of Teacher Elicitation by Cognitive Levels

	Total	**CE**	**PE**	**PRE**	**ME**
Questions	379 (68.8%)	116 (30.6%)	159 (42%)	27 (7.1%)	78 (20.6%)
Provocative statements	116 (21%)	19 (16.4%)	62 (53.5%)	19 (16.4%)	18 (15.5%)
Prolonged Utterances	18 (3.3%)	1 (5.6%)	15 (83.3%)	2 (11.1%)	0 (0%)
Use of a student's name	13 (2.4%)	1 (7.7%)	6 (46.2%)	1 (7.7%)	5 (38.5%)
Requests	22 (4%)	0 (0%)	15 (68.2%)	6 (27.3%)	1 (4.6%)
Total	551	137	257	55	102

Second, we found that the teacher provided prompts across the range of the four-level elicitation hierarchy. PE was the most common form (approximately 50% of all prompts), in keeping with the merits of student recall and their demonstration of factual knowledge, even when in the service of more conceptual reasoning and problem solving. The teacher used high-level prompts, which sought students' explanations and reflective thinking, least often.

Third, while the teacher adjusted his elicitations upward in the hierarchy about as often as he adjusted them downward, these adjustments were clearly influenced by the accuracy of students' statements. Table 2 shows that when students made correct statements, the subsequent elicitations were about twice as likely to move up the hierarchy (48 times, over the 4-day corpus) than down (24 times). When incorrect statements were made, the teacher was about twice as likely to move the next prompt down the hierarchy (32 times) than up (17 times). Partially correct responses were treated like a blend of correct and incorrect responses, with subsequent teacher elicitations going up and down about the same amount (12% and 18%, respectively). This supports our expectation that the teacher may move both up and down the elicitation hierarchy in a way that is responsive to students' knowledge exhibitions.

Table 2
The Frequency (and %) of Elicitation Adjustments Up, Down or No Change for Correct, Incorrect, and Partially Correct Responses by the Students over the Four Class Sessions

		Up	**Down**	**No change**	**Total**
All students' responses to a teacher elicitation	Correct	48 (45%)[a]	24 (23%)	74 (28%)	
	Incorrect	17 (16%)	32 (31%)	47 (18%)	
	Partially correct	13 (12%)	19 (18%)	54 (20%)	
	Neutral or others	28 (26.5%)	30 (28%)	91 (34%)	
	Subtotal	106	105	266	477
Unadjusted teacher elicitations due to absence of prior student response[b]					74
Total teacher elicitations					551

[a]Percentages are of total number of all responses for a given column. [b]The category *elicitations* with no prior response encompasses initial elicitations that do not follow from a prior response.

Finally, we found the predicted upward trend of the level of prompts made by the teacher over the four class periods (see Figure 1 and Table 3). By the final session, the lowest level CE prompts decreased by nearly 19%, while the highest level ME prompts showed a corresponding increase of 16% (see Figure 1).

Overall, there is evidence that the teacher adjusted his elicitations in a purposeful manner. It is against this backdrop that we illustrate how the teacher regulated the level of cognitive complexity of the instructional elicitations in reaction to students' responses and how this affected students' engagement and level of mathematical reasoning.

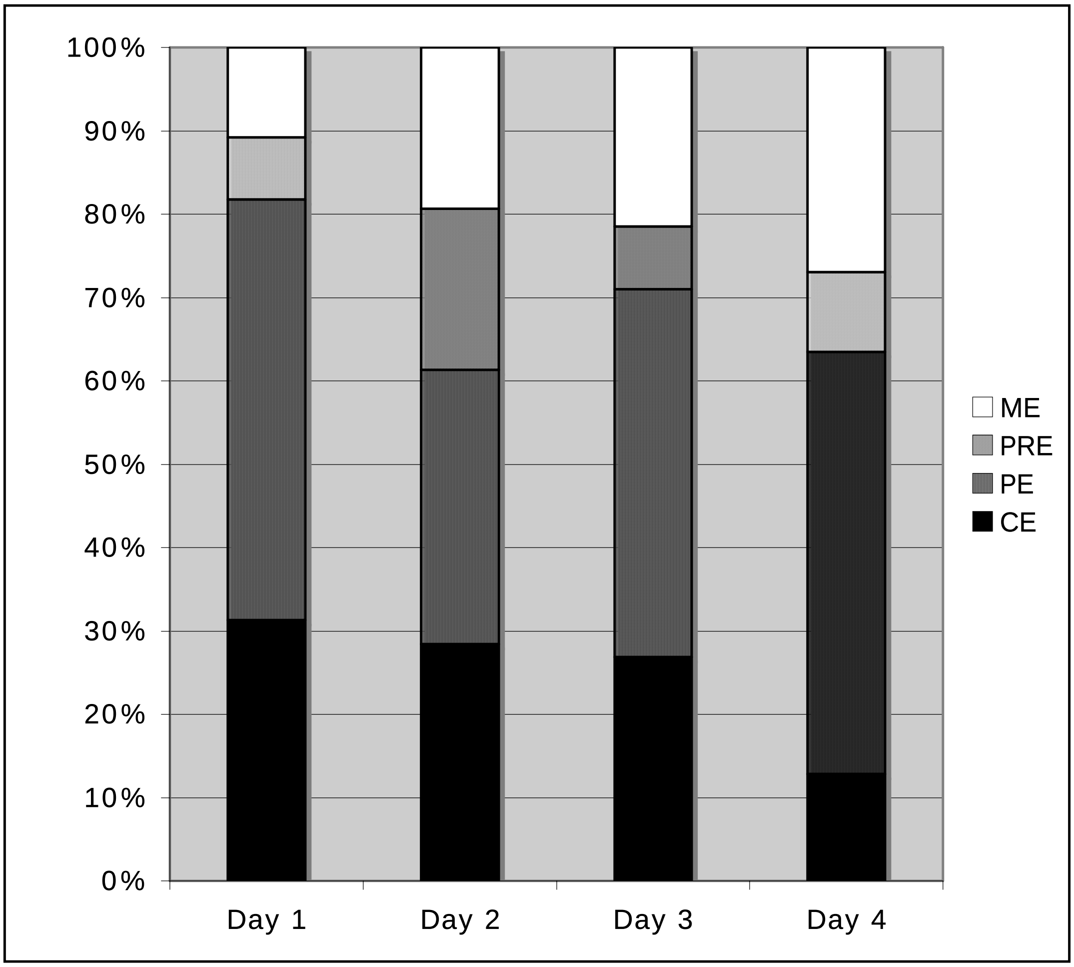

Figure 1. Percentage of each type of teacher elicitation used during each class session.

Table 3

*Frequency (and Percentage) of Each Type of Teacher Elicitation Used During Each Class Session (*N *= 551)*

	CE	PE	PRE	ME	Total
1st day	67	108	16	23	214
	31.3%	50.5%	7.5%	10.75%	
2nd day	25	29	17	17	88
	28.4%	32.9%	19.3%	19.3%	
3rd day	25	41	7	20	93
	26.9%	44.1%	7.5%	21.5%	
4th day	20	79	15	42	156
	12.8%	50.6%	9.6%	26.9%	
Total frequency	137	257	55	102	551

Teacher Elicitations Adjusted from Lower Order to Higher Order

In this first excerpt we illustrate how the teacher regulated the level of complexity of his elicitations in response to students' responses. Generally, when students struggled with the questions before them or when the group showed discord, the teacher adjusted the level of cognitive complexity of his elicitations downward. He often did this to provide interactional scaffolding, to publicly present relevant information that was foundational for a topic, or to direct students to solve a smaller piece of the larger problem. In contrast, when the students provided information that was mathematically correct, the teacher tended to increase the complexity of a subsequent elicitation. Often, he intended this increase to draw out elaborations of students' ideas or to elicit analytic justifications for their claims.

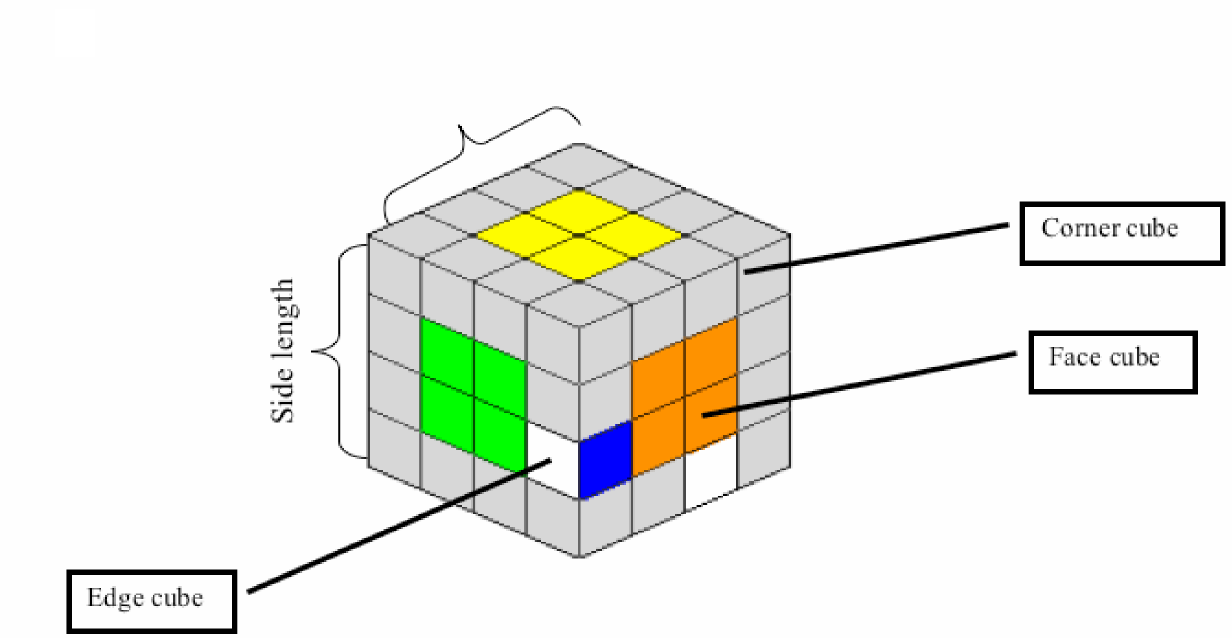

Figure 2. The anatomy of a cube as used by students in the class. The cube itself was made up of "minicubes," which were the individual blocks that played various structural roles on the finished cube, including edge cubes, face cubes, corner cubes, and hidden cubes (not shown).

In Excerpt I, the teacher was holding a wooden cube composed of smaller blocks ($4 \times 4 \times 4$). The assembled cube was about twice the size of his hand and easily visible from the back of the room. He oriented students to the upcoming unit on cubes by asking them what the wooden object (Figure 2) he was holding was called. Below, each elicitation is shown with the elicitation code (CE, PE, PRE or ME) to the left.

Excerpt 1: Naming the wooden object that the teacher holds in his hands

1. **PE-1→** T: What is it?
2. S1: A thing of blocks=
3. **PE-2→**T:=A thing of blocks. (0.4) OK, what shape is it? (.)

4. Ss: Cube.

5. S2: C[ube.

6. S3: A square.] (.)

7. Ss: Cube.

8. **PE- 3→** T: I just heard two answers (.) What shape is this? (.)

9. Ss: CUBE.

10. **CE-4→** T: Is this a square? (.)

11. Ss: No.

12. Ss: Yes. Yes. (.)

13. S2: Well it's a [square that is three dimensional.

14. S3: The sides of it are] sq[uares.

15. S1: It's a square cube.]

16. **CE-5→** T: The sides of it are squares,

17. S4: ºSquare faceº

18. **PE-6→** T: What would it... (0.7)

19. S1: It's a dice. (0.7)

20. S3: It's a [cube.

21. T: No, i]t is not a die.(0.8) It's a cube. ()

22. **ME-7→**T: So, why is this not a square? (0.5) This is not a square.() Why is it not?

23. S1: (   )

24. S5: Because a square, when you draw a square on like a paper, you just

25. draw equal sides, but a cube it has eight or six.

26. **PE- 8→** T: Has six what?

27. S5: A six flat sides, um, that are totally, that are totally equal and just a
28. regular square has one side on each face.
29. T: Okay. Henry.

Excerpt 1 shows how the teacher's elicitations led students initially to engage in lower level mathematical activities (e.g., to recall the name *cube*) but scaffolded them to eventually participate in higher order reasoning where they needed to justify their claims about the differences between two-dimensional squares and three-dimensional cubes. For example, the teacher started this new topic with a product elicitation (PE) question in Line 1 ("What is it?") and probed students' basic prior knowledge. Failing to get an appropriate mathematical response in Line 2, the teacher narrowed down the focus with the second PE question (Line 3) by asking "What shape is it?" This question succeeded in eliciting greater participation in this activity and led students to externalize their correct and incorrect ideas (Lines 4–7). The public exposure of misconceptions and inaccurate vocabulary is one of the documented benefits of discourse-based instruction, as it supports formative assessment (e.g., Nathan & Knuth, 2003) and creates an opportunity for re-teaching.

Although S3 produced erroneous mathematical information in Line 6, the teacher did not respond with evaluative negative feedback (Line 8). Rather, reformulating the previous question more specifically with a referential pronoun *this*, the teacher again engaged students' participation, and finally elicited the chorus of accurate answers from students (Line 9). Notwithstanding the correct responses, the lower level CE question in Line 10 targeted students' erroneous responses from an earlier turn (Line 6). This question provided one more opportunity for students to reflect on and restructure their thinking. This elicitation technique played a crucial role in generating more participation from students, as Lines 11–15 show. In this process of questioning and answering, the respondents produced multiple answers as well as longer turns. Even though some students were still confused and generated inaccurate mathematical terminology, such as *squares* and *square cube*, or somewhat incomplete responses, such as *square face*, the teacher continued to present elicitations. These elicitation questions provided interactional scaffolding, which drove the learners to verbalize their thinking and repair errors made by themselves and their peers (Line 20).

We also see the cognitive level of elicitation shift upward into the highest ME question in Line 22. After receiving correct mathematical responses and reiterating the proper terminology himself, the teacher then went on to probe the deeper reasoning behind the correct mathematical information. His approach was to go beyond the correct identification of the cube shape and to explore its unique properties and contrast them with the properties of the square. When this higher order ME question elicited a partially (but not completely) correct rationale from a student (Lines 24 and 25), we saw the teacher again regulating the cognitive complexity of his queries down to a lower level PE (Line 26). The PE partly served as a form of mitigated feedback (Nathan & Kim, 2006) and provided an opportunity for the student to externalize his own thinking and test his claim, as Swain (2000) maintained. In the subsequent turn (Lines 27–28), the respondent repaired his own error and provided the correct reasoning of how a cube is distinguished from a square. Finally, this correct response got a positive evaluation ("Okay") from the teacher in Line 29.

As illustrated above, the teacher interactionally scaffolded learners to upgrade their current level of reasoning and reach for higher order mathematical thinking that was accessible within their ZPD. As Webb and his colleagues (2006) asserted, this teacher moved from lower to higher level prompts that asked students to provide evidence or a rationale for their own responses. These elicitation questions played an essential role in providing more opportunities for students to verbalize their mathematical thinking and to engage in more sophisticated reasoning. Moreover, students' utterances created teaching opportunities for both speakers and listeners. Consistent with this, Valsiner (2001) argued that verbally articulating speaker's ideas influences listeners' cognition (hetero-regulation) while restructuring mental processing of the speakers themselves (auto-regulation).

Follow-Up Metaprocess Prompts to Elicit Higher Order Ways of Thinking

The second excerpt shows how the teacher probed the students' unspoken rationale for their mathematically accurate and inaccurate responses. This type of probe taps into higher order thinking because the students are being invited to justify their ways of thinking. In these data, the highest level metaprocess prompts (ME) were made in order to elicit multiple explanations for a formula that students generated and then used to compute the number of face cubes for a cube of any side length—that is, $(\text{side length} - 2)^2 \times 6$. At times, the ME need not be anything more than a back-channel (or *continuer*, Schegloff, 1982). We considered its function as encouraging the teller to continue. We also considered the contexts and looked to see what cognitive level was being encouraged. In this excerpt, the various parts of the cube as they were referenced by the members of the class are illustrated in Figure 2.

Excerpt 2: Reasoning underlying students' squaring of the number

1. **ME-1→**T: Why are you squaring something? Why are you squaring the
2. difference? Why are you squaring this new number?
3. S6: It's equivalent of multiplying it by itself.
4. **ME-2→**T: WHY?
5. Ss: (5.0) (no response)
6. T: It might help you if you see some more squares. (0.3) Some more faces.
7. ((At the white board, the teacher fills in the face cubes on the board with a
8. red color)) <u>Fa</u>ce cubes. <u>Fa</u>ce cubes.
9. S6: Oh, oh, oh, oh, oh.
10. **ME-3→**T: Why are you <u>squa</u>ring this difference? (.) Can't really see the red,

sorry. (Student's name)

S6: Um, so it's the side length minus two for the first square would be one,

ME-4→T: Uh huh.

S6: and, and when it (indecipherable) the second square four, side length minus two would be two.

ME5→T: Uh huh.

S6: Then squared, two times two is four that would give you the first face. Multiply that by six and you get all the faces. That's why you square it.

ME-6→ T: I'm not sure I'm following why. I understand multiplying it by six all the faces, but I didn't follow why you squared it. I think I understood but I'm not sure I completely followed it.

S6: You square it because that'll give you the two. When you have a flat square.

ME-7→T: Uh huh.

S6: You multiply one side by the other side to get the area, (.) it's just doing it backwards. Squaring it to get the whole area.

(6 lines omitted)

In pattern generalization tasks, students may be directed to find formulae that make the numbers work procedurally, but they may not understand structurally why they work or what the mathematics is "saying" about the patterns involved. This is akin to Piaget's distinction between *simple abstraction*—abstraction drawn from the objects themselves—and *reflective* or *reflecting abstraction*—abstraction of invariant features drawn from the (physical and mental) actions performed (Piaget, 2001). The latter requires the construction of new and more advanced cognitive structures.

The long-term objective of algebra instruction is to develop in students the capacity for reflecting abstraction and an appreciation of the meaning, utility, and properties of mathematical structures. In Excerpt 2 the teacher sought to scaffold students' understanding of the meaning of the formula for the number of face cubes for a cube of any side length. Face cubes must be counted exclusive of edge cubes (Figure 2), so the edge cubes must be mathematically removed (hence, side length – 2). Since face cubes grow with the surface area of the cube, the number of face cubes is in quadratic relation to the cube's side length (hence (side length – 2)^2).

In order to provide this scaffolding, the teacher used open-ended ME prompts to further students' reasoning after they successfully produced the correct formula for how to calculate the number of face cubes. In Line 1, the teacher asked about the use of squaring. The student response (Line 3) was generic; it applied to any squaring operation but said nothing about why squaring was warranted in this particular situation. Hearing only a partially correct response from a student, the teacher put forth a direct question (Line 4), "Why?" But even with considerable wait time there was no response (Line 5).

In Lines 6 and 7, the teacher pursued an inductive path, asking students to examine their tables of numbers and look for patterns across the different size cubes. A student provided a think aloud (Line 12) for the first entry in the table, a 3 x 3 x 3 cube, essentially applying the formula that they were all seeking to interpret. It is clear that the student understood how to apply the formula (Lines 12–19), and the meaning assigned to multiplication by six (to "get all the faces"; Line 18). The teacher provided back-channels "uh huh" (Line 13 and 16) to show that he was following, but, as with a *designedly incomplete utterance* (Koshik, 2002), the teacher was still expecting the ME prompt to be addressed. However, the students' explanation for squaring was still inadequate from a pedagogical standpoint.

The teacher provided no negative feedback in response to students' inaccurate responses until Line 20. When the teacher gave indirect negative feedback "I'm not sure I'm following why… I didn't follow why you squared it," this feedback operated as another ME question because it invited the audience's response to the question "Why?" Despite an inaccurate explanation from S6 (Lines 23–24), the teacher acknowledged the students' contribution (Line 25) but did not provide a negative evaluation or voice his own thoughts—actions that might have closed off student discussion. Whereas direct negative feedback might stifle further discussion and student engagement, the form of interactional scaffolding chosen by the teacher stimulated further involvement (Nassaji & Wells, 2000). In fact, another student (Lines 26–27) took up the invitation and made public the important connection of squaring to computing area.

This episode demonstrates how ME prompts scaffold students to engage in higher order mathematical reasoning, particularly that of reflecting on the mathematical structures that they created when generalizing from the patterns presented numerically in tables. In this interactional scaffolding, each ME prompt functions as a steppingstone for students to move further out beyond their original, unassisted thinking, to explore more complex mathematical reasoning (Verplaetse, 2000; Walsh & Sattes, 2005).

Making an Erroneous Statement to Elicit Deeper Mathematical Reasoning

In the previous excerpts we saw how the teacher regulated the cognitive demands placed on students based on their responses. In particular, in Excerpt 1 we saw that mathematically acceptable answers are often followed by higher order elicitations that are intended to engage students in public reflection, elaboration, and justification of their ideas. When students were unable to meet the current demand, the teacher offered lower order questions that invited students' participation and bolstered students' knowledge in order to support an upward move later in the discourse. In Excerpt 2 we looked more closely at how metaprocess prompts of the highest order can elicit the highest order reasoning, that of applying students' thinking more broadly and providing justifications and interpretations for mathematical generalizations.

In this final excerpt, we show how the teacher used another device—the "trick question"—to engage students in the classroom discourse and guide them to think deeply about the mathematics. Prior to the events described below, learners provided an accurate answer and a legitimate account of their mathematical reasoning for calculating the total number of blocks—or *minicubes*, as they came to be called (Figure 2)—needed to assemble a cube of any particular side length. In so doing, they developed the formula for the volume of a cube. However, the teacher wanted them to understand the idea of volume in a way that decoupled it from the notion of surface area, which is another way to describe the size of an object that seemed to confuse some students in this and other classes.

Originally, the teacher probed students for the meaning of their formula for volume, $(\text{side length})^3$. Failing to elicit the reasoning he was after, the teacher made an unusual shift: he intentionally made an *inaccurate* mathematical statement—a "trick question"—designed, apparently, to lead students to recognize and challenge it using counterfactual reasoning and other higher order forms of metaprocessing. Using physical materials as well as verbal and nonverbal responses, students negotiated the mathematical concepts and finally demonstrated to the class why the teacher's proposal was, in fact, incorrect. In so doing, students provided an analytic distinction between surface area and volume. This example illustrates another perspective of how the discourse can be regulated to foster metaprocess-level reasoning in reaction to a mathematically correct response.

Excerpt 3

ME1→T: I've had some people tell me that I can also count sixteen on the top and there's six sides so sixteen times six that's ninety-six cubes plus the middle, ninety-six cubes plus the middle, so the whole bunch of ones in the middle so that actually gets me up to one hundred four I think cubes. One hundred four cubes.

S7: That kind is cr↑azy↓.

ME2→ T: Gets me up to one hundred f↑ou↓r I think cubes. One hundred f↑ou↓r cubes.

S8: That's all right.

10. S6: If you did th↑a::t on each s↑i::↓de then you count the t↑o↓p then one of

11. the sides, (.) you'd be counting f↑ou↓r more over again. (0.3)

12. **ME3→**T: What do you mean counting four more over again?

((5 lines omitted))

13. S6: See::. ((going to the front of the class and turning around the desk

14. with the cubes)) see, (pointing a colored cube on the desk)

15. S1: I have something else.

16. S6: Se↑e:: see::↑ count thi::s to↑p, (.) ((spreading horizontally his palm on

17. the top layer)) and then you count one of the s↑i↓des you're counting the

18. four ↑edg↓es again. ((pointing to each face of the cube with the palm))

19. T: A::h,

20. S1: But you don't c↑ou↓nt the s↑i↓des. you count in l↑ay↓ers.

21. S6: Yeah ex↑act↓ly.

22. T: [So, so

23. S6: Sixt]↑ee:::n (0.3) times sixt↑ee↓n ((spreading his fingers horizontally

24. on the top layer)) or sixteen times one times, two times, three

25. ((indicating the second, the third, and the bottom layer with the palm))

26. sixteen times f↑ou↓r ((indicating the top layer with his palm several

27. times)). There's four l↑ay↓ers, so sixteen times four.

In this excerpt, the teacher prompted student involvement through a provocative assertion that conveyed the (intentionally) erroneous idea (Lines 1–5) that the total number of minicubes making up the large 4 x 4 x 4 cube was arrived at by computing the surface area (which is 96 *square* units) rather than the volume (64 *cubic* units). In addition, the teacher made another erroneous statement (Lines 3 and 7–8), because the total number should be the sum of the eight hidden cubes (a finding previously established) plus the ninety-six on the surface, to make up the entire volume of the cube, one hundred four minicubes.

The erroneous statements by the teacher constituted a violation of Grice’s conversational maxim of quality. However, the teacher effectively elicited evidence from students for and against the claim and required students to make comparisons while applying previous knowledge to a new situation. This had the potential to draw students into counterfactual reasoning, which Piaget (Inhelder & Piaget, 1954) identified as the most advanced form of logical reasoning. For these reasons, we coded this as an ME prompt.

The approach successfully promoted students’ active participation. S8 (Line 9) asserted that the teacher’s idea was right, while others (e.g., S7 in Line 6) strongly disagreed. In the subsequent turns (Lines 10 and 11), S6 argued against the teacher’s reasoning based on structural considerations. He claimed that with the teacher’s approach some mini-cubes would be counted twice, which violated basic rules about counting. Thus, S6 demonstrated very high-level justifications against the teacher’s original (erroneous) assertion, essentially using a form of proof-by-contradiction.

In response, the teacher provided another ME question to further draw out S6’s mathematical reasoning (Line 12). This prompted S6 to explain what he meant by “counting four more over again.” S6 voluntarily came to the front of the classroom to prove why the teacher’s reasoning contained a conceptual error (Lines 13–14, 16–18). This student used the physical materials as a representational tool to externalize his mathematical thinking and provide common ground for all of the participants. Gestures as well as speech were employed to enact the conceptual reasoning that had up to this point been exclusively part of S6’s internal mental processing. Specifically, the gestures pointing to the six faces showed the shared edges between the faces where the teacher double-counted.

S1 initiated further repair to the teacher’s erroneous statement using verbal descriptions and gestures to show that the double-counting problem would be avoided if they calculated the volume using a layer-based system of counting (Line 20), rather than quantifying all mini-cubes on each side. S6 showed his deep understanding by accepting S1’s repair (Line 21), and he went on to appropriate another student’s approach. With his fingers and palm spreading out on the surface of the cube, S6 reified S8’s layer method (Lines 23–27). As a result, using iconic gestures to denote the layered structure of the assembled cube along with the physical blocks themselves, S6 and S1 were able to co-construct an argument that disproved the teacher’s erroneous claim. It is also clear how the teacher’s elicitation technique using an erroneous claim was an effective way to engage students in the discourse and guide them to exercise the deep and complex mathematical processing of which they were capable.

Conclusion

In this age of education reform emphasizing the social and linguistic nature of knowledge construction (e.g., Vygotsky, 1987; Wertsch, 1979, 1994), there is a pressing need to understand how teachers use classroom talk as a mediational tool to foster higher order reasoning among students. While there is extensive research that focuses on teachers’ use of negative feedback in response to students’ erroneous utterances (e.g., Lyster, 1998; Lyster & Ranta, 1997; Nathan & Kim, 2006; Panova & Lyster, 2002), the analysis presented here illustrates how the instructor’s management of classroom talk was informed by correct as well as incorrect responses from learners.

The data presented here show how one teacher's elicitations promoted students' classroom participation and mediated mental processing by scaffolding students' mathematical discourse in a manner that helped them advance from the factual-knowledge level to higher levels of mathematical thinking and speaking. For example, when students gave inaccurate or incomplete answers, the teacher did not give direct, negative feedback, but instead reduced the level of cognitive complexity needed to respond. This helped engage students by saving face (Seedhouse 2004), while providing opportunities for participation and context-specific instruction that filled gaps in students' knowledge. Thus, the teacher scaffolded student participation and reasoning by decreasing the cognitive demands placed on them.

It was also clear that the teacher regulated the level of discourse as a reaction to students' successes as well. He often increased the elicitation level when students provided responses that were mathematically accurate. In this way, the teacher could assay the conceptual foundation upon which students' responses rested, and guide students to engage in more sophisticated forms of reasoning (Nassaji & Wells, 2000). It allowed students to operate at the outer edges of their respective ZPDs (Vygotsky, 1978; also see Bruner, 1984), to "try on" the kind of mathematical thinking that was ultimately expected of them, and to see what that form of cognitive activity was like from the inside. Over time, this approach influenced students' reasoning as they internalized the public pattern of discourse activity into their own forms of reasoning and reflection. This is evident from their greater use of meta-process statements such as making connections across mathematical ideas and providing justifications.

Instruction of this sort should be seen as socially mediated and communicative. When students model mathematical thinking and speech for one another, it helps to create a climate of discursive mathematical practice. At the same time, expressing a plurality of views invites students to listen and publicly evaluate multiple forms of mathematical reasoning and expression that might otherwise remain tacit. Students in this kind of learning environment need to consider alternative perspectives (Greeno & McWhinney, 2006) and work in both intra- and inter-psychological realms to establish a shared understanding (e.g., Lerman, 2001; Matusov, 1996; Nathan et al., in press). An example from our data was the way the trick question posed by the teacher engaged students in evaluative reasoning and counterfactual argumentation that helped them to cultivate higher level cognitive processes.

These data present a brief portrait of the forms that discourse-based styles of teaching can employ and reveal some of the power of this method for regulating student participation and facilitating higher order cognitive functioning and conceptual development. However, this portrayal is necessarily limited, based on several days of a single, beginning-level algebra class. Cases of this sort help us to develop the theory and methods necessary to study these behaviors in greater depth. It must be left to future studies to demonstrate the relationship between classroom talk and cognitive development, and to establish the extent to which these instructional strategies are applied skillfully in classroom settings.

Classroom discourse serves as a window through which we can observe communication and socially mediated learning and come to understand their interrelationship as they occur in natural settings. It also illustrates the value of dynamically diagnosing the current knowledge levels of speakers through their discourse as a way to inform and adjust instruction to suit each learner's ZPD. We believe that interactional scaffolding carried out in this manner is an effective way to nurture learners' cognitive development. This work also suggests that viewing instruction as communication provides valuable theoretical and methodological resources for advancing our understanding of classroom interactions.

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Appendix A

Examples of Each Type of Teacher Elicitation

1. Questions

1. S2: It's 4 by 4 right? 4 by 4. And,
2. →T: Well I'm sorry, why do you say 4 by 4?
3. S3: Because the four cubes.
4. S2: It's 4 by 6
5. S3: What are you talking about?
6. →T: What's 4 what by 4 what?
7. S: 4 cubes.. one side.. has four cubes in a row, by four cubes like that.

2. Provocative statements

1. S2: I remember them, but I forgot.
2. →T: OK, you called them edges, you called them corners, I heard something
3. else.
4. S3: Axis.
1. .

3. Prolonged teacher's utterances

1. S: Well the ones with three, just call them intercepts. The ones with two
2. to just count the edges, and the ones with one to just count the faces.
3. →T: Okay. So:::
4. S: So you don't count the faces on the intercepts.

4. Use of a student's name

1. S: Add two... if you add two.

2. →T: Jason↑
3. S: Um, okay, you take the side length and you square it and you take that answer and you multiply it by the side length again.

6. Requests to do something

1. S: Like the points.
2. →T: Here, come show us.
3. S: I can’t remember what they’re called but, it’s like this. Goes around
4. there, there, there, comes down here, there’s eight of them if you
5. count them all.
6. T: Ah! Very good.

Appendix B

Transcription Excerpts with Jeffersonian Notation Transcription Conventions

[	Point of overlap onset
]	Point of overlap termination
=	No interval between adjacent two turns
(2.3)	Interval between utterances (in seconds)
(.)	Very short untimed pause
<u>word</u>	Speaker emphasis
the:::	Lengthening of the preceding sound
?	Rising intonation, not necessarily a question
,	Low-rising intonation, suggesting continuation
.	Falling (final) intonation
CAPITALS	Especially loud sounds relative to surrounding talk
° °	Utterances between degree signs are noticeably quieter than surrounding talk
↑ ↓	Marked shifts into higher or lower pitch in the utterance following the arrow
( )	A stretch of unclear or unintelligible speech
(( ))	Nonverbal actions