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When Smart Groups Fail

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In this study I investigated how collaborative interactions influence problem-solving outcomes. Conversations of twelve 6th-grade triads were analyzed utilizing quantitative and qualitative methods. Neither prior achievement of group members nor the generation of correct ideas for solution could account for between-triad differences in problem-solving outcomes. Instead, both characteristics of proposals and partner responsiveness were important correlates of the uptake and documentation of correct ideas by the group. Less successful groups ignored or rejected correct proposals, whereas more successful groups discussed or accepted them. Conversations in less successful groups were relatively incoherent as measured by the extent that proposals for solutions in these groups were connected with preceding discussions. Performance differences observed in triads extended to subsequent problem-solving sessions during which all students solved the same kinds of problems independently. These findings suggest that the quality of interaction had implications for learning. Case study descriptions illustrate the interweaving of social and cognitive factors involved in establishing a joint problem-solving space. A dual-space model of what collaboration requires of participants is described to clarify how the content of the problem and the relational context are interdependent aspects of the collaborative situation. How participants manage these interacting spaces is critical to the outcome of their work and helps account for variability in collaborative outcomes. Directions for future research that may help teachers, students, and designers of educational environments learn to see and foster productive interactional practices are proposed.

The properties of groups of minds in interaction with each other, or the properties of the interaction between individual minds and artifacts in the world, are frequently at the heart of intelligent human performance (Hutchins, 1993, p. 62).

Collaborative intellectual activity can be a fertile context for learning and discovery, and we have much to learn about how to foster it. Historical and first-person

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accounts of creative work provide evidence that intellectual intimacy takes a variety of forms, including intense face-to-face exchanges, commentary that leads to revision of papers or other products, coproduction of designed or artistic artifacts, and membership in a community of scholars or practitioners who exchange ideas distally and structure opportunities for public sharing. These studies suggest that intense interaction between partners nurtures achievements when partners share interests, knowledge, personal history, and a commitment to the work (Csikszentmihalyi & Sawyer, 1995; John-Steiner, 2000). Recent ethnographic and experimental studies of scientific practice provide even more detailed evidence of the consequential ways in which social interactional processes contribute to the generation of theories, the design of experiments, and the sorting of evidence and warrants (Dunbar, 1997; Lemke, 1990; Okada & Simon, 1997).

Despite the potential of collaboration, groups are too frequently a source of aggravation for individual members, leading to wasted time and feelings of discouragement (Salomon & Globerson, 1989). Most striking are accounts in which the average prior knowledge of a group or dyad is equivalent, and the collaborative work assigned is the same, but the problem-solving and learning outcomes resulting from the members’ interactions differ significantly (Barron, 2000a; Hogan, Natasi, & Pressley, 2000; Webb, Zuniga, & Welner, 2001). These data suggest that there is much more to collective thinking than pooling knowledge and that although the capacity for mutual, coregulated engagement emerges in infancy (Stern, 1977; Trevarthen & Aitken, 2001), its achievement is never guaranteed.

A close look at research on collaboration and learning suggests the need for a better understanding of how social and cognitive factors intertwine in the accomplishment of collective thinking. Research on short-term collaboration among school-aged peers has compared group problem-solving outcomes to individual problem-solving outcomes and generally found that, on average, group work leads to better problem-solving and learning outcomes (Barron, 2000b; Johnson & Johnson, 1981; R. J. Stevens & Slavin, 1995; Webb & Palinscar, 1996). However, less research attention has been directed toward the variance between groups. Research on cognitive mediators of collaborative learning makes the important point that it is not simply the act of asking children to work in groups that is essential but rather the possibility that certain kinds of learning processes can be activated (Cohen, 1994). These include opportunities to share original insights (Bos, 1937), resolve differing perspectives through argument (Amigues, 1988; Phelps & Damon, 1989), explain one’s thinking about a phenomenon (King, 1990; Webb, Troper, & Fall, 1995), provide critiques (Bos, 1937), observe the strategies of others (Azmitia, 1988), and listen to explanations (Coleman, 1998; Hatano & Inagaki, 1991; Webb, 1985). There is even some intriguing experimental evidence that collaborators can generate strategies and abstract problem representations that are extremely unlikely to be observed when individuals work alone, suggesting that there are unique affordances of joint thinking (Schwartz, 1995; Shirouzu, Miyake, & Masukawa, 2002).
A key agenda for research on collaborative learning involves understanding the emergence of these kinds of opportunities and the processes that disrupt their emergence. Hutchins (1993, 1995) argued that human intelligent action is productively conceived as an accomplishment that arises from properties of interactions between people or between people and artifacts in the world. How a particular interaction unfolds depends on the efforts of the individuals involved, their understanding of the activity, the material resources they have available, and implicit or explicit conventions for proceeding with joint work. A core implication of this view is that to understand the nature of productive collaboration, we need to articulate how social goals and discourse practices interact with knowledge-building processes that lead to coconstruction of understanding. There is a need for better articulation of the characteristics of interactions that lead to differentially productive joint efforts.

To make progress on this agenda, measurement approaches are needed that capture variation in conversational exchanges and allow for analyses that preserve the group as the primary unit of analysis. Quantitative studies of collaboration frequently focus on the measurement of variables defined at the level of the individual and their effect on collaborative outcomes. For example, there are numerous studies that focus on the relation of group composition to collaborative outcomes in which composition is defined with respect to gender, prior achievement, personality, or other individual traits (Fuchs, Fuchs, Hamlett, & Karns, 1998; Hill, 1982). Process studies have also relied on individually measured behavioral variables as a way to assess mechanisms of collaborative learning. In these studies variables such as the number of explanations given during collaborative activities are correlated with learning outcomes (e.g., Webb, 1989) and the primary unit of analyses is the individual. Studies of conversational patterns that preserve the group as the unit of analyses may provide new insights about how and why some conversations are more generative than others for collective work and the emergence of learning opportunities.

The research in this article is concerned with advancing the understanding of how microinteractional processes between collaborators influence collective achievements and what individuals learn from their interactions. The analysis was initially motivated by an experiment on collaborative learning that found average benefits for sixth-grade triads over individuals asked to solve a mathematical and planning problem, but also revealed variability in group performance despite random assignment of high-achieving students to same-gender triads (Barron, 2000b). Subsequent case study comparative research (Barron, 2000a) suggested that to explain differences in collective accomplishment it would be important to develop constructs that reflect differences at the interactional level—that is, constructs that reflect between-person phenomena. In this article I extend the analyses to 12 groups and share three main general observations about collaborative ventures that might advance our understanding of how and why variability in collabo-
rative outcomes can occur, even when the knowledge or insights that individual members generate does not differ between groups. The evidence for these generalizations is provided later, but the main ideas in brief are as follows:

1. The management of attention is a fundamental aspect of interactional work during collaborative problem solving. Joint attention at solution-critical moments is crucial for the establishment of a joint problem space (Roschelle, 1992; Teasley & Roschelle, 1993) in order for there to be synergy of efforts and achievement of intersubjectivity. Challenges to the creation of joint problem-solving spaces emerge as individual participants are simultaneously managing their own efforts to understand pieces of the problem and trying to understand what others are doing. An important accomplishment is the coordination of attention so that joint engagement can proceed. The data in this article suggest that the achievement of joint attention was consequential for problem solving and learning.

2. Both speakers and listeners have consequential roles to play in establishing joint attention. Joint attention has primarily been studied during early development as it is first observed between 9 and 15 months (Adamson & Bakeman, 1991). Studies of infant–mother interaction provide interesting insights about the subtle ways in which partners help regulate the attention of the other and highlight how both partners are active contributors to the process. Studies of adult discourse also point to the highly skilled nature of multiparty talk (Goffman, 1981). The observations of elementary school participants in this article make clear the barriers that some participants faced having their ideas heard and how this was particularly challenging if partners were self-focused. Some participants were successful in gaining attention even under less than ideal conditions if they were persistent in their efforts. The examples in this article highlight how speakers and listeners are engaged in a dynamic, interdependent process that can be influenced by a variety of attention regulating strategies.

3. Relational aspects of the interpersonal context are needed to explain between-triad differences in the effective coordination of a joint problem-solving space. A close look at the interaction of some of the more challenged triads in this sample indicates that an analysis that only takes into account the cognitive aspects of the establishment of a “joint problem space” (Teasley & Roschelle, 1993, p. 229) will be inadequate for understanding variability in collaborative accomplishment. Collaboration might productively be thought of as involving a dual-problem space that participants must simultaneously attend to and develop a content space (consisting of the problem to be solved) and a relational space (consisting of the interactional challenges and opportunities). The content space and relational space are negotiated simultaneously and can compete for limited attention. Information made available in the space from the self and from others’ activities must be integrated. One needs to be able to monitor and evaluate one’s own epistemic process while tracking and evaluating others’ epistemic processes.
(e.g., Can I see how my partners are thinking, and do I agree with their reasoning?). The relational context is similarly complex and can be loaded with issues of identity related to both the self and one’s partners. For example, if I am more compelled by the thinking of a partner than by my own, can I subjugate my assertiveness in the process and have enough ego strength to support another? Conversely, if I am more compelled and convinced by my own thinking can I assert it strongly even if it means shifting the focus from another and perhaps risking offense? And, what if I do attempt to share insight and it is ignored or misunderstood, then how should this be interpreted and what should be done? Identity issues can emerge in other forms, for example, if I have no idea what you are talking about or what direction the problem solving should take, am I willing to express confusion or uncertainty with respect to ideas on the table? Coordinated mutual engagement (Bakeman & Adamson, 1984) can be challenged by issues that can arise in both of these spaces, and its accomplishment is both an interpersonal- and content-related process. The less successful groups in this data set exhibited relational issues that challenged mutual engagement and prevented the group from capitalizing on the insights of members.

In this article I present analyses that address three questions:

1. What interactional processes are associated with better group problem solving?
2. How does the quality group problem solving relate to individual learning as indicated by subsequent independent performance on the same and a related problem?
3. What social and cognitive factors contribute to the emergence of more and less productive interactional patterns?

Following a brief literature review, both cross-case quantitative analyses and idiographic case studies are presented that address these questions. These approaches correspond roughly to what Jerome Bruner (1986, pp. 12–13) called the “paradigmatic” and the “narrative” modes of knowing. First, results from quantitative analyses of the conversations of all 12 groups will be shared. Measures were developed to reflect phenomena observed in the earlier cases studied (see Barron, 2000a) and to appraise the conjectures just listed. These are analyzed by statistically comparing their frequency in more and less successful groups’ conversations. In addition, the learning outcomes of members of more and less successful triads are compared. In a later section these phenomena are exemplified in the context of actual conversations of four groups who differed in their success level. An idiographic approach is used to illustrate how social and cognitive events unfold over time within a particular group of children. These qualitative accounts are used to further illustrate the interweaving of social and cognitive factors in the regulation of collaborative work and concretize the afore-
mentioned ideas. Narrative description is used to provide what Geertz (1973) called “thick description” (p. 7). Features of interaction such as gestures, intonation, facial expressions, eye gaze, and body language are all communicative acts and thus play a critical role in the analysis.

RESEARCH THAT HIGHLIGHTS THE NEED TO UNDERSTAND COLLABORATIVE VARIABILITY

Case study research provides detailed portraits of collaborative interactions that are missing in studies that look for patterns across many groups. Clark (1996, p. 3) used the term “ensembles” to capture the interdependencies of partners in conversation. By focusing on the group or ensemble, researchers can describe interactions that capture the dynamic interplay in meaning making over time in discourse between participants, what they understand, the material resources they use, the types of contributions that they make, and how they are taken up or not in a given discourse. This kind of research highlights the complexity of learning together and can identify key processes. For example, the key notion of a joint problem-space was generated from a careful case study analysis (Roschelle, 1992; Teasley & Roschelle, 1993). A joint problem-space was defined as a shared conceptual structure developed in the course of collaborative work. In a study of two girls using a computer simulation designed to provide a dynamic view of velocity and acceleration, Roschelle argued that the creation of a joint problem-solving space was accomplished through repeated cycles of displaying, confirming, and repairing understandings. As the conversation progressed, the students expected increasingly explicit evidence that they understood one another. Although Roschelle’s analyses focused mostly on the cognitive aspects of creating a joint problem-space, other studies suggest that to deeply understand the nature of productive collaboration, attention must be paid to the ecology of relations that develops within interactions that allow group members to access and functionally express knowledge and other cognitive resources.

A recent article by Engle and Conant (2002) contributes to this research by analyzing the productive disciplinary engagement of a group of elementary school students. The students become involved in a sustained debate about the proper biological classification of Orcas as whales or dolphins. Driven by contradictory claims offered by various experts and adopted by opposing group members, this controversy remained alive for students over several weeks and reemerged in their discussions on eight occasions. Students’ passionate engagement was reflected in intensive emotional displays, persistence in having their ideas heard, additional research, and continued attention over weeks. A key aspect of their discourse that allowed for productive learning conversations rather than devolving into argumentative shouting matches was the appropriation of scholarly moves such as the use of
various kinds of evidence to justify their claims. In addition, the analysis of talk made it clear that although at times students spoke over one another and competed for floor time, they held themselves accountable to the contributions that others made. This was indicated by the proportions of turns in which students associated particular group members with controversy-relevant claims or evidence. Engle and Conant called this process “positioning” (pp. 480–483). This group work took place in a research-based experimental classroom designed as part of A. L. Brown and Campione’s (1996) Community of Learners Project. The arrangements for collaboration were theoretically driven, and the analyses pointed to four conditions that made the debate possible:

1. Making the subject matter problematic.
2. Giving students authority to address such problems.
3. Holding students accountable to disciplinary norms.
4. Providing relevant research resources.

Other case studies foreground more disappointing interactions that emerge despite the best of intentions to offer reform-based activities. For example, in a recent article Sfard and Kieran (2001) used a single case to question the claim that mathematics learning is best done in interaction. They described episodes from a dyad participating in a 30-hr-long algebra sequence designed to support students’ algebraic thinking. Two episodes of problem solving characterized by ineffectual communication were analyzed, showing a discrepancy between the two boys’ effort and willingness to work to understand one another. One boy continually tried to engage the other but was unsuccessful. These disparities led to less than ideal conditions for learning. In the end, the authors were cautious: “The road to mutual understanding is so winding and full of pitfalls that success in communication looks like a miracle” (p. 70).

Within-study, between-group variability in problem-solving outcomes have also been reported (Forman & Cazden, 1985; Resnick, Salmon, Zeitz, Wathen, & Holowchak, 1993). For example, the level of reasoning expressed in conversation in the context of an instructional unit designed to support the development of students’ knowledge of the nature of matter was described by Hogan, Natasi, and Pressley (2000). Knowledge-building dialogue was coded as one of three major patterns: consensual, responsive, or elaborative. They noted that, despite having an identical task, one of their four groups had a great deal of difficulty sustaining knowledge-building conversations on their own. The most successful group had high rates of affirming, agreeing, and accepting remarks. These kinds of responses served to prolong the discussion of ideas and led to higher levels of reasoning. Why one group had more trouble was unclear; however, their difficulties resulted in more teacher intervention, suggesting that this outcome was visible to her.
QUANTIFYING MARKERS OF MUTUAL ENGAGEMENT

Case study analyses like those just reviewed provide detailed accounts of dialogue and crucial portraits of interaction. They provide theoretical insight and identify phenomena that need to be studied more broadly. Due to the nature of evidence, case studies are not well suited for making broad claims about the usefulness of collaboration for initial problem solving or learning and cannot help estimate the frequency of processes that result in variability in outcomes. The studies just reviewed provide little sense of how representative the group interactions were relative to the overall population of groups in the classrooms. Frequently, case studies provide neither data on learning outcomes nor quantitative indicators of how much a group accomplished jointly relative to other groups or individuals. However, these studies do suggest ideas for the development of measures that reflect joint processes that can be quantified.

Quantification is useful as it can provide a way to (a) examine links between interactional processes and outcomes such as the quality of the group product and individual learning, (b) estimate the degree of between-group variability in a given population, and (c) advance our ability to specify important processes. Quantification of conversations also allows us to rule out simple explanations for variability in collaboration such as the possibility that no group member generated correct ideas. Coding with reliable schemes and subsequent quantification can also provide convincing evidence for researchers who are less confident in qualitative analytic work (National Research Council, 2002). For these reasons, measures of interaction were developed that would reflect how participants were responding to one another. Two main measures were the kind of responses that were given to proposals for solution, and the connectedness of a proposal to the content of the immediately preceding conversations. These are described in the Methods section.

ANALYTICAL APPROACH

I developed an analytical approach that uses the level of group performance on a complex problem as a lens through which it becomes possible to identify associated patterns of interaction that are more and less successful for joint work. I coded qualities of proposal and response sequences and compared them for more and less successful collaborative groups (cross-case examination). I focused on correct proposals for solution and addressed why in some groups correct proposals are taken up and documented whereas in other groups they are lost. The focus on correct proposals emerged from a review of transcripts that made it apparent that they were frequently not picked up. To address issues of uptake, responses to ideas were studied as well as the connectedness of ideas to preceding topics. Next, the ability of students to solve the same problem and a transfer problem independently during
subsequent sessions was compared as a function of the level of their group’s performance. This analysis extends our ability to understand the consequences of the quality of interaction for individuals. Finally, I describe for individual groups how types of proposal and response sequences emerge across time. This latter analysis allows us to develop a detailed portrait of the social and attentional factors that contribute to more and less successful collaboration.

METHODS

Design

Children were asked to solve a series of problems posed to the main character in a staged, 15-min video adventure, called Journey to Cedar Creek, the first episode in the series The Adventures of Jasper (Cognition and Technology Group at Vanderbilt, 1992, 1997). After a first session in which the entire class viewed Journey to Cedar Creek, in a second session triads in the class jointly solved a mathematics problem during a 1-hr session. In two subsequent sessions, students were asked to solve additional problems individually. To investigate learning outcomes for individuals, two types of follow-up problems were presented in these follow-up sessions: To assess mastery, the problem solved during the first session was re-administered and solved individually by all study participants; to assess transfer, a structurally identical problem with different numbers was administered and solved individually by all study participants. This research uses the level of triad performance as an analytic contrast to compare learning outcomes and interactional patterns that might help explain triad performance differences. This research design is summarized as follows:

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<th>1</th>
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<tr>
<td>Alone</td>
<td></td>
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<td>Solve JCC</td>
<td>Solve transfer</td>
<td></td>
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<tr>
<td>Team</td>
<td></td>
<td></td>
<td>Solve JCC</td>
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<td></td>
</tr>
<tr>
<td>Whole class</td>
<td>View JCC</td>
<td></td>
<td></td>
<td></td>
<td>Discuss solution</td>
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Note. JCC = Journey to Cedar Creek problem.

Participants

Participants were forty-eight 6th-grade students who scored at or above the 75th percentile on a nationally standardized achievement test in mathematics; they were randomly assigned to three-person, same-gender groups. Same-gender triads were
used to simplify data interpretations because prior research has documented differential patterns of participation as a function of the team gender composition (Webb, 1984). The participants all attended math classes taught by the same teacher at a public magnet school. The school served academically talented youth, especially ethnic minority students, and it was located in the southeastern region of the United States. The 16 groups of participants were videotaped while solving a Jasper problem (CTGV, 1997). Due to technical failure, four groups could not be included in the analysis; thus, this study analyzed data from 12 of the 16 groups. Four of these triads consisted only of female students.

Materials

**Journey to Cedar Creek video.** In *Journey to Cedar Creek* (CTGV, 1997), the main character is a young man named Jasper Woodbury. Jasper takes a river trip to see an old cabin cruiser he is considering purchasing. Jasper decides to buy the boat and plans to take the boat home that day. However, he has several major concerns about the feasibility of this plan (e.g., whether he can arrive home before sunset because the lights do not work and whether he will have enough fuel). The task for students is to identify and resolve these concerns.

**Journey to Cedar Creek storyboard.** To facilitate problem solving, each participant was given a set of 18 still movie scenes prepared in a storyboard format that contained all of the relevant numerical information needed to solve the Jasper problem. Beneath each picture was a caption that described the scene and provided additional quantitative information. When used in a classroom setting, *Journey to Cedar Creek* would not typically be accompanied by a storyboard. Instead students would access information by using a videodisk containing the video adventure. The storyboard reduces some of the challenge in identifying subproblems and quantitative information. However, for purposes of the experiment it was important to make sure that all students had access to the information.

**Workbooks.** For the purpose of assessing their planning and problem-solving performance, students were asked to complete a workbook assignment that posed eight questions. Time limits were set for each page to ensure that students spent the same amount of time on each workbook portion. The adequacy of these times was determined through a pilot study. There were two general planning questions, three subproblem planning questions, and three solution questions that ask students for quantitative solutions to subproblems. These prompts were used to ensure that all children would consider each subproblem even if they had not thought of the subproblem on their own. The analyses reported in this article are based on the first subproblem that focused on time and involved calculating the distance (D) traveled and travel time (TT) and then comparing...
the TT to the available time (AvT). One problem was selected due to resource constraints for transcription and to provide a deeper analyses of one conceptually distinct piece of the solution.

Transfer video. The transfer problem was presented in a 5-min video. The narrative and problem structure of the transfer problem were analogous to *Journey to Cedar Creek*. However, all of the quantities and character names were different. The decision making of the main character, a woman named Nancy, formed the basis for the problem.

Transfer information sheet. To facilitate students’ problem solving, an information sheet summarizing the story and the relevant numerical information was created.

Transfer workbooks. The types of questions in the transfer problem workbook were identical to those in the *Journey to Cedar Creek* workbook. The time allotted for each type of question was also the same. Only the characters’ names were changed.

Procedures

All students participated in four sessions, taking place on consecutive days, and each lasted approximately 1 hr. In Session 1, students viewed *Journey to Cedar Creek*. In Session 2, students were asked to solve the *Journey to Cedar Creek* problem with their partners. This is the only session in which the students worked together. In Session 3, students were asked to solve the *Journey to Cedar Creek* problem again, but all students solved the problem individually. In Session 4, students viewed the transfer video and solved the transfer problem. Again all students completed the problem alone. After all the data was collected, a final session took place during which the solution was discussed by the class as a whole.

**Session 1: Viewing the video.** In the first session students viewed *Journey to Cedar Creek* as a group in their classroom. They were told the following:

You are about to see a 15 minute video of a river trip taken by a person named Jasper Woodbury to see a boat he might buy. As you watch the video, you’ll see that Jasper has to solve some problems in order to get the boat back home. Please pay attention to the problems Jasper has to solve. Tomorrow, you will be asked some questions about these problems.

After the video was over students participated in an exercise designed to encourage easily interpretable written problem-solving protocols. This exercise con-
sisted of presenting a word problem and discussing how to write its solution so that someone else would understand what was done. In addition, students solved a problem on their own and practiced showing their work. The mathematical content and subject matter of the problems were unrelated to the types of problems contained in the Jasper problem.

**Session 2: First attempt to solve Journey to Cedar Creek.** The experimenter explained the format of the storyboard by telling students that the pictures and captions contained all the information relevant to solving the problem. Each caption was read aloud. Following this introduction to the storyboard, triads were brought to an empty room where several small tables were arranged, separated by office dividers. Each team was seated at a table with a video camera placed at the head. An adult sat at the end of each table to monitor the operation of the video camera. Before entering, students were asked to listen to one another as they worked. Students were also told to take turns recording the group’s answers by alternating writers after each page. Students were told that they would be given a set amount of time on each page and that they were not to turn the pages until told. The experimenter read the question on each page aloud as they came to it.

**Session 3: Mastery.** All students solved the problem individually in their classroom. Each student received a storyboard and a workbook. Workbook questions were read aloud, and students were told when to turn the page. The same amount of time was given for each page. In this session, only the experimenter and the teacher were in the room.

**Session 4: Transfer problem.** All students solved the problem individually in their classroom. Students first viewed a 5-min video that described the transfer problem. Each student received an information sheet that listed relevant information from the video. Workbook questions were analogous to those asked about Journey to Cedar Creek. All students solved the problem individually in their classroom. Procedures for administration were identical to the mastery session.

**Dependent Measures and Scoring Procedures**

Students’ written solutions during the collaborative and independent problem-solving sessions were scored. In addition, student conversations were transcribed and coded. The procedures for scoring written problem-solving solutions are described next.
Coding Written Solutions

Each triad was asked to generate a single quantitative solution to answer each of the three subproblems. The analyses reported here are based on the first subproblem in which students were asked to decide whether there was adequate time to deliver the boat home. To make this decision, students needed to determine the following:

1. The number of miles to be traveled on the return trip (D).
2. The length of time the return trip would take (TT).
3. The time that he would arrive back to his home dock (ArT) or the number of hours available for travel before the sunset (AvT).

Each calculation needed was given a score of 0, 1, or 2 points. Partial credit could be awarded if students used all of the correct numbers but carried out an incorrect operation or did the correct operation but used incorrect values. For each subproblem, the points earned were summed. This subproblem score was transformed into a percentage of the correct score by dividing the earned points by the total possible points.

Using the correct numbers was defined as using the correct values from the information sheet or from previous calculations. Occasionally students wrote a number incorrectly (e.g., wrote 132.4 instead of 132.6 for the mile markers on the river). These written errors were ignored in the scoring. Also, calculation errors occurred occasionally. Because conceptual understanding was the focus, these errors were also ignored in the scoring. In addition, if participants used a number in later calculation that was incorrect because of a calculation error, they were still scored as using the right number because they had used the right variable (e.g., if they made a calculation error on D and then used this number when calculating TT). To assess the reliability of the coding schemes, two coders independently coded 15% of the workbooks generated across the 3 days. Overall agreement ranged from 90% to 96% across schemes.

Coding Problem-Solving Conversations

Students’ problem-solving conversations were transcribed. The emphasis of the transcription was accuracy of content and sequence of turns rather than speaker intonation or other discourse properties. Transcripts were parsed into turns; each was defined as a segment of speaker-continuous speech. If an interruption stopped the speaker from speaking, then the turn was considered completed, even if the content of the turn was resumed later. If the student did not stop talking even though someone else was speaking, then all of the content was considered to be part of that same turn. Backchannel responses, such as “yes,” “uhm,” and so on, were also con-
sidered as turns. Three coding schemes were developed to summarize distinct aspects of the problem-solving dialogue, and they are discussed in the Results and Discussion section as they become relevant.

RESULTS AND DISCUSSION

Overview of Analyses

The analyses are presented in six sections.

1. In the first section I statistically compare the written group performance of more and less successful triads.
2. After confirming that this difference is significant, I provide analyses that test whether more and less successful triads differed on other variables that might account for the performance differences. These include the average prior achievement of partners, the number of turns taken by triads, the average difference between partners in number of turns taken, and the number of correct proposals made in conversation. These analyses confirmed that neither preexisting achievement disparities nor a number of plausible interactional variables could explain the differences in group problem-solving outcomes.
3. Having demonstrated the need to look more deeply at the nature of interaction around solution proposals, I present a coding scheme that differentiates types of responses to correct proposals to test the hypothesis that the group problem-solving outcomes might be related to the ways that partners respond to proposals.
4. Given that these analyses confirmed differences in the patterns of responses to correct ideas, the hypothesis that the extent to which a proposal is closely related to the preceding discussion makes a difference in the kind of response it receives is tested.
5. In the next section I focus on the implications of differences in interactional processes and group outcomes for individual learning. Students' individual performance on the same problem with different quantitative information and a transfer problem is compared as a function of whether they participated in a more or less successful triad.
6. In the final section I present four cases of interaction that exemplify in more detail the unfolding of interaction across time and that help provide a richer picture of how the social and cognitive aspects of interaction are intertwined.

Performance Differences Between More and Less Successful Triads

Of the 12 triads in the sample, 7 produced a written solution that was completely accurate. The remaining triads produced protocols that earned from 0% to 67%
correct. Using 50% correct as a criterion I classified the triads as more or less successful. Of the more successful triads, five consisted of boys and three consisted of girls. Of the less successful triads, three consisted of boys and one consisted of girls. As shown in Table 1, the mean percent correct for more successful triads and less successful triads were 96% and 29%, respectively. The significance of this difference was confirmed by a $t$ test, $t(2, 10) = -7.25, p < .001$.

Reasons for Variability in Collaborative Written Performance

There are several plausible explanations why groups might have varied in the success of their joint work despite the random assignment of individuals to groups. Alternative explanations were tested and are described in the following hypotheses:

Hypothesis 1: More successful groups had higher average math achievement scores than less successful groups.

To examine this possibility the average mathematics achievement scores obtained through a standardized achievement test of more and less successful triads were compared. As shown in Table 1, the difference was not significant, $t(2, 10) = -1.35, p < .21$.

Hypothesis 2: More successful groups were more talkative than less successful groups.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Performance Level</th>
<th>M</th>
<th>SD</th>
<th>$t(2, 10)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group problem solving score</td>
<td>More successful</td>
<td>.96</td>
<td>.12</td>
<td>–7.25*</td>
</tr>
<tr>
<td></td>
<td>Less successful</td>
<td>.29</td>
<td>.21</td>
<td></td>
</tr>
<tr>
<td>Prior math achievement</td>
<td>More successful</td>
<td>.91</td>
<td>1.5</td>
<td>–1.35</td>
</tr>
<tr>
<td></td>
<td>Less successful</td>
<td>.89</td>
<td>4.24</td>
<td></td>
</tr>
<tr>
<td>Total number of turns</td>
<td>More successful</td>
<td>128.00</td>
<td>69.00</td>
<td>–.13</td>
</tr>
<tr>
<td></td>
<td>Less successful</td>
<td>123.00</td>
<td>50.00</td>
<td></td>
</tr>
<tr>
<td>Mean turns per person</td>
<td>More successful</td>
<td>43.00</td>
<td>22.97</td>
<td>–.14</td>
</tr>
<tr>
<td></td>
<td>Less successful</td>
<td>41.00</td>
<td>16.7</td>
<td></td>
</tr>
<tr>
<td>Correct proposals</td>
<td>More successful</td>
<td>5.75</td>
<td>2.5</td>
<td>.78</td>
</tr>
<tr>
<td></td>
<td>Less successful</td>
<td>7.75</td>
<td>6.5</td>
<td></td>
</tr>
</tbody>
</table>

* $p < .01$. 
It is possible that even though students had similar scores that there were other
differences, such as the amount of speech production, that might have influenced
problem solving. To test this possibility, a comparison was made of the total mean
number of turns taken in more and less successful groups. As shown in Table 1, the
difference in number of turns was not significant, $t(2, 10) = -.13, p < .89$. To look at
this issue in another way, the average number of turns each participant took during
the problem-solving conversation was compared. Once again, as shown in Table 1,
the difference was not significant, $t(2, 10) = -.14, p < .88$.

Hypothesis 3: Groups differed in performance because no members of the
group could generate the correct proposals in conversation.

A plausible explanation for difference in written performance is that no one in
the group was able to generate the correct approach for finding the solution, or, if
they were able to, they kept it to themselves rather than sharing it with their peers.
To examine this hypothesis, the transcripts were examined for the articulation of
correct proposals. Specifically, the transcripts were coded for the presence of solu-
tions to the D, TT, AvT, and ArT variables. Both equations and outcomes were
coded. Sometimes a student would state the entire equation, for example, “Divide
24 miles by 8 miles per hour.” Other times a student would simply say, “Now you
divide.” If the numerical information had been given previously, this type of contri-
bution was counted as suggesting an equation. Sometimes students stated out-
comes along with the equations, and sometimes they stated outcomes but did not
provide equations. Two coders independently coded student contributions. Interrater reliability for each category was above 90%.

The average number of correct proposals generated in conversation for more
and less successful triads was then compared. Proposals were counted until they
were documented in the workbook. As shown in Table 1, this difference was not
significant, $t(2, 10) = .78, p < .45$. On average, less successful groups generated
one more correct proposal than unsuccessful groups. If we look at the number of
unique proposals generated, by excluding repetitions, a similar pattern emerges.

Interactional Differences in High- and Low-Scoring Triads

Given that differences in the performance of groups could not be accounted for by
a variety of plausible variables, I moved to a deeper level of analysis that looked for
more subtle variation in interactional processes. Interactions among students can
be quantified in many ways. Here the analyses were guided by the question of why
correct proposals were never documented in the workbooks. To address this ques-
tion, a coding scheme was developed to capture the responses of peers to the cor-
rect proposals generated. Three categories of responses were used: accept, discuss,
and reject or ignore. Accept responses included agreeing with the speaker or sup-
porting the proposal, proposing a next step, documenting the proposal, or assisting with documenting the proposal. Discuss responses included any response that would facilitate further discussion of the proposal. Thus, questioning a proposal, challenging it with new information or a different mathematical operation, and requesting time so that a previous task (usually documentation of a previous proposal) could be completed and then the discussion started were all responses that would fit in this category. Reject or ignore responses included reactions that did not promote further discussion of the proposal. Thus, providing no verbal response, ignoring a proposal or shrugging it off, and rejecting it were all part of this category. For consistency with the notion of no-verbal response, just observing, even attentively, and documenting previous proposals without commenting on current proposals were also responses placed in this category. Overall reliability between two coders on these items was 85.4%. Occurrence reliability for accept, discuss, and reject or ignore responses were 78.3%, 73.3%, and 76.5%, respectively. Examples of responses and the coding criteria are presented in Table 2.

Hypothesis 4: More and less successful groups differed in how they responded to correct proposals.

Do successful and unsuccessful groups differ in their pattern of responses to correct proposals? To address this question the proportion of each response type observed for more and less successful groups was calculated. In the first analysis the responses of both partners were included. This yielded a total of 92 responses to 46 proposals for the more successful groups and a total of 62 responses to 31 proposals for less successful teams. These data are shown in Table 3.

There were three times as many accept responses, twice as many discuss responses, and less than half as many reject or ignore responses in more successful groups. Chi-square analyses confirmed that the pattern of response types to correct proposals differed for more and less successful groups across each of these response types, $\chi^2(2, N = 154) = 30.79$, $p \leq .01$.

These results suggest that there is a significant difference between more and less successful groups in the way that partners respond to correct proposals. Previous research has pointed to the importance of reciprocal engagement of ideas for progress (Phelps & Damon, 1989). In the current coding scheme, I distinguished between acceptance and clarification responses. However, a request for clarification is in fact a form of engagement of the ideas. Thus, the accept response and the discuss response categories were collapsed into one category called engaged response and contrasted with the reject or ignore response category, which is called the nonengaged response category. This makes even more salient the difference between more and less successful groups in the quality of the responses. As shown in Figure 1, in more successful groups, two thirds of the responses to correct proposals engage the ideas by accepting them or making a bid to have them discussed.
### TABLE 2
Coding Criteria for Responses to Correct Proposals

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Accept</strong></td>
<td>Any response that indicates agreement with the content of the proposal. These include simple verbal acceptances, agreement with an elaboration of the answer by providing relevant warrants, a new proposal, or a new question that needs to be addressed. Also included are responses that take the form of documenting the proposal in the workbook.</td>
<td>“Yeah, okay.” “Yeah, because that is the distance between the mile markers.” “So, now we need to figure out how long it will take him.” “24 miles, that means he can make it home before sunset.”</td>
</tr>
<tr>
<td><strong>Discuss</strong></td>
<td>Responses that acknowledges proposals but does not accept them outright or reject them without rational. This includes responses that question the accuracy of a proposal or its warrants. Also included are responses that provide an alternative solution and instances when a student acknowledges the proposal by asking for more time due to other ongoing activity. Restatements that signal evaluation are also coded in this category.</td>
<td>“How did you get that?” “Why are you multiplying?” “What did you say?” “Just a minute.” “Let me think about that.” “But how fast does the boat go?” “It will take three hours?”</td>
</tr>
<tr>
<td><strong>Reject or ignore (nonengage)</strong></td>
<td>Responses that reject the proposal without a rational are coded in this category as are instances when there is a lack of a relevant verbal response within six turns and no nonverbal signals that students are listening (e.g., documentation or eye contact without turning away).</td>
<td>“We’re not doing that.” “That’s stupid, you’re wrong.” “I know what I’m doing.”</td>
</tr>
</tbody>
</table>

### TABLE 3
Proportion of Types of Responses to Correct Proposals in More and Less Successful Groups

<table>
<thead>
<tr>
<th>Type of Response</th>
<th>Accept</th>
<th>Discuss</th>
<th>Ignore–Reject</th>
</tr>
</thead>
<tbody>
<tr>
<td>More successful teams</td>
<td>.48</td>
<td>.22</td>
<td>.3</td>
</tr>
<tr>
<td>Less successful teams</td>
<td>.15</td>
<td>.09</td>
<td>.76</td>
</tr>
</tbody>
</table>

*Note.* Portions are based on 92 responses to correct proposals in more successful teams and 62 responses to correct proposals in less successful teams.
or clarified. In contrast, in less successful groups only one third of the responses engage the ideas in one of these ways. Note that the proportions are nearly inverted, with successful groups producing a fairly high rate of engaged responses, whereas unsuccessful groups produce a fairly high rate of nonengaged responses. Chi-square analyses confirmed that successful groups made significantly more engaged responses than unsuccessful groups, $\chi^2 (1, N = 154) = 30.52, p \leq .001$. Thus, the analyses suggests that the groups did differ significantly and in the direction that one would expect.

In addition to looking at individual responses to correct proposals, response pairs were examined. It is important to realize that when people work in groups, often one person’s response is taken to be the group’s response, especially if the other group members remain silent. Thus, to determine whether responses to correct proposals were different as a function of group success level if one looks at whether at least one partner engages the group, response pairs were examined. Maintaining the distinction between engaged and nonengaged responses, three types of response pairs are possible. These include engage and engage, engage and nonengage, and nonengage and nonengage. The proportions of each response-pair type are presented in Figure 2. Chi-square analysis indicated that successful groups and unsuccessful groups differed in their production of pair types, $\chi^2 (2, N = 77) = 30.23, p \leq .001$. Thus, these results suggest that one characteristic of the interactions of unsuccessful groups includes a lack of responsiveness by both the other partners. Again, it is interesting to note the magnitude of the difference between more and less successful groups. As shown in Figure 2, the proportion of nonengage response pairs observed in less successful groups was close to 10 times
greater than the proportion produced by more successful groups. In more successful groups, this occurred rarely. In less successful groups, this occurred more than half of the time a correct proposal was made.

Proposal Characteristics

The fact that in a high proportion of cases the partners did not respond suggested the need to also look at characteristics of the proposal in relation to the immediately preceding activity of the two partners. Specifically, given the case analyses reported in Barron (2000a), a reasonable hypothesis was that participants’ attention was not coordinated during problem solving and individuals were working in parallel. To examine how conceptually related the proposal was to the preceding conversation, a coding scheme was developed that differentiated proposals that were more and less connected to the preceding conversational topic.\footnote{I thank David Sears for his work on this aspect of the analyses. It was the basis for his first-year research project in the School of Education at Stanford University.}

Each correct solution proposal was coded for its relatedness to a group’s previous interaction. Originally, this code consisted of three categories: directly, somewhat, and distally related. However, due to challenging issues of achieving interrater reliability, the system was simplified to include only two categories—directly and not-directly related. To code proposals for relatedness, the directly preceding conversational turns were first coded for the problem space they addressed. Problem space consisted of four categories defined by the subproblems the groups needed to solve in order to arrive at a decision about leaving before sunset. These categories consisted of D, TT, ArT, and AvT. Thus, if participants were discussing how long it would take the boat to travel back to the dock, they would be discussing

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure2}
\caption{Proportion of paired peer response types in more and less successful triads.}
\end{figure}
TT (and working in the TT problem space). ArT refers to when Jasper would get back to his dock, and AvT refers to how much time Jasper had until sunset.

If a proposal matched the problem space the group had been working in just prior to the proposal, then it was coded as directly related. For example, if a team member said, “we need to find out how many miles he has to travel,” and then another student proposed that, “we need to subtract the mile markers,” then the proposal would be coded as directly related because the proposal addressed the problem the first speaker articulated. If the proposal did not match, then it was coded as not-directly related. For example, if a student said, “we need to know how many hours until the sun sets,” and his or her partner immediately proposed that, “we can find out how long it will take him to get home if we divide the 24 miles by 8 miles an hour,” then the proposal would be coded as unrelated because what was proposed would not address the problem introduced by the prior speaker.

In a few cases, the prior problem space was undefined because the group was jumping from one problem space to another or individuals were focusing on different problem spaces. These were coded as unclear. Occasionally, participants also moved from one solution directly to the next solution. For instance, if a participant said, “Jasper has to travel 24 miles (D) which at 8 miles per hour is three hours (TT),” then the statement would be broken into two correct proposals (D and TT), and the preceding problem space for the second proposal would be coded as a transition. (The problem space preceding the first proposal would be defined in the usual manner as just described.) Transition points and unclear points were coded for relatedness by seeing whether the speaker had at least one group member’s attention (if speaking to the group) or a single group member’s attention (if addressing that particular individual). Obtaining attention was defined as looking at the speaker or writing what he or she said. If the speaker had attention during the transition or unclear point, then his or her proposal was coded as directly related, otherwise it was coded as not-directly related.

The coding procedure involved identifying correct solution proposals on transcripts of the 12 groups and coding the relatedness of the proposal to the immediately preceding problem space. Coding stopped for each type of correct solution proposal (e.g., D or TT) after participants in the group agreed on an answer and began documenting it in their workbook. Interrater reliability on this coding system was 89%. The coded data were used to address Hypothesis 5.

Hypothesis 5: Do successful groups propose ideas that are coordinated with the content of the preceding discussion and are these more likely to be accepted?

**Relatedness of proposals.** The proportion of proposals that were directly related for more and less successful groups is shown in Table 4.
Chi-square analyses confirmed that more successful groups produced a higher proportion of directly related proposals than less successful groups, \( \chi^2 (1, N = 77) = 31.12, \ p \leq .001 \). As shown in Table 4, unsuccessful groups produce a much higher proportion of not-directly related proposals than successful groups, suggesting that their group cohesiveness as indicated by turns connected topically is lower than those of successful groups. More than half of the proposals produced by less successful groups were not directly related to the preceding conversation. In contrast, virtually all of the proposals produced by the more successful groups were directly related.

Do responses to proposals differ according to how they are produced? As shown in Table 5, the means indicate that directly related proposals were accepted at a much higher rate than not-directly related proposals, and they were rejected or not verbally addressed at a much lower rate.

Do successful and unsuccessful groups differ in how they respond to directly related versus not-directly related proposals? The results indicated that less than half the time unsuccessful groups respond to directly related proposals by engaging

<table>
<thead>
<tr>
<th>TABLE 4</th>
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</thead>
<tbody>
<tr>
<td><strong>Relatedness of Correct Proposals to Proceeding Conversation in More and Less Successful Groups</strong></td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>Relatedness</td>
</tr>
<tr>
<td>More successful teams</td>
</tr>
<tr>
<td>Less successful teams</td>
</tr>
</tbody>
</table>

*Note.* Proportions are based on 46 proposals in more successful groups and 31 proposals in less successful groups.

<table>
<thead>
<tr>
<th>TABLE 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Responses to Related and Indirectly Related Correct Proposals by More and Less Successful Groups</strong></td>
</tr>
<tr>
<td>----------------------------------</td>
</tr>
<tr>
<td>Type of Response</td>
</tr>
<tr>
<td>Related</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Indirectly related</td>
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<td></td>
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</tbody>
</table>
them. In contrast, successful groups engaged both directly related and non-directly related proposals most of the time. For not-directly related proposals, however, they tend to reject or not verbally respond to them at a very high rate.

**What Is the Relation Between Group Performance and Individual Transfer?**

It seems likely that triads that both generated and documented correct solution procedures may have provided better learning opportunities for students. To address the question of whether the effect of collaboration would extend to individual problem-solving sessions, all students were asked to solve the *Journey to Cedar Creek* problem a second time. In the third session, students were asked to solve the near-transfer problem. The near-transfer problem was administered to evaluate whether students’ learning extended to an analogous problem with different numbers rather than being tied to superficial features such as which numbers their team used on a particular page. The questions posed about the transfer problem and the dependent measures derived from answers were otherwise identical to the original problem.

During the first problem-solving session, students in teams produced only one problem-solving protocol and hence received a single score. Because there is only one score for all three group members, completing a repeated measures analysis would be inappropriate due to the lack of independence between the scores. Thus, the first set of analyses reported compares performance on the same problem and on a near-transfer problem as a function of whether the student was originally in a more or less successful group. These analyses examine whether initially solving the problem in a high-scoring group had no effect, a positive effect, or a negative effect on individual performance as compared to a low-scoring group. Due to the nature of the design, direct statistical comparisons between students’ initial performance and mastery and transfer performance were not made. However, for comparative purposes, performance scores for all three sessions, as a function of condition and problem-solving measure, are presented in Figure 3.

Independent *t* tests revealed that students in successful groups performed significantly better than their peers in unsuccessful groups on both the mastery test, *t*(31) = −3.53, *p* < .01, and the transfer test, *t*(31) = −2.34, *p* < .03. Although the mean score for the students in the more successful groups decreased slightly from the group session to the mastery session (−5.6%), the transfer score was virtually the same as the group score (−1.5%) suggesting they benefitted from their high-quality collaborative interactions.

The pattern was quite different for students in the less successful groups. Recall that their group score had to be 50% or below to qualify as an unsuccessful group. On the mastery test, however, their mean was up to 68.1%; and on the transfer test, their mean increased to 73.7%. Note that the mean scores for the first attempt at the problem are lower than those obtained by students who were randomly assigned to the individual condition in the original experiment (see Barron, 2000b). The aver-
The average score for the 48 individuals on the sunset problem in the original experiment was .68 ($SD = .33$). However, the mastery and transfer scores for students in less successful groups are similar to those of students in the individual condition. The average score was .71 ($SD = .33$) in the mastery session and was .77 ($SD = .31$) in the transfer session. These findings could be interpreted as suggesting that if you are in a problematic group, you might as well be working alone; if it is your only chance at performing, then you are actually better off working alone. Despite this finding, note that poor collaboration did not harm learning when compared to conditions of working alone.

**Summary of Quantitative Findings**

The quantitative analyses established that groups that differed in their level of joint success did not differ on a number of variables that might plausibly account for the observed difference. These variables included prior achievement, the number of turns, or the number of times correct proposals were brought into the group. What differed between more and less successful groups was how peers responded to ideas. More successful groups responded to correct proposals by engaging them in further discussion or accepting and documenting them. In contrast, less successful groups had a high probability of responding to ideas with silence or by rejecting them without rationale. Further analyses suggested that the conversations in less successful groups were not as aligned topically as those in more successful groups. Frequently when a peer generated a correct proposal, the conversation that was occurring just previously was not closely related to the proposal. A reasonable hy-
hypothesis is that this would make it harder for peers to recognize the significance of the proposal. However, almost half of the correct proposals were directly related and most were still not accepted or taken up in the conversation. To understand in more detail the various reasons why the correct proposals were not taken up, I provide some example cases in the next section. The data on learning outcomes suggest that understanding in detail the nature of more and less successful interactions is important for individual learning as well as for joint performance.

Case Analyses That Preserve Interactional Properties of Joint Work

Although the previously discussed quantitative analyses provide convincing evidence of the interdependence of partners in joint problem-solving work, they do not offer accounts that might provide theoretical insight into the deeper reasons that more and less productive interactions arise. To understand why these interactional patterns emerged in the quantitative findings, a contextualized analysis that allows for a fuller utilization of the available information to make interpretations about what was happening (Bateson, 1972; Erickson, 1977; Kendon, 1982; Levinson, 1983) when proposals were ignored, rejected, questioned, or accepted is needed. Thus, although the quantitative analyses help identify how groups fail and the consequences of this failure, the qualitative analyses constitute a localized account of why groups fail.

Maintaining the group as the unit of analysis focuses attention on the emergent patterns of interaction and allows for the identification of individual conversational moves that can shift patterns. Interactions are temporally ordered in histories that accumulate in effect but are also subject to disruption and changes in trajectory if there is sufficient energy and persistence to gaining floor or being understood. These phenomena are critical to our understanding of the nature of collaborative exchange and to the prospect of helping teachers recognize and foster productive learning interactions.

Video records of interactions make possible the incorporation of multiple kinds of data into the analyses. An important property of language in interaction is its flexibility and generativeness. Silence, repetition of ideas, eye gaze, gestures, physical synchrony, laughter, pauses, interruptions, and overlaps in turn taking do not have single meanings but have a productive ambiguity; thus, depending on the context, they can serve to signal different things to participants. Such behavioral displays all become available through video interaction analysis for making sense of how interaction unfolds over time and for drawing out the relational and social aspects of collaborative problem solving.

In the following section, I provide synopses of the interactions of four triads, two more successful and two less successful. These cases were selected to provide examples of the three main generalizations offered earlier in this article:
1. The management of attention in collaborative groups is a fundamental piece of interactional work. The groups differed in the extent to which joint attention was achieved and, consequently, whether an understanding of the problem was shared. In all groups, strategies for recruiting and maintaining joint attention were deployed. These included nonverbal strategies like pointing, tapping one another on the arm or shoulder, and moving to share visual perspective on the workbook. Participants also offered metacommunicative comments about the need to keep pace with one another and, at times, sharp commands to listen. These attempts were not always successful and less so in the lower scoring groups.

2. Both speakers and listeners had consequential roles to play in establishing and maintaining attention. Getting and keeping the floor (Goffman, 1981) was a challenge for some students, and the task was made more difficult when partners were highly self-focused. Mitigated proposals were quite ineffective when potential responders were otherwise occupied. However, persistence coupled with increasing strength of presentation paid off for some individuals in challenging conversational contexts. These shifts highlight the dynamic nature of problem-solving conversations and draw attention to the importance of understanding students’ strategies, or lack of them, for repairing communications when they become problematic.

3. Relational aspects of the interpersonal context are needed to explain between-triad differences in effective coordination of a joint problem space. In some of these groups, problematic relational issues did arise, often when one or more members did not display a strong intent to collaborate or what has been called an “intersubjective attitude” (Crook, 1996, p. 116). Such intent can be expressed behaviorally by how participants orient to others and by how willing they are to engage in coregulation of the interaction (Fogel, 1993), their attention to partners’ contributions, and the sharing of ownership over the work. A willingness to coregulate the interaction was missing in some of the less successful triads. Instead, exchanges were oriented toward dominating the problem solving and may have stemmed from a need to protect one’s identity as a competent problem solver. The unwillingness to negotiate a shared space interfered with processes of distributed reasoning and resulted in failures to solve the problem.

Cases 1 and 2 are drawn from the less successful subsample. In Case 1 the primary theme is one of a struggle between two members about who gets to generate the solution. Barron (2000a) analyzed this case in detail, so I summarize it here. In Case 2 the establishment of a joint space is problematic due to the combination of a self-focused partner and a hesitant contributor who, nonetheless, has something important to offer. Case 3 offers an example of a triad who confronted some of the same issues of establishing a joint space but who had members that demanded the joint attention be preserved (or recruited others to agree to this point) and hence avoided breakdown. Case 4 offers an example of a well-coordinated triad whose interactions were not atypical in the more successful triads.
The Problem and Alternative Solution Paths

For the reader to follow the dialog, the relevant quantitative information is provided here. The problem posed to the students was to make a decision about whether Jasper had enough time to make it home in his new boat before the sunset as the boat had no running lights. To make this decision, students needed to determine the number of miles to be traveled on the return trip (D), the length of time the return trip would take (TT), and the time that he would arrive back to his home dock (ArT) or the number of hours available for travel before the sunset (AvT). As mentioned previously, students were given a storyboard with 18 stills from the movie that helped them to remember relevant scenes and quantitative information. To determine D, students needed to subtract the mile markers associated with each dock. The starting dock was located at mile marker 156.6 and the destination dock was located at mile marker 132.6, so the total D they needed to travel was 24 miles. TT could be calculated in one of two ways. Rate was provided as 8 miles per hr and as 7.5 min per mile. If students use the former, then they divided 24 miles by 8 to arrive at 3 hr. If they used the latter, then they multiplied 7.5 by 24 to arrive at 180 min, which then needed to be translated into hour units. Finally, students needed to calculate ArT by adding TT to departure time and then comparing ArT to sunset time. Departure time was 2:35 p.m. Adding 3 hr yielded an ArT of 5:35 p.m., which was earlier than the 7:52 p.m. sunset time. Alternatively they could compare TT to AvT. AvT could be calculated by subtracting sunset time and departure time, yielding 5 hr and 17 min of AvT, which was more than the 3 hr needed to get there.

As will become apparent, some students focused not just on time but started to think about fuel capacity and whether he would have enough fuel to arrive home. This problem is one of the problems they needed to resolve and was asked next in the workbook. It is conceptually related (if not enough fuel, then time to get fuel may extend the TT) but is not the focus from the standpoint of the question posed in the workbook.

CASE EXAMPLE 1: COMPETING TO KNOW

A salient aspect of this group’s interaction was the competitive nature of the exchanges. The still image in Figure 4A was taken from a sequence of interaction that co-occurred with the episode of dialogue presented here:

Example Excerpt 1: Two solution paths, competitive talk, and claims of competence.

81. Brian: I know, okay, it’s 2:35, okay, so we need to say umm umm times three, three thirty-five, times two, two thirty-five times two.
82. Chris: See if it’s 24 miles (he points at frame # 2) eight miles per hour (points at frame # 14) and it’s 20, 24 miles it would be. (Chris glances back and forth from his storyboard to Brian’s face as he speaks.)

83. Brian: Now, just write this down (to Alan). I know what I’m doing.

84. Chris: No, I do (softly with slight smile while looking down at his storyboard).


86. Chris: See if he has 24 miles and the boat goes at eight miles per … eight miles per hour and there’s 24 miles.

87. Brian: I know what I’m doing.

88. Alan: We gotta label.
89. Brian: I know what I’m doing, 5:35.
90. Chris: It would be 5:35.
91. Brian: 6:35, we have to write it down (he glances quickly at Chris). Okay so it’s going to take one, two … It’s going to take about 4 hours, it’s going to take 4 hours and …
92. Alan: 5 hours, 5 hours (softly, looking toward Brian).
93. Brian: (sighs) From two to three is one, from three to four is two …

In Figure 4A we see Brian, seated in the middle, with his hand on the workbook as he directs Alan, seated to his left, to write. Chris, on the far right, is pointing to his own storyboard to mark the referents of the numbers he is using in his proposed solution. Neither Alan nor Chris is attending to the other except to claim his own understanding, and their relational space is a competitive one rather than cooperative one. This exchange takes place after several attempts by Chris to explain how to find D and TT. These correct proposals have been previously rejected by Brian and now are being ignored.

In turn 81 Brian returns to his own line of reasoning that involved determining how many hours are available for travel before the sun sets. He does not articulate this, but rather he begins counting up the hours between departure time and time of sunset. He does not make eye contact with the others, and his talk appears self-directed, reminiscent of what Vygotsky’s (1978) concept of self-regulating egocentric speech would suggest.

Chris did not give up trying to have his reasoning heard and he, in turn 82, repeats what he figured out, talking simultaneously with Brian, inserting information in the pauses present in Brian’s stream of talk. There are other violations of turn-taking conventions in this episode. Utterances normally relate back to the referents and predicates in the previous utterance. Speakers can compete by what has been called “skip connecting” (as Sacks, 1971 cited in Coulthard, 1985, p. 82, noted from mimeo lectures). Each time one speaker gets a turn, he declines to talk about the previous speaker’s topic and reasserts his own. In this episode Chris does not take up either Alan’s statement about cruising speed or Brian’s initiation of his own attempt at a solution. He instead (turn 82) repeats the information provided previously which had been ignored by the others. This attempt to be heard is not effective, although he is looking back and forth to Brian. Brian is completely engrossed in his own solution and, in turn 83, he directs Alan to write down what he is saying (in an irritated, commanding tone) and claims his understanding and sense of entitlement over the problem solving: “I know what I’m doing.” In turn 84, Chris counters Brian’s claim to knowledge with his own. His assertion is weak compared to Brian’s, as Chris once again speaks softly, with a slight smile on his face. In turns 85 and 86, both Brian and Chris continue their own turns, once again talking simultaneously. Chris continues his strategy of repetition in turn 86. He is interrupted by Brian, who again claims he knows what he is doing. Chris then falls silent and watches Brian work.
Although both Brian and Chris were self-focused in their talk, the two boys differed in the extent to which they each attempted to be heard by the other during this episode. Brian’s attention was focused on the workbook and making sure Alan wrote what he said. He did not attempt to get Chris’s attention. In contrast, Chris makes several subtle attempts to gain Brian’s attention. For example, he begins his explanation with “see,” and he glances back and forth from Brian’s face to the storyboard which he is using to anchor his explanation (e.g., he points to cell number 2 when stating that the distance is 24 miles).

In the following turns, Chris makes a more explicit attempt to get Brian’s attention by asking him for an explanation for what he has been doing. Rather than listening to the fuel explanation, Chris begins his own explanation again. In Figure 4B we see the boys at a point where Chris is trying again to have his proposal heard, only to have it rejected by Brian. To this, Alan on the far left expresses his frustration by throwing his pencil, while Brian’s head goes down on the table.

Following this exchange Brian continues to vocalize his reasoning without explicitly engaging the others. As shown in Figure 4C, Chris and Alan disengage, Alan withdraws behind the storyboard, and Chris taps his fingers gently on the table. Eventually, Brian gets lost in the numbers and finally says “Okay, I’m lost.” Chris takes this as an invitation and explains again. However, it falls short of being understood. After a final round of explanation, Brian finally asks a question that allows the two to share understanding of Chris’s solution. This shift is marked by a physical movement of Brian toward Chris that allows them to share visual perspective.

In summary, across the 7 min of interaction excerpted from this problem-solving session, there is evidence of struggles of control, failures to understand one another, repeated attempts at explanation, rejections of that explanation (even when invited), self-focused talk, admissions of confusion, and then eventual convergence. It was apparent that, at least initially, the students brought different orientations or expectations about the collaboration. Brian’s behavior suggested that he was not really interested in working together on the problem but rather was mainly concerned with working out his own solution. This individualistic focus seemed to lead one of his partners, Chris, who was initially quite inviting in his contributions, into a self-focused position. Both boys engaged in topic switching (or skip connecting), interrupting, and making claims to the validity of their own knowledge. The third partner, Alan, was the designated writer and, for the most part, he tried to represent Brian’s solution attempts. However, he was also attuned to Chris’s contributions and joined him in expressing frustration at Brian’s resistance to the ideas Chris presented.

Brian’s assertions of control and of knowing were especially marked in these excerpts. In response, Chris offered his own claims of knowledge, and he was persistent in his attempts to be heard. His strategy was one of repetition and talking over Brian. Because of the self-focused nature of the exchanges, the process of sharing, repairing if necessary, and mutual sense making reported in productive exchanges was dis-
rupted (Roschelle, 1992). As Fogel (1993) noted, true communication takes coregulation, a willingness and openness to be influenced by the other. Coregulation is a central aspect of the relational space that must be attended to (and mutually agreed upon) in the development of a joint problem-space.

CASE EXAMPLE 2: TWO’S COMPANY

Like the previous group, the members of this triad were challenged when it came to building a joint problem-solving space due to parallel efforts on different parts of the problem. Early on in the session, team member Andy was focused on fuel and fuel consumption, whereas his partner Brad focused on distance. Brad had to struggle to recruit Andy’s attention. In Figure 5A we see Brad, the middle partner, making a physical bid to gain his attention—in this case, he taps Andy on the arm. The third member Sean was mostly an observer during the first part of the 7-min exchange. In fact, it was striking that in watching this triad (if the screen was split in half, it would have appeared as a dyad) on very few occasions did either of the two more active partners look to him. This general configuration can be seen in Figure 5B. Although the workbook was turned over to him at the appropriate time and without question, as soon as the process began it was taken back—without any response from Sean.

Although one might think from this description that Sean was not engaged in the efforts, his timely contribution contradicts this interpretation. In the following dialogue, Sean proposes a solution for how to find the TT. His attempts to contribute come after Andy has acknowledged that he does not know how to write down anything about their thinking (turn 74), claiming that he always does it in his head (turn 78). This timing and the appropriateness of Sean’s contribution demonstrates sensitivity to the state of his partners.

Episode 1: TT: Correct proposal quietly offered and ignored.

69. Brad: And, sunset’s at 5:15.
70. Andy: Okay, let’s see (or “‘that’s enough’” to himself) Sunsets at 5:15? Okay he’s not.
71. Brad: [interrupting ] And it takes him seven and one half minutes to go one mile, whew.
72. Andy: Seven and a half minutes, to go one mile? I don’t see.
73. Brad: I don’t think he can make it home.
74. Andy: I don’t see how we’re supposed to write this down.
75. Brad: Well, just write down everything that we know. (louder, takes workbook from Andy)
76. Andy: I never write down this stuff.
77. Brad: Okay.
78. Andy: I always do it in my head.
79. Brad: Miles apart. [as he is writing, he is labeling his equation and outcome carried out earlier]
80. Sean: There’s twenty-four miles.
81. Brad: Okay.

FIGURE 5  Stills from Case Triad 2.
82. Sean: There’s twenty-four miles/Twenty four times seven and a half [he says this in a very quiet voice—he is ignored].

83. Brad: And the sunset’s at … Is at … 5:15.

84. Sean: (whispers something and laughs)

85. Andy: No no no that’s sunrise. That’s sunrise, sunset is at 7:52, okay, hold on.

86. Brad: Oh, 7:52, I think he can make it home, I mean even at seven and a half, let’s see seven and a half minutes at cruising speed per mile.

87. Sean: What we need to do is seven and a half times twenty four. (whispers)

88. Andy: The fuel tank can carry twelve gallons because it was half full.

89. Brad: Three times twenty-four. (glancing at Sean)

90. Sean: No, seven and a half times twenty four.

91. Andy: Listen Brad, Yes Andy, Okay Brad, Brad, How you doing Brad. (sing song voice)

92. Brad: Okay! (grabs Andy’s arm to signal his attention).

Across turns 80 and 82 Sean offers up a proposal for how to find TT. Although he leans forward when making this proposal as shown in Figure 5C, he speaks quietly and is ignored. In turn 86 Brad conjectures that he can make it home, even at 7.5 min per mile. In turn 87 Sean repeats his suggestion, but did not offer any strong rationale and again spoke somewhat quietly. This time Brad looks over to him, but Andy almost simultaneously brings up fuel capacity; when Brad explicitly turns to Sean to catch what he said, Andy interrupts and in a sing song voice attempts to regain Brad’s attention. Brad acquiesces, and he grabs Andy’s arm to signal his attention. This exchange is similar to what Erickson (1996, pp. 37–38) described as “damaged turns:” ones that begin a turn with hesitation or with the shrugging of shoulders. It provides others with an opportunity to step in. Volume and voice quality may also invite interruption. A breathy quality could be read as hesitant. Damaged turns are vulnerable to those who may wish to hold the floor—what Erickson called “turn sharks.” As he vividly put it, “Turn sharks step in at the smell of blood in the water—that is, damaged turns.”

Interestingly, Sean attempted to pass on his proposal to Brad rather than address both partners. It may be that he recognized that he had a better chance of having his idea survive the interaction and contribute to the shared problem space if he was revoiced by Brad.

Having successfully garnered the attention of Brad, Andy launches into his reasoning about fuel capacity and Brad engages the ideas. Sean, having been unsuccessful three times, repeats his proposal one more time (turn 97) while touching Brad’s arm. Again, Andy interferes with this exchange by starting another turn that continues the conversation about fuel. In the remainder of the session, the conversation focuses on fuel with Sean making comments about fuel as well. Sean does not make another attempt, and the group does not figure out how much time or fuel is needed.
To summarize, in this group expertise was distributed among the participants, but the nature of the interactions did not afford the possibility of coconstruction. Sean’s contributions were offered softly; he did not insist that his voice be heard. In contrast to Group 25, his responses were never rejected—they were simply ignored. If the interaction had been between Brad and Sean, things may have turned out differently because he seemed to make an attempt to attend. The softness of his contributions was more problematic in the context of Andy’s self-focus. All of Sean’s strategies—as subtle as they were—came to naught as the direction of the conversation was shifted by Andy back to the question of fuel consumption, which is where it stayed for the remainder of the session. This was consequential for the group’s work, as it was not generated by his two partners.

CASE EXAMPLE 3: “WAIT,” “LISTEN,” AND “WATCH”

During the brainstorming part of the session, all three members of this group contributed ideas rapidly and all were visibly excited and engaged. As they moved to the page where they need to formulate a quantitative response, one student, Carlos, immediately began to write down specific quantities, and Ben moved close to him to keep tabs on the progress. His work to keep close tabs on progress, explicitly confirming specific information using the storyboard, reflected his joint ownership of the problem-solving process and the documented work.

As Ben and Carlos jointly work to write down relevant quantitative information and calculate AvT before the sun sets, Adam, as shown in Figure 6A, sits back in his chair and lets the others focus on the writing. During this time he has been thinking about how to calculate TT, as it becomes apparent in the dialogue excerpt that follows.

Episode 1: Unsuccessful attempt to share proposal to find TT.

118. Adam: What you do is you add.
119. Carlos: Just a minute.
120. Adam: I mean, you multiply 24 miles.
121. Carlos: Stop it! (he lifts his fist and puts it back down for emphasis)
122. Ben: Wait until we get it down first.
123. Carlos: Seven. (broadcasting as he writes)
124. Adam: You said it’s 24 miles. (to Ben)
125. Ben: 5 hours. (to Carlos)
126. Carlos: 5. (writing)
127. Adam: (taps Ben) You said it, you said it’s 24 miles.
128. Ben: (to Adam) Yes, it’s 24 miles, yes.
129. Adam: Then 24 times seven thirty, 24 times 7 and a half.
130. Ben: 24 times eight. (points to workbook)
131. Adam: Because whatever 24 times 7 and half is, that’s how long it’s going to take him.

132. Ben: It’ll be …

133. Carlos: No, you divide. (pointing to Adam with his pencil)

134. Adam: 24 times 7 and a half is going to tell him how long it’s going to take him. (speaking louder)

135. Ben: (overlaps Adam) Get the information down first.

In turn 118 Adam begins to make a proposal, and he is asked to wait by Carlos in turn 119. He does not comply with this but continues his turn, correcting himself and proposing that they multiply 24 miles by 7.5. In response, Carlos who is writing, repeats his request that Adam not suggest something new—this time more forcefully. He looks directly at him in turn 121, hits his fist slightly on the table (as shown in Figure 6B), and says, “Stop it!” in a quiet though insistent voice. Ben chimes in at turn 122 with, “Wait until we get it down first.” The “it” in this case is a completed solution to how much AvT there is before the sun sets.

It is clear that his contribution at that time is seen by his partners as disruptive to the ongoing work, and both Ben and Carlos mark this in their comments, explicitly attempting to regulate the flow of information. However, Adam cannot seem to wait and, in turn 124, tries to confirm the distance with Ben and perhaps recruit his engagement around this idea for finding TT. However, Ben’s attention is still focused on working with Carlos to document their work on AvT. Adam persists, this time upping his bid for attention by tapping Ben on the arm in turn 127 while asking him for confirmation on D. This gets Ben’s attention, and he affirms the D; without a moment’s pause, Adam repeats his proposal for finding TT in turn 129. This time, in turn 130 Ben acknowledges his proposal by contradicting it, “24 times eight,” as he points to the workbook. Adam repeats himself, Carlos jumps in at this juncture, points his pencil directly at Adam (as shown in Figure 6B), and says, “No, you divide.” At this point there are three proposals on the table—to multiply the number of miles by 8 (Ben’s suggestion), to multiply by 7.5 (Adam’s suggestion), and to divide by an unknown number (Carlos’s suggestion). In turn 134 Adam repeats his idea for the fourth time. Ben responds in turn 135 by repeating his request that they get the information down first (i.e., the work that they had been doing before).

This time Adam seems to get the message and for the next 35 sec he sits back and is quiet as Ben and Carlos work on calculating AvT. In turn 153 he sees his chance again and starts his turn only to be interrupted by Ben who contradicts him again offering 8 rather than 7.5 as the number to multiply. Carlos agrees with Ben, echoing that “it goes eight miles an hour.”
Episode 2: Argument about how to figure out TT, along with disagreement with joint attention and an attempt at explanation.

153. Adam:  *Now*, 7 and a half.
154. Ben:  No, eight.
155. Adam:  Times twenty-four.
156. Ben:  No times *eight*. That’s eight miles an hour, times eight.
157. Carlos:  Eight miles an hour, it goes eight miles an hour.
158. Adam: Listen.
159. Ben: Wait, what time is?
160. Adam: Shut up, I’m right.
161. Carlos: Wait a minute. (surprise in his voice)
162. Ben: What?
163. Carlos: If it takes him eight miles an hour, it will take him 3 hours!
164. Ben: What are you talking about?
165. Carlos: Because.
166. Adam: (overlaps Carlos) What is seven and a half times 24?
167. Carlos: Here, he has 24 miles to go, watch. (starts writing) Twenty-four,
168. Adam: Yeah, what do you think I’m saying stupid?
169. Carlos: 24 miles ’till home, listen.
171. Carlos: Because it takes him …
173. Carlos: Eight miles an hour. So, how many times does eight go into 24 miles, 24 …
174. Ben: Hmm.
175. Carlos: Three times. Three hours. (starts writing 3 hours to go home)

In turn 158, Adam makes another attempt, starting off with “Listen,” but he is interrupted by Ben. Adam, clearly frustrated, tells Ben “Shut up, I’m right” in turn 160. In turn 161, Carlos says “Wait a minute,” with surprise in his voice and offers the solution to TT in turn 163. Ben asks for an explanation in turn 164, “What are you talking about?” Carlos begins to explain his reasoning while Adam makes his final attempt to offer up his idea for how to find the same value, “What is seven and a half times 24?” In turn 167, Carlos tells them both to watch and he explains using the workbook to show his calculations as he speaks. Both Adam and Ben look on, and Ben draws the conclusion that Jasper will make it. Adam has watched all of this and neither agrees nor disagrees explicitly. The triad immediately goes on to fuel, and for the remainder of the conversation, Adam stays coordinated with the other two. In the end, the fact that his approach was not the one taken did not seem to bother him.

In this example we have a different group who had a similar situation to Case Example 2—that is, a pair in the triad form a subgroup and are working closely on a piece of the overall solution, and the third member is working on a different piece. Here, the triad managed to have a different outcome. Although the third member had difficulty inserting his insights into the ongoing work stream, he was not ignored. In comparison to the student in Triad 2, his bids for attention were stronger (e.g., tapping his partner on the arm, learning over and hovering until he saw his opportunity for inserting a turn). Rather, he was asked to wait until his partners could pay attention. The explicit awareness to the need for joint attention and
insistence on coregulation—and persistence in getting it—highlights the unique blending of social and cognitive work that students’ collaborative inquiry requires. In the end, Adam’s solution is not recognized, because one of his partners offers a solution and is effective in having it listened to and heard. Why Carlos was more effective cannot be explained entirely though his strategy of asking his partners to watch—a version of Show and Tell—and his provision of a reasoned explanation are plausible accounts. Also, Ben had previously highlighted the rate as 8 miles an hour (as opposed to 7.5 min per mile), so perhaps there was less work to do to have his reasoning recognized. From a learning perspective, the fact that the group never discussed the equivalency of the two approaches is not ideal, and one cannot say from this interactional data whether or not at least Adam had worked it out.

The interactions in this group illustrate the challenges of multiperson problem solving and how students need to manage the communicative and metacognitive demands that are unique to these kinds of arrangements if they are to take advantage of the collective knowledge of the group. One can imagine a different outcome if Adam refused to yield to the attempts of his partners to stay in more of a coordinated state. If Carlos had not generated an alternative correct proposal, Adam may have finally got his chance. In this group the interactions had a very different tone from those in Triad 1 in which the presence of competition and lack of coregulation was striking. Here, the content felt less competitive and more a case of an eager participant wanting to contribute an insight at a moment when the partners were already occupied.

CASE EXAMPLE 4: COORDINATED COCONSTRUCTION

In this final case the members’ interaction is trouble free and not unlike several of the other more successful triads. On the solution page, the exchange of conversational turns is rapid with all three boys—Alex, Barry, and Charles—participating. In this group joint attention is maintained throughout the session. In Figure 7A, joint attention is expressed by mutual pointing to the shared referent of the storyboard. Solutions are generated across speakers as one identifies a problem-solving goal and another finds relevant quantitative information and suggests a possible set of relations between numbers.

For example, in the exchange that follows, the turns are tightly coordinated and the students are each focused on generating and documenting the solution to D. In turn 118, Alex proposes that they write down one of the mile markers that locates Jasper’s home dock; in turn 119, Barry immediately offers the other mile marker that marks where Jasper would start his trip that Alex is seeking. Alex pays close attention to Charles as he writes, simplifying his speech (giving the numbers as single digits, in the form that they would be written) so that the quantities are easier to record. Barry follows Alex’s model of sensitivity to the need of the writer as he repeats the quantity for the other mile marker by using the same simplified form as
Alex. Meanwhile, Charles has been writing, carries out the calculation, and states the outcome.

Episode 1: Alex, Barry, and Charles each contribute to arriving at D.

118. Alex: Put one thirty-two point six, one thirty-two point six, (points to workbook), and then you put his dock, put Jasper’s dock, and put, um, um, and we should put this above it. (looks at storyboard)

119. Barry: Here it is, one fifty-six point six. (points to frame # 11, all three boys are huddled over the workbook)

120. Alex: One, five, six, point six. (slowly)

121. Charles: See how much time, see how many miles.

122. Alex: Just put one, five, six, point six.

123. Charles: Then one, three, two, point six. (slowly)

124. Alex: Then his dock and Cedar Creek.

125. Charles: Okay, zero, four, two, so he has twenty four miles to go.

The interaction represented in Figure 7B shows how directly Alex and Barry face and address Charles when he questions an aspect of the solution, as seen in turns 147 through 150. When they are ready to document their thinking, the talk focuses on details of how to write numbers, how to label each number, and the accuracy of the calculations being carried out. The recorder of the moment frequently vocalizes what he has written so that others have auditory access to their shared solution, giving them an opportunity to make corrections or suggestions. As shown in Figure 7C, the workbook is visually shared as well. Frequently, one or more of the boys is out of his seat in order to watch what is being written or to make suggestions about where something might be written. Again, in the exchange that follows, all three members are focused on affirming and documenting the solution for TT.

Episode 2: The three continue to document, and several slips are identified and repaired along the way.

146. Barry: Put eight divided by 24.

147. Charles: No, but this is the little boat.

148. Alex: 24 divided by 8.

149. Charles: This is the little boat … no we be going back.

150. Alex: No this is the big boat because … 8 miles, put eight miles.


152. Alex: No, 24 divided by 8.

153. Barry: Oh yeah, no, it’s 3. (shakes his head, as if to clear it)

154. Alex: It’s 3 exactly.

155. Barry: Yeah, right.
156. Alex: Erase that point 0, on both of them, no leave it on the other one because …
157. Charles: Okay 3 hours.
158. Alex: Yeah. put “to home” (instructing Charles to write this) … to, home, yeah.
159. Charles: Eight miles per hour, 24 miles. (as he writes)
160. Alex: Home … now you can put, he can.
161. Charles: And it only takes 3 hours. (as he writes)
Barry repeats the initial equation for TT but makes two slips, reversing the order of the numbers. Alex corrects these immediately, again indicating a high degree of joint attention and joint problem space regulation. In contrast to Triads 1 and 2, the interactions of this group were relatively seamless, coordinated, and relationally comfortable, with members playing complementary roles (like the cooperative interactional style described in Forman & Cazden, 1985). There were several examples of what has been called coconstruction of solutions. Coconstruction has been defined with respect to three situations: (a) when participants make statements that, taken individually, do not represent a complete idea; (b) participants make utterances that, taken together and across speakers, either complete or continue another participant’s idea; or (c) both (a) and (b), that is, one partner offers a partial equation with others filling in needed information and carrying it out (Keenan, Schieffelin, & Platt, 1976; Rafal, 1996).

The workbook served as a “center of coordination” (Suchman, 1997, p. 42) for the group’s work. There was attention paid to the details of how the work was to be documented and a justification of this attention “so they will know what we are talking about” (“they” are the experimenters interested in problem solving). In contrast to the less successful groups, the conversational tone was respectful and their visual attention and conversation were coordinated throughout the episode. There was frequent eye contact and constant monitoring of both what was said and what was written. This joint attention and monitoring each others’ thinking made possible the correction of slips. At the end of this episode, Alex and Barry snap their fingers, pleased with the work on the problem.

In these two more successful groups, we see an interweaving of members’ own content space work with an awareness of others’ progress; when there was a sense that another member’s work or duo’s work might be more productive, there was a willingness to feed information into that work. This is regulative activity at the relational level of the group rather than at the individual level. Constructing a joint problem-solving space requires that one makes his or her own thinking visible to the group (e.g., Brown, Collins, & Duguid, 1989) and bringing out or recognizing others’ thinking.

**GENERAL DISCUSSION**

The primary goal of this research was to investigate reasons for variability in the problem-solving performance of high-achieving sixth-grade triads. Initial analyses ruled out the possibility that this variability was due to differences in the quantity of the talk, the average achievement levels of students, or whether anyone in the group had made explicit proposals for solution. Detailed coding of responses to proposals indicated that more and less successful groups differed in how they responded to correct proposals. More successful groups responded by accepting or discussing the proposals, whereas less successful groups had a high probability of
rejecting or ignoring the proposals. Analyses of how related the proposals were to
the preceding discussion indicated that in more successful groups, it was rare that a
proposal was not directly linked to the prior conversation. In contrast, proposals in
less successful conversations were directly linked only half of the time. The relat-
edness of proposals might be considered an indication of the degree to which par-
ticipants were jointly focused on the same topic.

A secondary goal of this research was to document the consequences of this
variability for individual learning. The results indicated that students who had
been in successful groups scored better on the same and a related problem during
solo problem-solving sessions than did students who were in less successful
groups. In general, students who were in less successful groups scored better than
their group had scored but, on average, about as well as they would have done had
they been asked to solve the problem initially by themselves. This estimate was
made by looking at the average scores of individuals obtained during the original
experiment (Barron, 2000b). It easy to see how the kinds of interactions observed
in the less successful groups might be disruptive for learning. Experimental re-
search that manipulates the extent to which a listener conveys that they are attend-
ing to a speaker has shown that nonattentiveness can disrupt the speaker’s process-
ing, leading to less coherent narratives (Tatar, 1998). This work has been
interpreted as reflecting the fact that attentional engagement is a prerequisite for
coordinated interactions. It is not that joint attention needs to be maintained at all
times but rather that partners need to be able to regain it at solution-critical times
(Barron, 2000a). Without this timely joint attention, the basic processes that we
know are responsible for some of the benefits of collaboration such as sharing per-
spectives, increased monitoring, and providing explanations are compromised.

Qualitative analyses of the conversation of four triads illustrated the broader
interactional contexts in which proposals were made and to which they were re-
sponded to. These portraits depicted the challenges that arose for some triads as
participants attempted (or not) to coordinate individual perspectives into a joint
problem-space. In the less successful cases, relational issues arose that prevented
the group from capitalizing on the insights that fellow members had generated.
These included competitive interactions, differential efforts to collaborate, and
self-focused problem-solving trajectories. Behaviorally, these issues manifest in
violation of turn-taking norms, difficulties in gaining the floor, domination of the
workbook, and competing claims of competence. Although constructs such as
status (Cohen & Lotan, 1995) may be called on to explain these patterns, it is in-
formative to attend to the dynamic shifts that were observed. It was apparent that
both speakers and listeners played consequential and interdependent roles in the
uptake and documentation of ideas. For example, mitigated (Linde, 1988) or in-
direct contributions were especially problematic in the context of self-focused
peers. However, persistence and resistance to dominating efforts were effective
strategies to combat a self-focused partner, although they may have come at
some cost to continued engagement or even a future desire to work together. The construct of status as typically defined does not reflect the complexity of interaction and does not explain the dynamic shifts in states of coordination that were observed here.

Groups that did well engaged the ideas of participants, had low rates of ignoring or rejecting, paid attention to attention, and echoed the ideas of one another. Their successful achievement of a joint problem-solving space was especially reflected in high rates of huddling around the workbooks and mutual gaze. These nonverbal, synchronized movements suggest an intense level of joint ownership over the production and representation of the work. It was not that more successful groups were immune to problems of coordination but rather that members used strategies that evoked or recruited joint focus of attention. For example, when documenting solutions, the writer might broadcast his or her writing and thus make it available for monitoring. In addition, some groups evolved more explicit expressions of metacommunicative awareness as indicated by their monitoring of joint attention and possible disruptions to it. Thus, successful coordination was accomplished through a variety of strategies that included the use of external representations, conversational devices, and physical moves.

These case analyses served to highlight the dual nature of the group task: work on a content space and a relational space that could be integrated more or less successfully to achieve a joint problem-solving space. The relationship between social and cognitive aspects of learning are particularly salient in small, collaborative work groups and thus provide a powerful site to push theorizing about how these dimensions interrelate. The data in this article suggest that one important way social and cognitive factors intertwine is in the development and maintenance of a between-person state of engagement. This between-person state of engagement might be thought of as a continuum of intersubjective awareness that ranges from almost complete lack of joint attention to continual coordinated participation. A highly coordinated state has cognitive affordances that a more loosely coupled state does not. For example, Shirouzu et al. (2002) proposed that the switching of roles from doer to monitor allows for reflection to occur that leads to abstraction and the development of a quantification strategy. For this kind of interperson work to occur, the partners must be highly attuned to one another and their evolving understanding.

The idea that relational issues express themselves in conversational processes is not new: Sociolinguistic research is based on this insight and is organized to study the specific mechanisms through which they exert their influence. What needs further specification is how relational and identity issues that are prominent for school-age students and shaped by classroom-related practices influence interaction in learning activities. Three kinds of relational issues may be particularly prominent when we think about small-group learning situations. First, a well-studied dimension of school life is the cooperative–competitive dimension. If learning is organized to stress individual competition and grade making over mutual gain
through cooperative learning, then one can expect to see more problematic interactions in small groups. Research on motivation suggests that the more competitive the environment, the more students focus on finding ways to document and protect their individual competence rather than learning for the sake of learning (Ames, 1981). A reasonable hypothesis is that when schooling values student identities that are based on being smarter than others, the extent to which students are willing to engage mutually in intellectual discourse may be compromised.

Second, insights from situative learning perspectives (as well as developmental socialization theories) suggest that we look to the kinds of practices that students have been accustomed to in school (Boaler, 2000). An analysis of practices would articulate how learning is organized, show the way subject matter is presented, and identify the kinds of underlying subject-matter norms (Cobb, 2002) that organize classroom lessons. Such an analysis would seek to understand the constraints and affordances that students had become accustomed to and that would influence how they engaged in academic pursuits both alone and with others (Greeno, Collins, & Resnick, 1996). For example, there is good evidence that through participation in intentionally designed discourse communities students come to appropriate conventions for discussing subject-matter content as well as use and interpret symbolic representations (Lampert, 1986; Michaels & Sohmer, 2001). There is evidence that beliefs about learning are influenced by classroom norms (Nicholls, Cobb, Wood, Yackel, & Patashnick, 1990). As noted earlier, Engle and Conant (2002) made an explicit connection between the disciplinary discourse practices that were being used in whole-class discussions and the small-group interactions that took place when students worked independently. During the debate students appropriated the practice of positioning or associating members with different arguments. This kind of conversational move is not common in elementary school students, and Engle and Conant suggested that the classroom norm of accountability to the ideas of other intellectual stakeholders in the classroom and beyond fostered this interactional pattern.

Third, a relational factor that is infrequently found in the literature on situative learning but is certainly important is that of personal relationship or friendship. Experimental research that manipulates the friendship status of collaborating partners has shown that friends engage in more productive dialogue during learning activities than those who are not friends. This friendship effect has been demonstrated in the context of creating musical compositions (Miell & MacDonald, 2000) and scientific-reasoning tasks (Azmitia & Montgomery, 1993). Friends are more likely to engage in transactive exchanges (Berkowitz & Gibbs, 1983) that elaborate and extend the thinking of their partners. They also talk more and offer more ideas to one another. It has been suggested that these findings are due to both shared past experiences with the partner and motivation to nurture the relationship. Friends are used to building joint problem-solving spaces and are consequently more familiar with the prior knowledge, communicative strategies, and thinking styles of their partners.
They are also more interested in creating shared spaces and are perhaps willing to work harder to do so than those who are not friends. These factors are important mediators of better conversations.

A basic conclusion of this work is that some patterns of interaction are more productive than others for establishing a working joint problem-space that allows the group to capitalize on the resources available to solve problems and to learn from one another. Rather than focusing on issues of composition defined with respect to individual characteristics like prior achievement or only on cognitive aspects of the development of a joint problem-space, these findings suggest we pay attention to the relational context that is developed as students work together. Work on the role of status in learning groups has been productive in highlighting how issues of power can play out in small-group learning contexts (Cohen & Lotan, 1995). Interventions derived from status accounts include assigning competence tasks to low-status students and designing tasks likely to capitalize on diverse kinds of expertise. These interventions have been shown to be effective (Cohen & Lotan, 1995). However, there are important differences in goals and desired outcomes between this perspective and sociocultural perspectives that focus more on how local contexts and discourse communities shape interactional patterns (e.g., Cobb, Stephan, McClain, & Gravemeijer, 2001; Lampert, 1986; Warren & Rosebery, 1995). Status interventions are designed to increase rates of participation from low-status students. Sociocultural approaches focus on the form of participation rather than the frequency. Approaches that promote use of discourse conventions associated with established intellectual practices hope to bring students to ways of working and talking that are productive for coordinated, mutual engagement (Duschl & Osborne, 2002).

Evidence That School Practices Influence Collaborative Capacity or Orientations

Because this was not an ethnographic study, I am unable to provide detailed data on the kinds of norms that pervaded the participants’ school with respect to work or the types of knowledge-building practices in which they were involved. However, a recent comparative study by Stephenson (2000) of the learning implications of mathematics teaching practices in two schools lends support to the idea that practices can influence how students orient to one another when asked to collaborate. One of the schools in the study was a traditionally focused school in which the teacher utilized individual desk work combined with lecture to teach. The other school was a magnet school that was organized around cooperative, project-based learning and emphasized prosocial development. In addition to collecting individual problem-solving data, students from each school were asked to collaborate on two complex mathematics problems. Using the coding system that focused on proposals and reactions reported in Barron (2000a), Stephenson found that collabora-
tors from the traditional school had high rates ignoring or rejecting responses, whereas the collaborators from the magnet school were more likely to engage ideas, elaborate them, and did better on solutions. Thus, the groups from the traditional school looked more like the less successful triads described here, whereas the groups from the magnet school look more like the successful triads.

Similarly, Matusov, Bell, and Rogoff (2002) were able to characterize broadly interactional patterns of dyads who attended two different schools that engaged in different kinds of institutional practices in the context of schooling. One school was highly collaborative, whereas the other favored more traditional discourse and participatory patterns. Using a five-level coding system, these researchers were able to score reliably global patterns of interactional styles that were differentiated by the extent to which the partners engaged in unilateral or joint decision making and whether they built on one another’s ideas or worked individually. Students from the collaborative school were more likely to build consistently on one another’s ideas and work through achieving consensus.

Whether the results of these two studies are due to greater amounts of experience in collaboration, differences in valued discourse patterns, or, more generally, differences in the quality of preexisting relationships among children is not clear. These factors are difficult to untangle as collaborative schools often stress positive interpersonal engagement and experience collaborating has been shown to have positive relational outcomes such as deeper friendships (Barron, Martin, Roberts, Osipovich, & Ross, 2001; Johnson & Johnson, 1981).

CONCLUSIONS AND FUTURE DIRECTIONS

The research reported here extends and further articulates interactional dimensions that underlie more global differences in the quality of collaboration that have been described in case studies. Furthermore, these data provide evidence that shows that learning outcomes as well as concurrent joint problem-solving outcomes are influenced by qualities of interaction. These findings point to the need for a better theoretical understanding of joint learning that integrates cognitive, relational, and social practice aspects of learning (Lave, 1988). Much of the empirical research on collaboration has utilized individually defined traits and outcomes. This is likely due to the challenge of translating theoretical insights about system-level effects into reliable measures. The findings reported here confirm the importance of between-person processes in learning and collective thinking and highlight the need for further empirical work at this level of analysis.

Given the importance of collaborative activity, both in school and out, four main directions of future research seem of special interest. First, it would be productive to continue to understand the basic conversational dynamics of knowledge-building conversations. One way to extend the current findings would be to test the hypothesis that the amount of variance accounted for by quality of interac-
tion measures will be greater than more traditional individually derived measures. In this study responsivity and connectedness were measured. Other variables might include self versus other reference (Barron, 2000a) and the frequency of transactional responses across all types of turns (e.g., Azmitia & Montgomery, 1993). As work on collaborative variability progresses, it will be possible to develop more complete taxonomies of generative conversational processes. For example, what kinds of moves keep fragile knowledge alive? What kinds of representational practices support the development of joint problem-solving spaces? A better articulation of the dynamics of learning conversations paves the way for empirical research that will allow us to identify the kinds of learning artifacts and institutional discourse practices that are involved in their maintenance.

Second, it would be of interest to know the form and variety of collaboration knowledge. It may be that students develop metaknowledge about joint activity that they use in interaction with others. There is evidence that following an intensive collaborative design experience, some students develop insights about collaborative work processes (Barron et al., 2002). How general are these metacommunicative reflections? Do these kinds of insights transfer to other collaborative contexts? Do students become better at regulating the dual-space demands of collaboration? Are they better able to recognize a fragile joint space and find ways to build it? Longitudinal studies of collaborative interaction would begin to address the question of whether expertise in collaborative thinking can be developed.

Third, an important question that has only been partially addressed is whether certain school cultures or more narrowly defined classroom practices result in ways of participating in learning that are more or less productive in supporting generative collaboration. Focusing on the relation between the interactional–intellectual practices embodied in learning environments and how collaborative student peer groups learn together may be a productive and fresh way to approach the study of collaborative learning. To explore these ideas further research needs to be designed that can simultaneously look at classroom discourse practices and small-group appropriation of those practices. Rogoff (1998) made a useful distinction between three planes of analyses that can be studied independently but that must be understood as interrelated. These are the community plane, the interpersonal plane, and the individual plane. Analyses at each of these levels requires different methods of inquiry. For example, analyses of the community plane benefits from ethnographic studies that can capture regularities in the organization of practices over time (Erickson, 1977; O’Connor & Michaels, 1996; Schiefflin & Ochs, 1996). Analyses at the interpersonal plane focus on interactions at a more microlevel that occur between dyads or small groups. Analyses at the individual level foreground the reasoning, beliefs, or problem-solving outcomes produced by individuals. Both experimental and ethnographic methods might be used to compare classrooms that do and do not focus on collaborative discourse. Outcome measures should include interactional variables on novel collaborative tasks as well as learning outcomes. The question of how
students appropriate ways of interacting, investigating, questioning, and collaborating as a function of the material contexts, tools, and classroom discourse communities of which they are part is a rich research agenda that will require a wide range of methods and theoretical perspectives.

Fourth, how can we help teachers learn to see and foster productive collaboration and diagnose and redirect unproductive activity in collaborative groups? These results may suggest that communication skills should be taught. In fact, Sfard and Kieran (2001) interpreted their case study in this manner. The way this is done needs careful thought. Communication skills taught out of the context of subject matter are not likely to enhance disciplinary-specific, joint-thinking practices. Developmental literature on communicative competence in infancy suggests that from early on we develop sophisticated abilities to monitor, recruit, and maintain joint attention (Trevarthen & Aitken, 2001). Thus, what we need to pay attention to is not communicative competence per se but how to foster norms of accountability to the thinking of others and standards of disciplinary engagement. There is little available research on how teachers perceive these aspects of small-group interaction or on the different degrees of expertise teachers may have in establishing and developing such practices. We do know that it can be challenging even for expert teachers who have clear goals and deep understanding to develop new discourse norms (Lampert, Rittenhouse, & Crumbaugh, 1996). Given that many aspects of managing the dual-space requirements of collaboration are subtle, it is likely that teachers might benefit from the development of video cases that highlight contrasting cases and connect interaction to learning outcomes and to their own discourse practices.

Classroom-based research is particularly important as the experimental nature of the research reported in this article may raise questions about the ecological validity of the findings. Collaborative projects carried out in classrooms can be structured in numerous ways that lead to very different patterns of interaction. For example, groups frequently evolve divide-and-conquer strategies that may minimize interactional difficulties but also compromise opportunities for mutual learning (Stevens, 2000). Alternatively, with longer time periods students may have more opportunities to repair problematic patterns independently. Formative assessment opportunities may be designed to provide an explicit forum for reestablishing mutual engagement. Collaborative phenomena may also differ across disciplinary contexts, and the methods of analysis utilized here may not directly transfer if the collaboration is organized around other kinds of problems such as historical interpretation or literary analysis. More classroom research is needed to establish the generality of the present findings.

In closing, my findings underscore the need to shift from a purely instrumental view of collaboration as a tool for learning to a view that foregrounds learning to collaborate on intellectually challenging activities as a fundamental human competence. How one develops a capacity to engage others in joint work in ways that capitalize on the potential of distributed reasoning is an issue that has the potential to reshape our conceptions of what should be valued in schools. Learning through-
out the life span, especially postschooling, is often a social affair (Meegan & Berg, 2002; Sternberg, 2000). Becoming a better colearner may be one of the more important things we help students to do.

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