Group Cognition in Online Teams

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This chapter represents a disciplinary perspective from Computer-Supported Collaborative Learning (CSCL), an interdisciplinary field concerned with leveraging technology for education and with analyzing cognitive processes like learning and meaning making in small groups of students (Stahl, Koschmann & Suthers, 2006). *Group cognition* is a theory developed to support CSCL research by describing how collaborative groups of students could achieve cognitive accomplishments together and how that could benefit the individual learning of the participants (Stahl, 2006). It is important to note that while it may very well be the case that a group of students working together manage to solve problems faster than any of them may have been able to do alone, the most important benefits to group cognition are the potential for genuinely innovative solutions that go beyond the expertise of any individual in the group, the deeper understanding that is achieved through the interaction as part of that creative process, and the lasting impact of that deep understanding that the students take with them when they move on from that interaction, which they may then carry with them as new resources into subsequent group problem-solving scenarios. Group cognition can then be seen as what transforms groups into factories for the creation of new knowledge.

The types of problems that have been the focus of exploration within the group cognition paradigm have thus not been routine, well-structured problems where every participant can know exactly what their piece of the puzzle is up front in such a way that the team can function as a well oiled machine. Many critical group tasks do not fit into well-known and practiced protocols—for example, low-resource circumstances that may occur in disaster situations, where standard solutions are not an option. In acknowledgement of this, the focus within the group-cognition research has been on problems that offer groups the opportunity to explore creatively how those problems can be approached from a variety of perspectives, where the groups are encouraged to explore unique perspectives. The processes that are the concern of group-cognition research have not primarily been those that are related to efficiency of problem solving (as in some other chapters of this volume). Rather, the focus has been on the pivotal moments where a creative spark or a process of collaborative knowledge building occurs through interaction. Our fascination has been with identifying the conditions under which these moments of inspiration are triggered, with the goal of facilitating this process of group innovation and collaborative knowledge creation.

In this collaboratively written chapter, we consider insights from group cognition in light of synergistic ideas from other subcommunities within CSCL. Within the field of computer-supported collaborative learning, the topic of what makes group discussions productive for learning has been explored—with a similar focus and very similar findings, perhaps with subtle distinctions—under different names, such as *transactivity* (Berkowitz & Gibbs, 1983; Teasley, 1997; Azmitia & Montgomery, 1993; di Lisi & Golbeck, 1999), *uptake* (Suthers, 2006), *social modes of co-construction* (Weinberger & Fischer, 2006), or *productive agency* (Schwartz, 1998). Despite differences in orientation between the subcommunities where these frameworks have originated, the conversational behaviors that have been identified as valuable are quite similar. Specifically, these different frameworks universally value explicit articulation of reasoning and making connections between instances of articulated reasoning. For example, Schwartz and colleagues (1998) and de Lisi and Golbeck (1999) make very similar arguments for the significance of these behaviors from the Vygotskian and Piagetian theoretical frameworks, respectively. The idea of transactivity as a property of a conversational contribution originates from a Piagetian framework and requires that a contribution contain an explicit reasoning display and encode an acknowledgement of a previous explicit reasoning display. However, note that when Schwartz describes from a Vygotskian framework the kind of mental scaffolding that collaborating peers offer one another, he describes it in terms of one student using words that serve as a starting place for the other student's reasoning and construction of knowledge. This implies explicit displays of reasoning, so that the reasoning can be known by the partner and then built upon by that partner. Thus, the process is very similar to what we describe for the production of transactive contributions. In both cases, a transactive analysis would say that mental models are articulated, shared, mutually examined and potentially integrated.

The theory of group cognition has been explored primarily using data from the Virtual Math Teams (VMT) Project, documented in (Stahl, 2009a). While much of the analysis of VMT data takes the form of detailed case studies conducted manually (often in group data sessions), the VMT Project and CSCL generally are also interested in the use of software algorithms to aid in the analysis of online discourse (Rosé et al., 2007; Rosé et al., 2008; Kang et al., 2008) or collaborative recorded speech (Gweon et al., 2009), especially with the promise that effective facilitation of collaborating groups can eventually be automated (Kumar et al., 2007; Cui et al., 2009; Chaudhuri et al., 2009; Kumar et al., in press). Some of this automatic analysis work has focused explicitly on properties like transactivity (Joshi & Rosé, 2007; Rosé et al., 2008), while other work focuses on lower-level conversational processes that can be seen as building blocks that enable the recognition of transactivity (Wang & Rosé, 2007; Wang & Rosé, in press; Ai et al., submitted) or more general-purpose text-mining techniques related to making fine-grained stylistic distinctions (Joshi & Rosé, 2009; Arora, Joshi, & Rosé, 2009; Mayfield et al., submitted). As part of this effort, we have worked to transcend the theoretical underpinnings of frameworks like transactivity to think more about a linguistic-level lens through which to view the data that might serve as a form of *interlingua*, or intermediate representation, that would make it more natural to bridge between different theoretical frameworks (Howley, Mayfield, & Rosé, in press). This objective of working towards a linguistic-level lens that is close to being theory neutral with respect to learning-science theories is particularly key for our collaboration because of the way that the group-cognition framework does not made the same assumptions about mental models and cognitive processes as do many of the above-mentioned other frameworks.

Group cognition is a post-cognitive theory, like some of the theories presented in other chapters of this book. Post-cognitivism is a tradition characterized by situated, non-dualistic, practice-based approaches, as described by Musaeus (this volume). Cognitivism—which tends to retain theoretical remnants of the Cartesian dualism of the mental and physical worlds—originally arose through the critique of behaviorism, with the argument that human responses to stimulae in the world are mediated by cognitive activity in the mind of the human agent. This argument was particularly strong in considerations of linguistic behavior (Chomsky, 1959). More recently, post-cognitivist theories have argued that cognitive activity can span multiple people (as well as artifacts), such as when knowledge develops through a sequence of utterances by different people and the emergent knowledge cannot be attributed to any one person or assumed to be an expression of any individual's prior mental representations (e.g., Bereiter, 2002, p. 283).

In his seminal statement of post-cognitivist theory, Hutchins (1996) pointed to group-cognitive phenomena: "*The group performing the cognitive task may have cognitive properties that differ from the cognitive properties of any individual*" (p. 176). "*The cognitive properties of groups are produced by interaction between structures internal to individuals and structures external to individuals*" (p. 262). However, rather than focusing on these group phenomena themselves, Hutchins usually analyzes socio-technical systems and the cognitive role of highly developed artifacts (airplane cockpits, ship navigation tools). In focusing on the cultural level—characteristically for a cultural anthropologist—he does not often analyze the cognitive meaning making of the group itself.

Group-cognition theory explicitly focuses on these inter-personal phenomena and investigates data in which one can observe the development of cognitive achievements in the interactions of small groups of people, often in online collaborative settings, where interactions can be automatically logged. By interaction, we mean the discourse that takes place in the group. Thus, what Beck & Keyton (this volume) say for macrocognition or team cognition applies to group cognition, namely that it is communicatively based and can be tracked in team members' interdependent messages. Group cognition is fundamentally a linguistic (speech or text) process, rather than a psychological (mental) one, as mentioned above. Thus, unlike the theory of transactivity described above, this post-cognitive approach does not assume cognitive constructs such as mental models, internal representations or retrievable stores of personal knowledge. In the online setting of VMT, cognition is analyzed by looking closely at the ways in which meaning is built up through the interplay of text postings, graphical constructions and algebraic formulations (Çakır, Zemel & Stahl, 2009). Methodologically, our case studies of group cognition use a form of interaction analysis (Jordan & Henderson, 1995) adapted from conversation analysis (Sacks, 1962/1995) to the CSCL context (Stahl, 2009a, p. 47). In our ongoing collaboration, we are exploring ways of extending these approaches in light of linguistic frameworks such as systemic functional linguistics (Christie, 1999; Martin & Rose, 2003; Martin & White, 2005).

The title of this chapter already reflects a tension that permeates this book as a whole (see Koschmann, this volume): that between the human sciences and the natural sciences, between *understanding* team cognition (e.g., with micro-analysis of situated case studies) and *explaining* it (e.g., modeling, confirming general hypotheses, formulating laws and specifying predictive causal relations). Group cognition in online teams involves both humans and computers, both highly situated collaborative interactions and programmed computer support. Our methodology therefore includes both micro-analysis of group discourse in unique case studies and the automated coding of the discourse log for statistical hypothesis testing.

The field of CSCL is particularly interested in the ways small groups can build knowledge together thanks to communication and support from networking technology. We hope that CSCL environments can be designed that make possible and encourage groups to think and learn collaboratively. In our research, our colleagues and we look at logs of student groups chatting and drawing about mathematics in order to see if they build on each other's ideas to achieve more than they would individually. How do they understand each other and build shared language and a joint problem focus? What kinds of problems of understanding do they run into and how do they overcome those? How do they accomplish intersubjective meaning making, interpersonal trains of thought, shared understandings of diagrams, joint problem conceptualizations, common references, coordination of problem-solving efforts; planning, deducing, designing, describing; problem solving, explaining, defining, generalizing, representing, remembering and reflecting as a group? What can we say about the general methods that small groups use to learn and think as groups? How can we support and encourage this better with software support for social awareness, social networking, simulations, visualizations, communication; with intelligent software agents; with pedagogical scaffolds and guidance; with training and mentoring; with access to digital resources; with new theories of learning and thinking? To answer these complex questions, we must look carefully at the details of discourse in CSCL groups and develop innovative tools (both analytic and automated) and theories (of cognition by individuals, small groups and discourse communities).

VIEWS OF LEARNING AND THINKING

The learning sciences view learning as involving meaning making by the learners (Stahl, Koschmann & Suthers, 2006). Students who just passively accept instruction without thinking about it and coming to understand it in their own way of making sense of things will be wasting everyone's time. Why? Because they will not be able to *use* the new knowledge or to *explain* it. Of course, this construction of meaning takes place over time: someone can learn something one day and make sense of it later, when they try to use it in different circumstances and to explain their use to other people and to themselves. But if they never integrate what they have learned into their own thinking and acting—by applying it where appropriate and talking about it clearly—then they will not have really learned. What sociologists like Bernstein, as presented in Hasan's overview (1999), know about social interactions and contribute to our understanding of the significance of group cognition is the way participants internalize the resources that evolve within one interactional context and then recontextualize them in new and radically different contexts they find themselves in later. In this way, the new knowledge that is created, or the new or enhanced knowledge-building skills that are appropriated, can replicate and spread contagiously. It is the magic that, for instance, makes seemingly inconsequential interactions between mothers and children while cleaning the oven play a key role in a child's preparation for schooling (Cloran, 1999). It is precisely because of the tremendous impact the results of these interactions can have going forward that the local sacrifice that may occur in terms of efficiency of the interaction can be viewed as a small price to pay when one considers the long-term cost-benefit ratio, the profound impact of one transformational experience of group cognition.

Vygotsky *(1930/1978)* made an even stronger argument. He showed for the major forms of human psychological functioning that the individual capabilities were derived from interpersonal experiences:

> *An interpersonal process is transformed into an intrapersonal one*. Every function in the child's cultural development appears twice: first, on the social level and later, on the individual level; first *between* people (*interpsychological*), and then *inside* the child. This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher functions originate as actual relations between human individuals. (p. 57)

Although all functions of individual cognition are derived from group cognition, the reverse is not true. As Hutchins (1996) demonstrated with his example of the bridge of a large Navy ship, not all group cognition can be internalized by an individual: "The distribution of knowledge described [in the book] is a property of the navigation team, and there are processes that are enabled by that distribution that can never be internalized by a single individual" (p. 284). Whether or not specific skills and knowledge can be mastered by individuals or only by teams, the learning of those skills or knowledge seems to rely heavily and essentially on group cognition. That is why we try to promote and to study group cognition.

What we, as learning scientists, have learned about learning and thinking in recent decades in the West is influenced by what philosophers before us said. For instance, most Western philosophers until the middle of the 1900s thought that knowledge could be expressed by propositions, sentences or explicit statements. If that were true, then the learning of knowledge could, indeed, consist simply of students individually hearing or reading the right sentences and remembering them.

But Ludwig Wittgenstein's book, *Philosophical Investigations*, published in 1953, questioned this view of learning and thinking. It looked at math as a prime example. Mathematical knowledge can be seen as a set of procedures, algorithms or rules. Wittgenstein asked how one can learn to follow a mathematical rule (Wittgenstein, 1944/1956, Part VI; 1953, §185-243, esp. §201). For instance, if someone shows you how to count by fours by saying, "4, 8, 12, 16," how do you know how to go on? Is there a rule for applying the rule of counting by fours? (Such as, "Take the last number and add 4 to it.") And if so, how do you learn to apply that rule? By another rule? Eventually, you need to know how to do something that is not based on following a propositional rule—like counting and naming numbers and recognizing which numbers are larger. The use of explicit rules must be somehow grounded in other kinds of knowledge. These other kinds include the tacit knowledge of how to behave as a human being in our culture: how to speak, count, ask questions, generalize, put different ideas together, apply knowledge from one situation in another context and so on. *And these are the kinds of things that one initially learns socially, in small groups or in child-parent dyads.* Wittgenstein's question brought the logical view of knowledge as explicit propositions into a paradox: if knowledge involves knowing rules, then it must involve knowing how to use rules, which is itself *not* a rule.

Wittgenstein was an unusual philosopher because he said that problems like this one could not be solved by contemplation, but rather by looking at how people actually do things. He said, "Don't think, look!" (1953, §66). In studying group cognition, we try to follow Wittgenstein's advice. We try to view how small groups of people actually *do* things. Our focus is on understanding how the group magic occurs concretely in interaction.

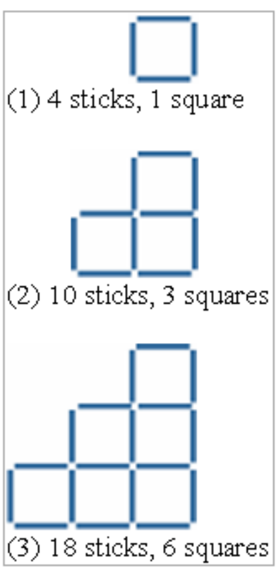
A perspective on cognition is a particular way of viewing it. Rather than telling you what our *views* or ideas are about learning and thinking in CSCL groups, we will show you how we *view* or observe learning and thinking in CSCL groups. The term "view" has this double meaning: it means both viewing by looking at something with ones eyes and also viewing in the metaphorical sense of thinking about something from a conceptual perspective. Although Wittgenstein himself did not actually look at empirical examples of how people follow rules in math, we can. By carefully setting up a CSCL session, we can produce data that allows us to view groups of students learning how to follow math rules and thinking about the math rules. This is what we do to view learning and thinking in CSCL groups. It is the basic approach of the science of group cognition (see Stahl, 2009b for a discussion of the scientific methodology).

The work of our research teams and other colleagues involves looking closely at some rich examples of student groups learning and thinking about math. We would like to share a brief excerpt from one of these examples with you and talk about how we go about viewing the learning and thinking of this group of students. In particular, how do they construct their group cognition through collaborative meaning-making activities?

In this chapter, we will look at the meaning-making work of a group of students, analyzing their language-based interaction at multiple levels: the overall *event*, a specific hour-long *session* of the two-week event, a discussion *theme* that arose, a discourse *move* that triggered that theme, a pivotal *interchange*, a single *utterance* and a particular *reference* in the utterance. By looking at the linguistic connections, we can see how the syntax, semantics and pragmatics weave a network of meaningful references that accomplishes a set of cognitive achievements.

On the one hand, we can see the linguistic elements of the log and their structure of temporal and hierarchical relationships as accomplishing group cognition by, at each moment, constraining the next utterance as situated in the context of event, session, theme, discourse moves, eliciting adjacency pairs, preceding utterances and network of references. On the other hand, human actors creatively design accountable responses (see Koschmann, this volume) within the constraining situation defined by these contextual elements. That is, among the constraints on the actors is the requirement that their linguistic actions make sense in the on-going discourse and that they reveal their meaning and relevance in their linguistic design. Although people often design their utterances to convey the impression that they are the result of psychological processes (change of mental state, expression of internal reflections), we can analyze the group cognition in terms of the linguistic effects of the observable words and drawing actions, without making any assumptions about individual mental representations. The individual students are active as linguistic processors—interpreting and designing the utterances—but the larger mathematical and cognitive accomplishments are achieved through the group discourse, which exists in the computer displays, observable by the students and—even years later—by analysts. As Koschmann suggests, we can see and make explicit how teams become teams in the ways that they manifest the contingencies and accountabilities of their unique situation, using conventional linguistic structures as resources.

THE EVENT: VMT SPRING FEST 2006 TEAM B



N	Sticks	Squares
1	4	1
2	10	3
3	18	6
4	?	?
5	?	?
6	?	?
...	...	...
N	?	?

Session I

1. Draw the pattern for N=4, N=5, and N=6 in the whiteboard. Discuss as a group: How does the graphic pattern grow?

2. Fill in the cells of the table for sticks and squares in rows N=4, N=5, and N=6. Once you agree on these results, post them on the VMT Wiki

3. Can your group see a pattern of growth for the number of sticks and squares? When you are ready, post your ideas about the pattern of growth on the VMT Wiki.

Sessions II and III

1. Discuss the feedback that you received about your previous session.

2. WHAT IF? Mathematicians do not just solve other people's problems — they also explore little worlds of patterns that they define and find interesting. Think about other mathematical problems related to the problem with the sticks. For instance, consider other arrangements of squares in addition to the triangle arrangement (diamond, cross, etc.). What if instead of squares you use other polygons like triangles, hexagons, etc.? Which polygons work well for building patterns like this? How about 3-D figures, like cubes with edges, sides and cubes? What are the different methods (induction, series, recursion, graphing, tables, etc.) you can use to analyze these different patterns?
3. Go to the VMT Wiki and share the most interesting math problems that your group chose to work on.

Figure 1. Topic for VMT Spring Fest 2006.

Here, we will be talking about an online event that occurred three-and-a-half years ago. The interaction is preserved in a computer log, which can be replayed by researchers. Three students, probably about 16 years old, were assigned to be Team B and they met with a facilitator in an online chat environment on May 9, 10, 16 and 18, in 2006, for about an hour in the late afternoon each day. The participants were distributed across three time zones in the US. The event was part of the VMT research project. Neither the students nor we know anything more about each other's personal characteristics or background.

The topic for this event was to explore a pattern of sticks forming a stair-step arrangement of squares (see Figure 1) and then to explore similar patterns chosen by the students themselves. The VMT online environment consisted primarily of a synchronous chat window and a shared whiteboard. At the end of each session, the students were supposed to post their findings on a wiki, shared with other teams participating in the Spring Fest. Between sessions, the facilitator posted feedback to the students in a textbox on the whiteboard.

<Figure 1>

THE SESSION: SESSION 3, MAY 16, 7 PM

Let's look at an excerpt from the end of the third session. The three students had already solved the original problem of the stair-step pattern of squares. They had also made up their own problem involving three-dimensional pyramids. Now they turned to look at the problem that Team C had described on the wiki after session 2. Team B is looking at an algebraic expression that the other team of students had derived for a diamond pattern of squares. They start to draw the pattern in their whiteboard (see Figure 2) and chat as a team about the problem of this new pattern.

<Figure 2>

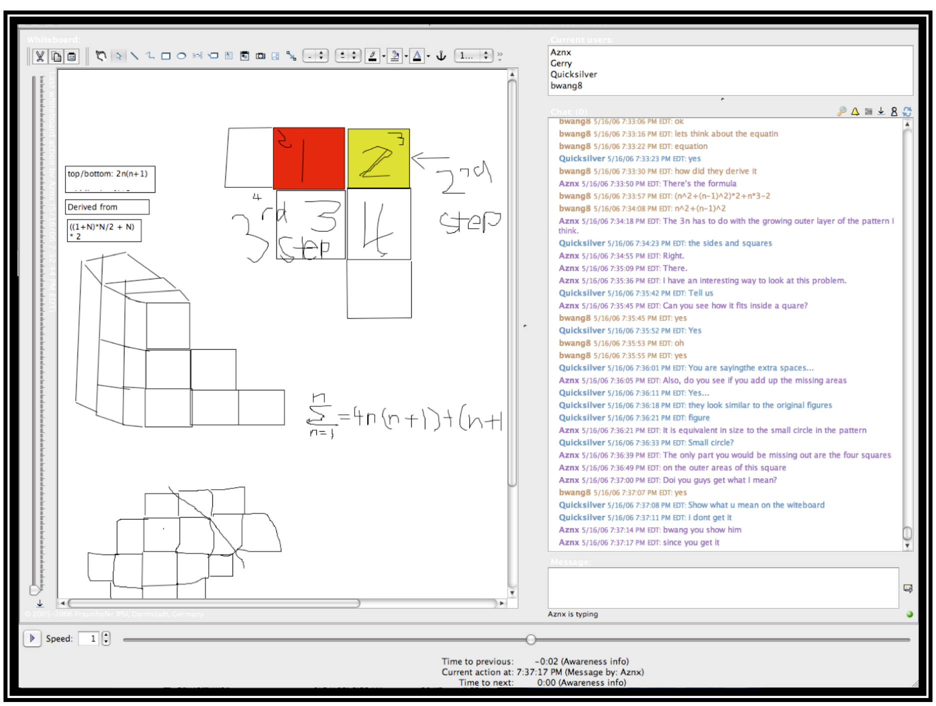


Figure 2. The VMT Replayer showing the VMT online environment.

THE THEME: "I HAVE AN INTERESTING WAY TO LOOK AT THIS PROBLEM"

One of the students, Aznx, begins to make a proposal on how to "look" at their problem. First, he announces, "I have an interesting way to look at this problem." Note that he uses the word "look" in the same double meaning of "view" that was mentioned above. As we will see, he means he has a new way to think about the problem mathematically—and that involves a way of observing a visual image of the problem. The group does its thinking both by typing text and algebraic expressions in the chat window and by simultaneously drawing and viewing diagrams or geometric constructions of the problem in the shared whiteboard (see Çakır, Zemel & Stahl, 2009 for an analysis of the coordination by the group of their text, symbols and drawings).

Aznx' announcement opens an opportunity for the group to discuss a way of looking at the problem. In fact, the group takes up the offer that is implicit in Aznx' statement and the students spend the next eight minutes trying to each understand it. As it turns out, they will work on this view of the problem for the rest of this session and most of their final session.

A VMT chat session can generally be analyzed as a series of themes or discussion topics. Often, themes come and go, and different themes overlap, with one wrapping up while another gets started. Researchers can identify the boundaries of a theme: when a new theme opens and an old one closes (Zemel, Xhafa & Çakir, 2009).

In this case, the group has been talking about how the diamond pattern grows as a geometric figure for a couple of minutes and then they discuss Team C's algebraic expression for a couple of minutes. As those themes get played out and there is a pause in the chat, Aznx makes a move to open a new theme for the group.

A MOVE: SHOWING HOW TO VIEW THE PROBLEM

Aznx' announcement that he has a perspective to share with the group is a way of introducing a new theme, a "pre-announcement" (Schegloff, 2007, pp. 37-44; Terasaki, 2004). Conversations often flow by new contributions picking up on something that was already being discussed. Online text chat tends to be more open than face-to-face talking; chat does not follow the strict turn-taking rules of conversation. However, it is still common to do some extra work to change themes even in chat. In a sense, Aznx is asking permission from the group to start a new theme. Quicksilver responds encouragingly right away by saying, "Tell us" (see Figure 3).

<Figure 3>

line	date	start	post	delay		
919	5/16/06	19:35:26	19:35:36	0:00:06	Aznx	I have an interesting way to look at this problem.
920	5/16/06	19:35:41	19:35:42	0:00:03	Quicksilver	Tell us
921	5/16/06	19:35:38	19:35:45	0:00:00	Aznx	Can you see how it fits inside a quare?
922	5/16/06	19:35:45	19:35:45	0:00:07	Bwang	yes
	5/16/06	19:35:49	19:35:52	0:00:00	Bwang	[user erased message]
923	5/16/06	19:35:51	19:35:52	0:00:01	Quicksilver	Yes
924	5/16/06	19:35:52	19:35:53	0:00:02	Bwang	oh
925	5/16/06	19:35:55	19:35:55	0:00:06	Bwang	yes
926	5/16/06	19:35:53	19:36:01	0:00:04	Quicksilver	You are sayingthe extra spaces...
927	5/16/06	19:35:58	19:36:05	0:00:06	Aznx	Also, do you see if you add up the missing areas

Figure 3. The move to introduce Aznx' new way of looking at the group's problem.

Actually, Aznx already starts typing his proposal before he gets Quicksilver's response, but it is not posted until afterward. The next step in his proposal is: "Can you see how it fits inside a square?" Here, he structures his contribution as a question, which elicits a response from the other members of the team. Note that he uses the term "see" in his proposal with the same double meaning as the term "look" in his prior announcement. As we shall see (in both senses), the group tries to work out and comprehend Aznx' proposal both conceptually and visually.

Both Bwang and Quicksilver respond to Aznx's proposal with "Yes". However, both modify this response. Bwang starts to type something else, but erases it; then he posts two messages: "oh" and "yes". This suggests some hesitation in responding to the proposal immediately. Quicksilver follows his initial positive response with, "You are saying the extra spaces …" He is asking for more clarification of the proposal. While Quicksilver is typing his request for clarification, Aznx is typing an expansion of his initial proposal: "Also, do you see if you add up the missing areas …"

The analysis of interaction moves is central to the science of group cognition. This is the level of granularity of many typical group-cognitive actions. Discourse moves are ways in which small online groups get their work done. They often follow conventional patterns—speech genres (Bakhtin, 1986) or member methods (Garfinkel, 1967)—which makes them much easier for participants to understand. Researchers can also look for these patterns to help them understand what the group is doing.

In this case, a new theme is being opened, one that will provide direction for the rest of this group's event together. This move is an example of one way in which a group can establish a shared understanding of a diagram or select a joint problem conceptualization (depending on how we take the terms "look" and "see"). Other moves that we often see in VMT logs are, for instance, defining shared references, coordinating problem-solving efforts, planning, deducing, designing, describing, solving, explaining, defining, generalizing, representing, remembering and reflecting as a group.

A PAIR: QUESTION/RESPONSE: "CAN YOU SEE HOW IT FITS INSIDE A SQUARE?" / "YES"

In conversation analysis, one typically looks for "adjacency pairs" (Duranti, 1998; Sacks, 1962/1995; Schegloff, 2007). A prototypical adjacency pair is question/answer. Aznx' offering of a question—"Can you see how it fits inside a square?"—followed by Bwang and Quicksilver's responses—"yes", "Yes"—illustrate this structure for the simplest ("preferred") case: one person poses a yes/no question and the others respond with an affirmative answer.

Response structures are often more complicated than this. Text chat differs from talk in that people can be typing comments at the same time; they do not have to take turns and wait until one person stops talking and relinquishes the floor. They will not miss what the other person is saying, because unlike with talk, the message remains observable for a while. The disadvantage is that one does not observe how people put together their messages, with pauses, restarts, corrections, visual cues, intonations and personal characteristics. While it is possible to wait when you see a message that someone else is typing, people often type simultaneously, so that the two normal parts of an adjacency pair may be separated by other postings. For example, Quicksilver's question (line 926 in Figure 3) separated Aznx's continuation of his line 921 posting in line 927, because 926 appeared before 927 although 927 was typed without seeing 926. So in chat we might call these "response pairs" rather than "adjacency pairs." While they may be less sequentially *adjacent* than in talk, they are still direct *responses* of one posting to another.

Because the sequencing in online chat texting is less tightly controlled than in face-to-face talk, response pairs are likely to become entangled in the longer sequences of group moves. This may result in the common problem of "chat confusion" (Fuks, Pimentel & Pereira de Lucena, 2006; Herring, 1999). It can also complicate the job of the researcher. In particular, it makes the task of automated analysis more complicated. In convoluted chat logs, it is essential to work out the response structure (threading) before trying to determine the meaning making. The meaning making still involves participants interacting through the construction of response pairs, but in chat people have to recreate the ties among these pairs. Realizing this, the group members design their postings to be read in ways that make the response pair or threading structure apparent, as we will see (Zemel & Çakir, 2009).

AN UTTERANCE: QUESTION: "CAN YOU SEE HOW IT FITS INSIDE A SQUARE?"

In his posting—"Can you see how it fits inside a square?"—Aznx is comparing the relatively complicated diamond shape to a simple square. This is a nice strategy for solving the group's problem. The group can easily compute the number of stick squares that fill a large square area. For instance if there are five little squares across the width of a square area (and therefore five along the height), then there will be five-squared, or 25 little squares in the area. In general, if there are N little squares across the width, there will be N-squared to fill the area. This is a strategy of simplifying the problem to a simple or already known situation—and then perhaps having to account for some differences. So Aznx' posting seems to be relevant to thinking about the math problem conceptually.

At the same time, Aznx poses his proposal in visual or graphical terms as one of "seeing" how one shape "fits inside" of the other. The group has been looking at diagrams of squares in different patterns, both a drawing by Team C in their wiki posting and Team B's own drawings in their whiteboard. So Aznx's proposal suggests visualizing a possible modification to one of the diamond drawings, enclosing it in a square figure (see the white diamond pattern enclosed in the red square in Figure 4). He is asking the others if they can visualize this also, so that the group can use this to simplify and solve their problem with the diamond.

<Figure 4>

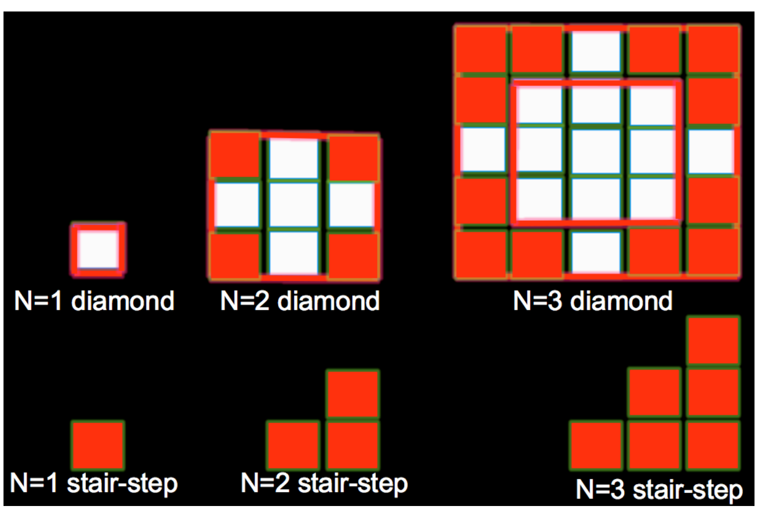


Figure 4. White diamond patterns and red stair-step patterns.

Aznx presents his proposal about re-thinking the problem as a question about visualizing the diagram. The group has been working in the VMT environment, going back and forth between text in the chat and drawings in the whiteboard. They have started with problems presented graphically and have discussed these graphical problems in their text chat. They have shared different ways of viewing the relationships within the drawings and they have gradually developed symbolic algebraic ways of expressing general relationships about patterns in these drawings, working out these symbolic expressions in the chat and then storing them more persistently in the whiteboard.

We have been calling Aznx' chat posting a "problem-solving math proposal" (Stahl, 2006, chapter 21). However, it is presented in the grammatical form of a *question*. Aznx did not simply state a proposal like, "I think we should enclose the diamond in a square, calculate the size of the square and then subtract the missing areas." Rather, he first announced that he had "an interesting way to look at this problem" and then explained his way of looking by asking if the others could "see how it fits inside a square." Presenting a proposal calls on the others to accept the proposal and to start to work on it. Of course, the others can reject the proposal, ask for clarifications about it, make a counter-proposal or ignore the proposal.

But Aznx' utterance is not a full proposal that the others must accept or reject. It is another preliminary step. It asks the others if they can visualize something. It puts this to them as a question. If they say yes, then Aznx can proceed to make his proposal—or perhaps the others will see the implications of his interesting way to look at the problem and propose the strategy without Aznx having to advocate it, explain it and defend it. If they say no—that they cannot see how it fits inside a square—then he can explain his view further so they will be better prepared to accept his proposal.

Aznx' chat posting avoids articulating a complete proposal; by starting the conversation about the visualization, it involves the others in articulating the proposal *collaboratively*. In fact, in the subsequent discussion, the others do "see" the strategy that is implicit in Aznx' interesting view of the problem and they do help to articulate the strategy and then pursue it. By designing his proposal as this preliminary question about viewing the problem, Aznx succeeds in directing the group problem solving in a certain direction without his having to fully work out a detailed, explicit proposal. Aznx does not seem to be presenting a solution that he has worked out in his head. Rather, he is presenting his "interesting idea" for an approach to solving the problem so that the group will proceed to use the idea and work as a group to try to solve the problem with this approach.

A REFERENCE: "IT"

Aznx' question is ambiguous at a purely syntactic level. It asks the others, "Can you see how *it* fits inside a square?" To what does the term "it" refer? People use pronouns like "it" rather than lengthy explicit noun phrases when the reference is clear from the context. This situates the utterance in its context—it's meaning cannot be gathered from the utterance considered in isolation. Often, "it" will reference something that was recently referred to in a previous contribution that the new utterance is building on. For instance, "it" could refer to something mentioned in Aznx' previous utterance, "I have an interesting way to look at this problem." But to say that it refers to "this problem" does not make complete sense. The *problem* does not fit inside a square.

However, a minute earlier, when the group was discussing Team C's equations, Aznx said about part of an equation, "The 3n has to do with the growing outer layer of the pattern I think."

He was referencing different aspects of the growth of the diamond pattern, particularly its "outer layer." So when he announces that he has an interesting way to view the problem, it is reasonable to assume that his new way of looking may be closely related to the observation that he had just reported about the outer layer of the diamond pattern. Because everyone in the group was following the flow of the discussion, Aznx could refer to the topic of the outer layer of the diamond pattern in the shorthand of the pronoun "it". When he typed, "Can you see how it fits inside a square?" he could assume that the readers of this posting would understand that he was referring to how some aspect of the diamond pattern can be seen as fitting inside of some square shape.

Although the reference to some aspect of the diamond pattern is relatively clear, the details are not clear about just what aspect of the diamond is to be visualized or focused on visually, where a square is to be constructed, and how the diamond fits inside the square. At this point, only a rather confusing image of a diamond pattern is visible on the whiteboard (see Figure 2). To *make sense* of "it", everyone has to follow the flow of discussion and the way in which the math topic is being developed as a "joint problem space", understood and visualized by the whole group.

Bwang and Quicksilver both respond initially to Aznx' question with "Yes." However, as we saw, Bwang indicates some hesitancy in his response and Quicksilver asks for further clarification. Aznx and Quicksilver discuss what they see when they fit a diamond pattern inside a square. Quicksilver notes that the "extra spaces" (colored red in Figure 4) look similar to the stair-step pattern that the team worked on previously. But Aznx goes on to talk about the four squares on the outer areas of the square, confusing Quicksilver. That is, as they each try to work out the details of Aznx' view, they display that they are not *seeing* things quite the same way. They have not yet achieved an adequate shared understanding or shared view.

Quicksilver suggests that Aznx show what he means on the whiteboard, so the ambiguity of his proposal can be resolved. Rather than drawing it himself, Aznx asks Bwang to do a drawing,

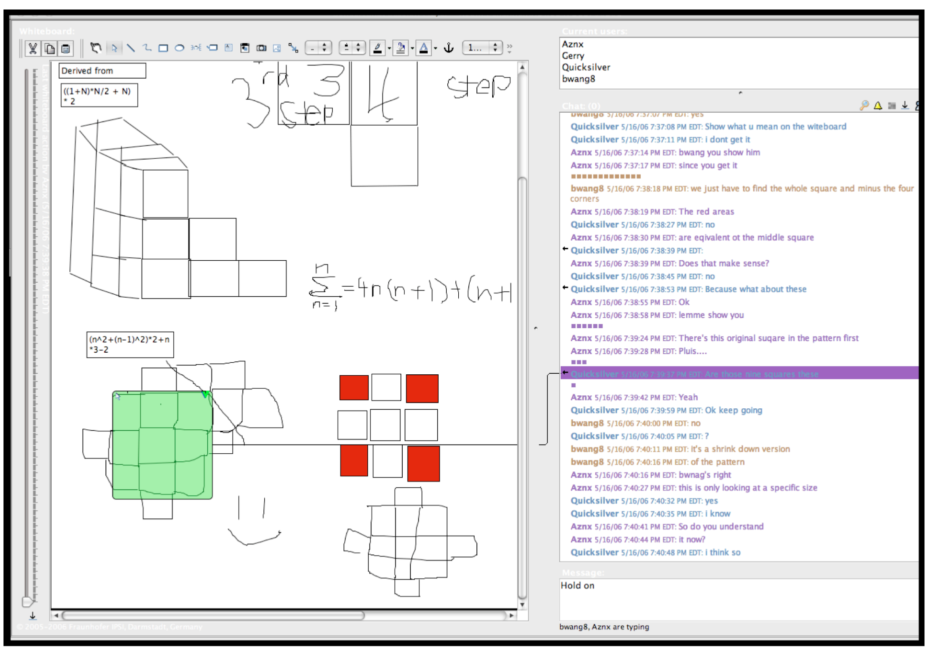


Figure 5. Bwang has drawn the white diamond for N=2 with red squares filling in the corners of an enclosing square. Quicksilver is pointing to a diamond pattern for N=3, also re-drawn lower on the whiteboard.

since Bwang said he could see what Aznx was talking about. Bwang has in the past shown himself to be skilled at making drawings on the whiteboard, while Aznx has not tried to draw much.

Bwang draws a very clear diagram on the whiteboard for the diamond pattern when N=2 (see Figure 5). As soon as Bwang completes his drawing, he makes explicit the problem-solving proposal that is implicit in Aznx' way of viewing the problem or the pattern: "We just have to find the whole square and minus the four corners." His drawing has made this process very visible. He drew the diamond pattern with white squares and then filled in a large square that the diamond fits into by adding red squares. The red squares fill in symmetrical spaces in the four corners of the diamond pattern. The group can now look at this together in the shared whiteboard, providing a shared view of the matter to the group.

<Figure 5>

The group then discusses the view of the diamond pattern fitting into an enclosing square. They eventually realize that some of their observations are only true for the diamond pattern at a certain stage, like N=2.

So Bwang then draws the pattern for N=3. Here it starts to become visible to the group that the red squares in each corner follow the stair-step pattern (see Figure 6).

<Figure 6>

The group has realized that viewing a graphical image of a mathematical pattern can be very helpful in thinking about the pattern. They treat the whiteboard as a shared, viewable image of aspects of the joint problem space of their collaborative work. Viewing this image and pointing out elements of it ground their chat discourse.

However, the image drawn by Bwang captures just one particular stage in the pattern, one value of N. They then start to look at images for different values of N or different stages in the growing pattern. They count the number of red squares in a corner as N increases and notice that it goes: 0, 1, 3, 6 (see Figure 4). This pattern is familiar to them from their earlier analysis of the

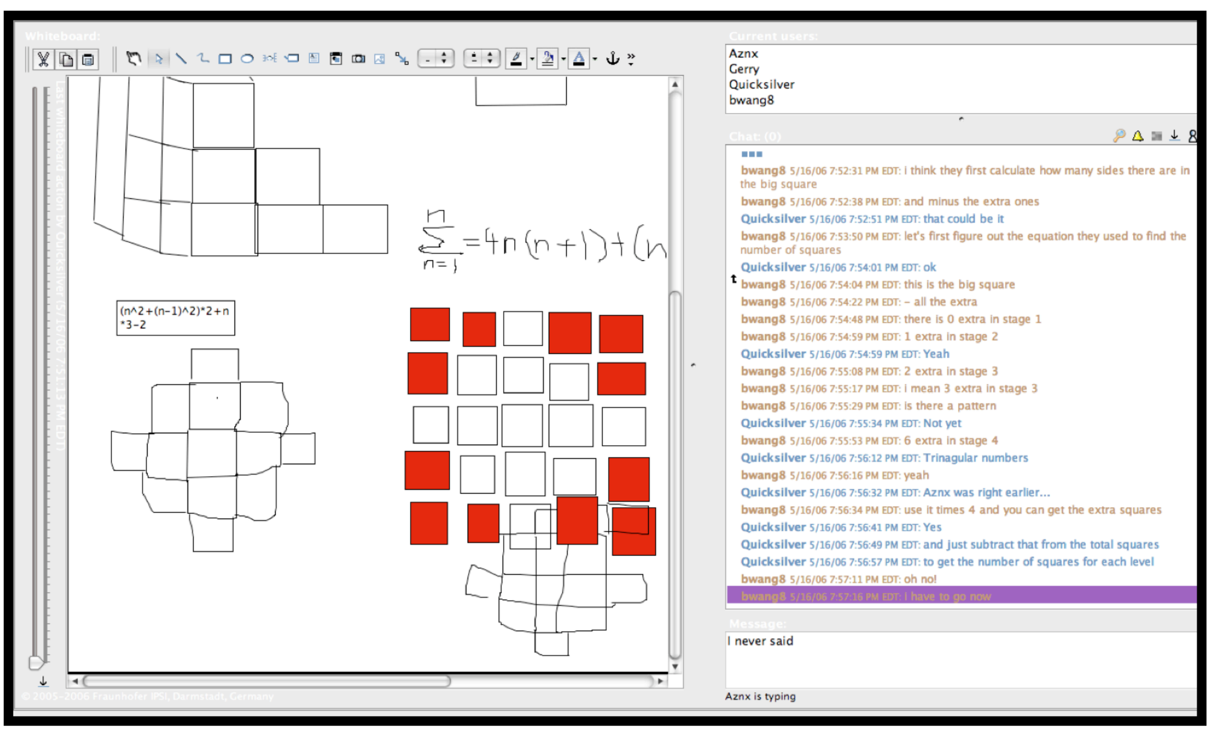


Figure 6. Bwang expanded his drawing to make the diamond for N=3. Note the red corners are now stair-step patterns.

stair-step pattern. They call this sequence “triangular numbers,” from Pascal’s triangle, which is often useful in combinatorics math problems. They know that this sequence can be generated by Gauss’ formula for the sum of the consecutive integers from 1 to N: (N+1)N/2. Unfortunately, at that point Bwang has to leave the group. But when they return in session 4, they will quickly put together the simple formula for the enclosing square minus this formula for the number of squares in each of the four corners, to solve their problem.

VIEWING THE LEARNING AND THINKING

Let us pause now from all these details about the case study of three students in a virtual math team session and talk about how we view learning and thinking in CSCL groups. We have tried to demonstrate how we view learning and thinking in CSCL groups by *viewing* with you how a group of three students engaged in collaborative thinking and learning processes within an online environment for drawing and chatting.

We went through several levels of analysis of the group discourse (see Figure 7). We started by mentioning the overall context of the *event*. This was an online event in which Team B, consisting of three students, met in the Virtual Math Teams environment to discuss patterns of squares formed by sticks. We then focused on the smaller *session* unit, looking at Team B’s third session, in which they considered a pattern that another group, Group C, had analyzed. Within this session, we identified one of several *themes* of discussion in that session, namely the one involving Aznx’ “interesting way to look at this problem.”

Event:	**VMT Spring Fest 2006, Team B**
Session:	**session 3, May 16, 7:00 pm**
Theme:	**“I have an interesting way to look at this problem”**
Move:	**Show how to view**
Pair:	**“Can you see how it fits inside a square?” “Yes”**
Utterance:	**“Can you see how it fits inside a square?”**
Reference:	**“it”, diamond pattern**

Figure 7. Levels of analysis of online group discourse.

<Figure 7>

Aznx introduced the theme by initiating a group problem-solving *move*. Namely, he got the group to view the problem in a certain way, as a diamond enclosed in a square. We saw how the group ended up drawing images in their shared whiteboard of diamond patterns enclosed in squares. Aznx introduced this group move in a subtle way; he did not simply come out and say, “We should analyze this pattern as partially filling an enclosing square.” Rather, he first announced that he had an interesting view, involving the others in his approach to make it a group problem-solving process. Then he asked if the others could view the problem in a certain way. He did this through a question/answer response *pair*: he asked a question, which elicited a yes-or-no response from the others. By eliciting the response, he oriented the others to looking at the diagram in the whiteboard in a certain way—namely in the way that his question implicitly proposed. A set of lines on the whiteboard are not immediately meaningful—they must be seen (interpreted) *as* something (Heidegger, 1927/1996, §32; Wittgenstein, 1953, §II xi).

Aznx’ formulation of his question looks like a simple *utterance* in question format, but it entails selection from a number of different ways of picturing the relationships among the diamond pattern, the enclosing square and the empty corners. To begin with, one must decide what the *reference* to "it" is doing.

Indexical references like the pronoun "it" are ubiquitous in online text chat—and unavoidable according to Garfinkel (1967). They require the reader to understand or reconstruct the implicit threading or response structure of the chat. The difficulty of doing this often leads to confusions, which require the participants to spend time clarifying the content and structure of their discussion. For instance, in our example of the move of seeing the diamond in the square, the group had to engage in a couple minutes of chatting and drawing to co-construct a shared understanding of the problem.

Issues of shared understanding can be analyzed as linguistic problems of reference. In other words, in order to view learning and thinking in CSCL groups, we do not try to figure out what is going on in the heads of the students; rather, we try to figure out what is going on in their chat postings and their drawing actions. This is what we call the group's *interaction*. In VMT, the interaction of the virtual math team consists of sequences of chat postings and drawing actions.

Our first step in figuring out what is going on in the chat postings and drawing actions is generally to try to analyze the sequencing of these by reconstructing their response structure—what previous action each new action is responding to and what kinds of action it is eliciting, what it is opening up an interaction space for, or what kinds of responses it is making relevant as next postings. Often, this leads to some kind of threading diagram (Çakir, Xhafa & Zhou, 2009), uptake graph (Suthers et al., 2010), or interaction model (Wee & Looi, 2009). This represents graphically a basic structure of the meaning-making sequencing. Then we try to understand what problem-solving work is being accomplished at each point in the sequence. This involves looking at different levels of granularity, such as the event, session, theme, move, pair, utterance and reference. Understanding the meaning that the group is co-constructing in their interaction generally involves going back and forth through these different levels and integrating partial interpretations from the different levels (Gadamer, 1960/1988).

Through this process, we can gradually view the learning and thinking that takes place in the CSCL group. This learning and thinking is not something that takes place primarily in the minds of the individual participants (although the individuals in the group are each continuously using their linguistic skills to understand what is going on and to respond to it with their postings and drawings). Rather, when there is an intense collaborative process taking place in the online environment, the thinking and learning takes place in the visible text and graphical interactions.

According to the theory of group cognition, thinking in a CSCL collaborative interaction does not take place so much the way we usually think of thinking. Thoughts, or cognitive processes, do not take place by neurons connecting and firing in a brain; they take place by text postings and drawings referring to each other and building on each other, in the spirit of the idea of transactivity introduced earlier. We will look more at how this takes place in a minute. Similarly, learning does not take place the way we learned about learning. It is not a change in the amount of knowledge stored in a brain. Rather it is a matter of knowledge artifacts being gradually refined through sequences of text postings and graphical drawings that are interrelated and that explicate each other. The knowledge artifacts may be statements about a problem the group is working on, as viewed from a new perspective that the group has developed. The knowledge artifact might be a drawing like Bwang's in Figure 6 or an algebraic formula that sums up the group's analysis of pattern growth.

CONSTRUCTING THE JOINT PROBLEM SPACE

When one studies logs of virtual math teams, one sees that the teams spend a lot of time and effort constructing shared understanding about references in their postings. The reason that teams and other small groups devote so much time and energy to resolving confusing references is that the network of references that they build up together plays an essential role in their group learning and thinking. In the theory of CSCL, there is considerable emphasis on the idea of "common ground" (Clark & Brennan, 1991) and "joint problem space" (Teasley & Roschelle, 1993). A group establishes common ground largely by reaching a shared understanding of how references work in their discourse. As it interacts over time, a group co-constructs a network of references that can become quite complex.

The "shared understanding" that is built up is akin to the notion of *co-orientation*, which "refers to the mutual orientation of individuals in a group toward an object (knowledge, belief, attitude), and can be traced back to the interactionist social psychology of John Dewey and George Herbert Mead" (Poole, this volume). Psycho-linguistic metaphors of comparing stored mental representations are unnecessary and can be misleading, reducing all knowledge to individual mental possessions. Team members share a world centered on their task; they orient as a group to the objects that populate that world, such as Aznx' proposals, Bwang's drawings and Quicksilver's queries. *Because they share a common world*—which they co-constitute largely through their discourse, mediated by the larger common social, cultural and historical horizons of their world—*they co-construct a shared understanding*.

The shared network of references defines the context or *situation* in which the group discourse continues to take place (Heidegger, 1927/1996, §18). Aznx' reference to "it" that we looked at contributed to a network of meaning that the group built up continuously through their interaction. This network included images of sticks in various patterns (like diamonds at stage N=2 and N=3), the relationships of the patterns (like a diamond enclosed in a square with stair-step empty corners), concepts referred to by technical terms (like "triangular numbers" or "summation") and symbols representing mathematical operations (like equations for number of squares in a pattern).

As a group builds up its network of shared references, it can use more shortcut references (symbols, names, pronouns) to point to things without creating confusion. People can use deictic references to point to things in the network, like "this formula", "the second equation" or "it". In linguistic terms, the shared network of references provides a background for referring to things, a so-called "indexical ground of deictic reference" (Hanks, 1992).

In problem-solving terms, the network of references forms a joint problem space, a shared view of the topic that the group is addressing (Sarmiento & Stahl, 2008). For Team B, the joint problem space starts in their first session with the stair-step pattern and the chart of the number of sticks and squares for each stage of this pattern as presented in the topic description for the event (Figure 1). By the middle of session 3, it includes the diamond pattern and the view of "it" enclosed in a square, forming empty corners. It also includes triangular numbers and their associated formula, as well as several other equations from Team C and from Team B's own work. The team's interaction (the text postings and drawings) gradually creates this joint problem space and is (reflexively) situated within it. The work and utterances of the team can only be understood (by the participants and by us as researchers) through an on-going understanding of the joint problem space as a network of meaningful reference.

Achievements of group cognition are not automatic and they can be quite fragile. They require work not only to construct shared understandings, but also to maintain the understanding of knowledge artifacts and to transfer their meaning to changing situations. After Bwang left the third session, Aznx and Quicksilver tried to review the group's accomplishments. They become confused about various equations and unsure of their ability to explain what the group has figured out. They ended the session with Quicksilver saying, "then let's pick it up next time when Bwang can explain it." This ends one session and projects what will happen in a future session. When the group meets for its fourth session, Aznx and Quicksilver do eventually get together with Bwang to review the derivation of the equation based on the view of the problem that Aznx introduced in the theme we just considered. The discussion in session four refers back to the group's work in session three and also to Team C's work in session two. But it does this in ways that are situated in Team B's session-four context (Sarmiento-Klapper, 2009). The team members and the memories they bring with them from the past are re-constituted in the new group situation, made relevant to the current themes, problem space and available resources.

FORMING GROUPS AND CO-CONSTRUCTING KNOWLEDGE ARTIFACTS

At the beginning of session one, the students were not part of a particularly effective group or team. They did not build much on each other's contributions and were hesitant to make proposals, ask each other to undertake tasks, produce permanent drawings or manipulate mathematical symbols. That all changed dramatically in the course of their four-session event. By the end they had many graphical, narrative and symbolic representations or expressions related to their mathematical topic. They worked effectively together and solved their problems well. Problem-solving methods that one person introduced were later proposed and used by the other group members.

You may be wondering if each of the students learned mathematics. An interesting thing about looking closely at what really went on in this event is that what we traditionally consider to be the math content actually plays a relatively minor role in the group's problem solving. Yes, content is brought in: the students talk about triangular numbers and they apply the formula for summing consecutive integers, for instance. Often, this math content is brought in quickly through proposals by individuals. It is then discussed through responses to the proposal that check that everyone understands the math content and agrees on its applicability. However, the bulk of the hard work is not accessing the traditional math content, but selecting, adapting, integrating, visualizing, sharing, explaining, testing, refining, building on and summarizing sequences of group response pairs. These proposals and discussions reference not only math content, but also various related resources that the group has co-constructed or made relevant.

The learning and thinking of the group takes place through the group's discourse, as a temporally unfolding multi-level structure of response/adjacency pairs interwoven into larger sequences of group moves, problem-solving themes and sessions of events. The group learns about the mathematics of its topic by building and exploring an increasingly rich joint problem space. It thinks about the mathematical relationships and patterns by following sequences of proposals, raising and responding to various kinds of questions and engaging in other sorts of interactional moves. Some of this gets summarized in persistent knowledge artifacts like drawings, concepts, equations, solution statements and textual arguments. The building of the joint problem space generally requires a lot of work to resolve references and to co-construct a shared network of meaning.

The math skills—like following certain procedures to do long division or to transform symbols—are not where the deep learning takes place and real knowledge is involved. Rather, the ability to sustain progressive inquiry through methods of group interaction is the real goal.

This ability makes use of the math content and skills as resources for answering questions and coming up with new proposals. Learning math is primarily a process of becoming a participant in the discourse community of people conversant in mathematics. Learning math collaboratively involves engaging in linguistic methods of shared meaning making—and other semiotic practices like geometric construction and algebraic symbolization. These are the tacit foundations of mathematics, the abilities needed in order to follow the rules of explicit math procedures.

If you wonder how to view learning and thinking in CSCL groups as an example of team cognition, follow Wittgenstein's advice: "Don't think, look!" Our colleagues and we have tried to do this by looking at the work of virtual math teams in the way we have just described. We have been amazed to discover that collaborative learning and group cognition are a lot different than people traditionally thought.

LOOKING FORWARD: TOWARDS ENHANCING TRANSACTIVE INTERACTIONS WITH AUTOMATIC FACILITATION

In this chapter we have described the group-cognition framework in relation to work in other subcommunities within the broader CSCL community, where similar conversational processes have been examined from different perspectives, with different styles. While group cognition has not typically been investigated through categorical coding aided by automatic text processing technology as has been done frequently within the transactivity tradition (Joshi & Rosé, 2007; Rosé et al., 2008; Ai et al., in press), the advantage of approaching the analysis that way is that it enables the possibility of automatic monitoring as well as automatic triggering of support.

There have already been quite a few successful studies of student groups benefitting from the support of automatically triggered conversational agents that enrich the interaction between students (Wang et al., 2007; Kumar et al., 2007; Cui et al., 2009; Chaudhuri et al., 2009; Kumar et al., in press), many of which employed a version of the Virtual Math Teams environment augmented with this form of dynamic collaborative learning support (Cui et al., 2009; Kumar et al., 2009). For example, early evaluations measured the extent to which students learned more in conditions when automatic support was offered in the environment in comparison to conditions where it was not (Wang et al., 2007; Kumar et al., 2007). These early studies showed that insertion of a support agent into the environment increased pre to post-test learning gains by about one standard deviation, which is a full letter grade. Subsequent studies compared alternative versions of this form of automatic support. These evaluations showed additional increases in effectiveness as we successively refined the design of the support. For example, Chaudhuri et al. (2009) showed that students learned more when the support agents allowed the students to put off discussion with the support agents until they were ready to give it their full attention. Kumar et al., (submitted) showed that students learned more when the support agents engaged in social behavior in addition to just offering cognitive support.

Encouraged by these early successes, which we celebrate, we are continuing to push forward with this intellectual and technical integration of group-cognition analysis using manual and automated methods. For example, we acknowledge that much of the richness of the type of thick description presented in this chapter is lost when the analysis is reduced to a sequence of a small number of labels, tags or codes. Furthermore, we acknowledge that even with perfect knowledge of where pivotal moments in collaboration are occurring or not occurring, this analysis is not the same thing as having the wisdom to know when to intervene or not, and how to guide the conversation effectively. These recognitions do not leave us discouraged, however. Rather they convince us of the great potential that our collaboration holds. With this in mind, then, in our current work, we are striving for a deeper intellectual integration between these different analytical traditions in order to create a yet more powerful form of dynamic collaboration support that will eventually make the power of group cognition as ubiquitous as the World Wide Web.

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