Meaning making in CSCL: Conditions and preconditions for cognitive processes by groups

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Abstract. Meaning making is central to the interactions that take place in CSCL settings. The collaborative construction of shared meaning is a complex process that has not previously been analyzed in detail despite the fact that it is often acknowledged as being the distinguishing element in CSCL. Here, a three-minute excerpt from a discussion among three students is considered in some detail. The students are reflecting on their analysis of mathematical patterns in a synchronous online environment with text chat and a shared whiteboard. Several interaction methods and group cognitive processes are identified. The analysis suggests a number of conditions and preconditions of such interaction. These are necessary for achieving the potential of CSCL as the accomplishment of high-order cognitive tasks by small groups of learners. An understanding of the conditions and preconditions of the small-group meaning-making process may aid in the design and analysis of CSCL activities, as well as in the development of a theory of group cognition.

THE UNIQUENESS OF CSCL

The vision of CSCL is that networked computers can bring learners together in new ways and that shared digital environments can foster interactions that produce new understandings for the groups and their participants. Accordingly, the uniqueness of CSCL pedagogical and technological designs consists in their techniques for supporting group interactions that can solve problems, gain insights, build knowledge. To guide design, CSCL theory needs to explicate the processes by which groups accomplish these cognitive tasks and to specify the preconditions for such interactions to take place.

In the formative days of the history of CSCL (see Stahl, Koschmann, & Suthers, 2006), collaboration was defined as "a process by which individuals negotiate and share meanings relevant to the problem-solving task at hand… a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem" (Roschelle & Teasley, 1995, p. 70). The study of collaboration so defined suggests a shift away from the psychology of the individual to the small group as the unit of analysis, and a process-oriented focus on the socially-constructed properties of small-group interaction: "Empirical studies have more recently started to focus less on establishing *parameters* for effective collaboration and more on trying to understand the *role* that such variables play in mediating interaction" (Dillenbourg *et al.*, 1996, p. 189, emphasis added). These re-definitions of the object of research differentiate *an approach to CSCL interested in group cognition* from the orientations of educational-psychology studies of individual learning in settings of cooperation and/or distance learning.

CSCL has been defined explicitly in terms of the analysis of *meaning making*. A keynote at CSCL 2002 proposed: "CSCL is a field of study centrally concerned with meaning and the practices of meaning making in the context of joint activity, and the ways in which these practices are mediated through designed artifacts" (Koschmann, 2002, p. 18). Recently, this approach has been re-conceptualized as studying the "practices of understanding" (Koschmann & Zemel, 2006). At the CSCL 2005 conference, a research agenda for the field was proposed in terms of "intersubjective meaning making" (Suthers, 2006b). This emphasis has a two-fold implication. It suggests that empirical studies investigate the processes of meaning making that take place in the studied settings. But also, in theoretical terms, it implies that we should be analyzing the nature of shared meaning and the structures of small-group meaning-making processes in general.

For all the talk about meaning making, there has been little empirical analysis of how meaning is actually constructed in small-group interactions. It is generally assumed that meaning is created and shared through processes of interaction, communication and coordination. But the nature of these processes is taken for granted. Even a special journal issue on "Meaning Making" presents alternative analyses of a particular interaction recording and reflects on the methodologies used, but never explicitly discusses what is meant by the term "meaning making" (Koschmann, 1999). Similarly, a recent book devoted to the topic of *Meaning in Mathematics Education* concludes that “various aspects of communication which may affect the construction of meaning are discussed. On the other hand, the problem of the construction of meaning itself is not really tackled” (Kilpatrick *et al.*, 2005, p. 137).

For some time, I have been trying to work out structures of collaborative meaning making. At ICLS 2000, I presented a model of collaborative knowledge building (Stahl, 2006b, Ch. 9), followed at CSCL 2002 with a theoretical framework for CSCL (Stahl, 2006b, Ch. 11). In an extended analysis of building collaborative knowing illustrated with my SimRocket data, I presented elements of a social theory of CSCL centered on meaning making (Stahl, 2006b, Ch. 15). I subsequently distinguished between interpretation from individual perspectives and meaning as shared and embodied in artifacts in the world in my CSCL 2003 paper (Stahl, 2006b, Ch. 16). At CSCL 2005, I argued that groups can think, that they can have cognitive agency (Stahl, 2006b, Ch. 19). My book on *Group Cognition* develops this notion that small groups of learners—particularly with the support of carefully crafted digital environments—have the potential to achieve cognitive accomplishments, such as mathematical problem solving. Here, the term “group cognition” does not refer to some kind of mental content, but to the ability of groups to engage in linguistic processes that can produce results that would be termed “cognitive” if achieved by an individual, but that in principle cannot be reduced to mental representations of an individual or of a sum of individuals. Thus, the theory of group cognition is similar to theories of distributed cognition, but now the emphasis is more on distribution among people rather than with artifacts, and the cognitive accomplishments are high-order tasks like math problem solving rather than routine symbol manipulations.

Recently, my colleagues and I have been investigating specific structures of meaning-making practices, analyzing online interactions among math students. For instance, we characterized “math-proposal adjacency pairs” (Stahl, 2006d), looked at how a group could solve a math problem that none of its members could solve (Stahl, 2006a), and investigated how students used a referencing tool in our environment (Stahl, 2006c). We try to closely analyze brief interactions in well-documented case studies to determine the social practices or methods that groups use to accomplish their meaning making. Thereby, we seek to determine structures of small-group cognitive processes. We believe that the foundation of CSCL as a unique field of study is the investigation of the meaning-making processes that take place in online collaborative settings. The analysis of intersubjective meaning making or group cognition is not the whole story; one can, of course, also analyze individual learning and other psychological phenomena or larger activity structures and communities-of-practice, but we believe the processes of small-group interaction are of particular centrality to CSCL.

A CASE OF GROUP COGNITION

Although meaning and related topics like grounding have been debated for millennia, they have usually been discussed using examples that were made up by the authors to seem like natural, commonsensical interactions or using data from laboratory conditions. To study interaction “in the wild” or with examples that occurred in real-life situations is a new and important approach that we can borrow from ethnography (Hutchins, 1996) and ethnomethodology (Garfinkel, 1967). However, finding cases of interaction that are relevant to CSCL research interests cannot be left up to chance. CSCL research aims to inform technological and pedagogical design. Therefore, cycles of design-based research are often appropriate. One must put students in situations where they are motivated to pursue certain kinds of tasks in particular kinds of environments. The situations must be instrumented to capture an adequate record of the interactions that take place.

In this paper, we will observe meaning making in a brief excerpt from Spring Fest 2006 of the Virtual Math Teams (VMT) service at mathforum.org. The collaborative context was set by organizing a contest: members of the most collaborative teams would win prizes. Students were recruited globally through teachers who were involved in other Math Forum activities. The team in the excerpt consisted of two students who apparently went to the same school and one from another time zone in the US, as well as a facilitator from the Math Forum, who provided technical assistance—this is all that either the students or the facilitator knew about each other. Pedagogically, the topic for discussion was an open-ended exploration of geometric patterns. An initial pattern of squares formed from sticks was given. The students were to figure out the formulae for the number of squares and the number of sticks at stage N first, and then explore other patterns that they or other teams invented. The technological environment combined text chat with a shared whiteboard. It included a referencing tool for pointing to areas of the drawing from chat postings (Mühlpfordt & Stahl, 2007). There was a supplementary wiki for sharing results between teams. To support the research methodology, all activities were logged. The chat and whiteboard could subsequently be replayed at any speed and stepped through. Virtually all aspects of the group interaction including everything that the participants knew about each other’s actions were captured and available for analysis (see Table 1 and Figure 1).

Each team in Spring Fest 2006 met for four sessions over a two-week period. Each session lasted a little over an hour. At the end of each session, the teams were supposed to post their findings on a wiki for the other teams to read. Between sessions, the facilitators posted feedback to the teams on their whiteboards. The feedback generally acknowledged the team's accomplishments and suggested next steps. In the case considered here, the team was particularly encouraged to explain what they had done because it was not clear to the facilitators from the interactions that the team members always understood what each other was doing.

Table 1. A three minute excerpt of the chat log. Line numbers have been added and the delay in seconds from the previous message has been calculated.

line	participant	chat posting	time	delay
1393	Quicksilver	(a) was define the problem, (b) was the solution which we got...	07.29.46	
1394	bwang8	we calculated the # of square if the diamond makes a perfect square	07.29.48	2
1395	Aznx	We can define the problem.	07.29.48	0
1396	Aznx	We got the solutions.	07.29.55	7
1397	Quicksilver	yes	07.30.12	17
1398	Quicksilver	the added corners	07.30.16	4
1399	Aznx	But I'm not sure how to explain how we got to the solutions, although it makes prefect sense to me.	07.30.18	2
1400	Quicksilver	to make a square	07.30.19	1
1401	Aznx	I'm just not sure how to explain it.	07.30.24	5
1402	Quicksilver	and we found those were triangular numbers	07.30.25	1
1403	Aznx	Well, I can explain the second formula.	07.30.32	7
1404	Quicksilver	lets go step by step	07.30.35	3
1405	Quicksilver	NO!	07.30.37	2
1406	Quicksilver	we don't know hte second formula	07.30.42	5
1407	Aznx	It was done through the method of finsing the pattern of triangular #s.	07.30.45	3
1408	Aznx	Yes we do.	07.30.50	5
1409	Quicksilver	?	07.30.55	5
1410	Aznx	Suppose their second formula is our third.	07.30.56	1
1411	Quicksilver	That was taem c's tho	07.31.06	10
1412	Aznx	No.	07.31.12	6
1413	Aznx	They didn't do.	07.31.16	4
1414	Aznx	The nuumber of squares	07.31.20	4
1415	Quicksilver	ohj!	07.31.25	5
1416	Aznx	or the find the big square	07.31.26	1
1417	Quicksilver	that formula	07.31.27	1
1418	Quicksilver	i thot u meant the other one	07.31.31	4
1419	Quicksilver	yeah that is ours	07.31.36	5
1420	bwang8	point formula out with the tools so we don't get confused	07.32.37	61
1421	Aznx	So we're technically done with all of it right?	07.32.49	12
1422	Quicksilver	this is ours	07.32.51	2
1423	Quicksilver	all right...lets put it on the wiki	07.32.58	7
1424	Aznx	That is theirs.	07.33.02	4
1425	Quicksilver	adn lets clearly explain it	07.33.05	3
1426	Aznx	bwang you do it. =P	07.33.11	6

Pattern problems are commonly used in teaching the concepts of beginning algebra. The research literature on this shows that explaining solution paths is generally particularly difficult for students (Moss & Beatty, 2006). By pressing the students to explain their work in the wiki posting—and to prepare for this in their chat interaction—

we encouraged the creation of data that allows us to see something of how a group of students made sense of their mathematical problem solving and where they had difficulty in conducting group practices leading to understanding.

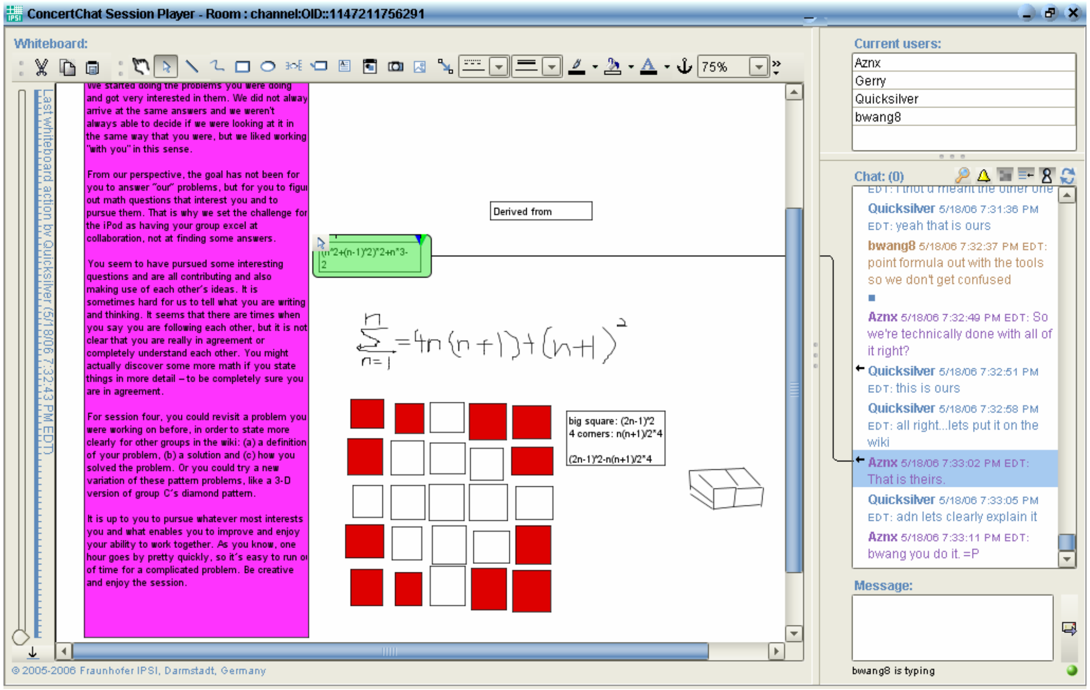

Figure 1. View of VMT-Chat environment during excerpt. The selected chat message appears as line 1424 in Table 1. Note the graphical reference from this posting to a formula on the whiteboard.

ANALYSIS OF THE MEANING MAKING

At first glance, the excerpt in Table 1 seems hard to follow. In fact, that is why the VMT research group started to look at this segment in one of its data sessions. The postings themselves express lack of clarity (e.g., line 1410), inability to explain what is going on (line 1401) and confusion about what is being discussed (line 1418). In addition, it is hard to understand how the postings hang together, how the participants are responding to each other and making sense together. It is often informative to focus on such excerpts. When the taken-for-granted flow of conversation breaks down—seemingly for the participants as well as for the researchers—the nature and structure of the interaction is likely to be made explicit and available for analysis. For instance, in my SimRocket excerpt (Stahl, 2006b, Ch. 12), the students' shared understanding of the facilitator's reference broke down, and they had to work hard to make the reference successively more explicit until everyone saw it the same way. Similarly, the analysis of deictic referencing in the VMT environment (Stahl, 2006c) looked at how students combined available resources to define a math object that was not at first clear and that required considerable work to establish agreement on what was being referenced. In the excerpt in this paper, the meaning-making process is displayed by the participants as problematic for them—presenting an analytic opportunity for us as researchers to observe characteristics of meaning making rendered visible in their announced breakdown and explicit repair.

This is a common pattern in collaborative small group interactions. In our corpus of about 1,000 hours of online collaborative problem solving, it is frequently a driving force (as discussed in Stahl, 2006d). It becomes apparent to the participants that they are not understanding each other or do not know what references are pointing to. The participants gradually make more explicit what they mean or the object of their references, using various available resources in their environment or their communication media. Eventually, each participant acknowledges that they understand the others, at least well enough to continue what they were doing before they paused to repair their mutual confusion. Thus, the nature of collaborative processes work to align individual interpretations to a gradually shared meaning that is itself co-constructed in this process. In this way, "group cognition" is not something that exists somewhere outside of the interaction, but is a gradually emerging accomplishment of the group discourse itself (Stahl, 2006b). It is also important to note that the collaborative meaning-making process that produces the shared group meaning tends to produce in parallel individual interpretations of this meaning.

Accordingly, when the individual participants later leave the group, the understandings of the group accomplishment may remain available to the individuals and can be re-introduced by them in subsequent group interactions.

In our present excerpt, the students are responding to the feedback in the large text box in Figure 1, where the facilitators wrote, “For session four, you could revisit a pattern you were working on before, in order to state more clearly for other groups in the wiki (a) a definition of your problem, (b) a solution and (c) how you solved the problem.” We can see that the students are oriented to this feedback because line 1393 translates it from a suggestion by the facilitators to the students (“you”) into a summary by the students of what they (“we”) should do. The students are hesitant to post a statement of how they solved the problem on the wiki for others—including, of course, for the facilitators who will be judging whether they are one of the best teams and deserving of a prize. So in line 1394, they begin to go over their solution path together. But lines 1395 and 1396 do not continue this review; they return to line 1393 to agree that they accomplished parts (a) and (b). It is ambiguous what line 1397 is responding to. The line is continued (by the same participant) in line 1398. To understand this new line requires recalling how the students solved the pattern problem in a previous session.

Look at the large diagram in Figure 1. The white (empty) squares form a diamond pattern of width 5 squares. The red (filled) squares fill in a large square encompassing the diamond, by adding 4 corners each composed of 3 red squares. One can compute the number of squares that it takes to form a diamond pattern by first easily computing the number of squares in the large encompassing square and then subtracting the number of squares in the 4 corners. This was the strategy used by the group in a previous session. If we now look at the sequence of postings by Quicksilver, we see that they make sense as a response to Bwang’s posting. Quicksilver is taking up Bwang’s description, recalling that the square was formed by adding the “corners” and then further specifying the strategy as treating the number of squares in a corner as being part of a “triangular number” sequence. Meanwhile, Aznx’s postings in lines 1395, 1396, 1399 and 1401 seem to form an independent sequence of statements, focusing on the problem of step (c) from the feedback, explaining how the problem was solved. If we follow the sequences of different students, they seem to be working in parallel, with Aznx despairing of explaining the group solution path even while Bwang and Quicksilver are reviewing it.

It is a well-known phenomenon that chat technology results in confusion because the turn-taking rules of face-to-face conversation do not apply in chat. Participants type in parallel and the results of their typing do not necessarily immediately follow the posting that they are responding to. When more than two people are chatting, this can produce confusion for the participants and for researchers (Herring, 1999). Moreover, in an attempt to prevent postings from becoming too separated from their logical predecessors, people rush to post, often dividing their messages into several short postings and introducing many shortcuts, abbreviations, typos, mistakes and imprecision. Technological responses to this problem have been explored (e.g., Fuks, Pimentel, & de Lucena, 2006). Analytically, it is important to begin a study of a chat record by reconstructing the threading and uptake structure of the chat log. Threading specifies what posting follows what and when the structure diverges into parallel or unrelated threads (Cakir *et al.*, 2005). The uptake structure indicates which specific elements of a posting, gesture, reference, drawing action, etc. are building upon previous elements (Suthers, 2006a).

While Aznx (in lines 1395, 1396, 1399, 1401, 1403) and Quicksilver (in lines 1397, 1398, 1400, 1402) seem to be following their own independent threads, there are also increasing signs of interaction between these threads. While one is complaining that he (or she) does not know how to explain their solution path, the other is demonstrating a way of systematically explaining, or at least enumerating, the path. Aznx’ “Well, I can explain the second formula” (line 1403) delimits his previous general statement that he could not explain their solution. Now he is stating that he can explain part of the solution—possibly the part that Quicksilver (line 1402) has just characterized as finding that the pattern of the corners followed the pattern of “triangular numbers” (from Pascal’s triangle, which is relevant to many pattern problems). So line 1403 reacts to Quicksilver’s 1402 as well as continuing from Aznx’ own 1401. In chat, postings frequently continue a train of meaning making from the same participant as well as responding to a recent posting by another participant, thereby potentially contributing to intersubjective meaning making.

We have already seen that new postings do not only relate to previous postings. They also reference things outside of the immediate chat discourse. For instance, line 1393 made reference to the feedback displayed in the text box in the shared whiteboard. It did this partially by quoting an excerpt from the feedback and partially by transforming it from the facilitator perspective to the participants’ perspective. Line 1402 referred to Pascal’s triangle by using the phrase “triangular numbers” that the students had used before. Line 1403 refers to “the second formula.” The referent for this phrase is not obvious to the engaged participants or to us as retrospective analysts. Quicksilver says “No” in line 1405. This seems to be a response to line 1403 about the second formula, with 1404 being a response to 1401 and to the general problem of preparing an explanation for the wiki.

When references become unclear to some members of the discourse, it may be necessary to repair the breakdown in mutual understanding. A lot of important interaction in collaborative activities consists in such repair, clarifying the references by making them more explicit so that each participant comes to understand them well enough to continue the discourse (Koschmann & LeBaron, 2003). Clark’s contribution theory of grounding (Clark & Brennan, 1991) describes how this takes place among dyads in face-to-face informal conversation, illustrated with made-up examples. For online small groups using text chat in real examples of knowledge building, such as explaining math problem solving, the repair may be more complicated.

Quicksilver’s “No” is followed by, “we don’t know the second formula.” The phrase, “second formula” in line 1406 here is not referencing the same thing as “second formula” in line 1403, as indicated by the question mark in line 1409. In fact, it takes two and a half minutes and 21 postings (1403 to 1424) to reach the point where the discourse can go on. The confusion gets translated by line 1410 into which formula is this team’s and which was Team C’s solution that this team found on the public wiki. Aznx tries to clarify (lines 1413-1416) that the formula he is concerned with could not be Team C’s because Team C did not calculate the number of squares using the encompassing big square (they only proposed a formula for the number of sticks). Quicksilver describes his confusion, but the conversation does not continue; there is a one-minute silence, which is embarrassingly long in chat.

The silence is broken by Bwang’s suggestion in line 1420 to use the graphical referencing tool that is part of the VMT environment. As they wrap up the discussion, Quicksilver points to one formula (“ours”) in the whiteboard (line 1422) and Aznx to the other (“theirs”) (line 1424). This resolution of the confusion through the use of the available technology was thus accomplished by all three of them, using the referencing tool to point to objects in the whiteboard in coordination with labeling them with the terms “ours” and “theirs” in the chat. In parallel with this, the students propose to move on to post on the wiki: Aznx suggests that they may be finished preparing the explanation (line 1421). Quicksilver agrees, “all right, let’s put it on the wiki and let’s clearly explain it” (lines 1423, 1425). Finally, Aznx concludes the preparations by saying, “Bwang, you do it” (line 1426).

AMBIGUITY OF THE INTERACTION

We can follow the discussion taking place in the excerpt now better than at first sight. Not only do we have some sense of its structure and flow, but we see how it is embedded in the situation of the preceding interactions, the tasks that are driving the discourse forward, the items in the whiteboard and other available resources (wiki postings by other teams, math knowledge, etc.). We had to conduct a preliminary analysis of the meaning-making process in terms of the interactional threading, the uptake of one posting by a subsequent one, the continuity of postings by individual participants, the subsidiary discussions to repair confusions, the references to various resources and the repeated citation of terms or phrases. Only then could we look more deeply into the interaction or investigate specific research questions.

If we wanted to classify individual chat postings according to some coding scheme in order to compare our excerpt to other interaction records, we would have had to do such a preliminary analysis to know what the brief, elliptical chat postings meant. CSCL is a human science and the analysis of its data requires an understanding of the meaning that things had for the participants. One cannot code a posting like “No!” as a mathematical proposal, a repair of understanding, an argumentative move or an off-topic comment without having a sense of the meaning of what the participants were doing linguistically and interactionally. Of course, if a chat posting just says, “Hi,” then even a simple algorithm can code it as Greeting, Social or Off-Topic with high reliability. However, we have found that the most interesting interactions are challenging for experienced researchers and likely to inspire divergent but productive analyses.

So far our analysis of the excerpt is quite preliminary. There is still a lot of ambiguity about what is going on. Line 1396/1399 remains quite intriguing: “We got the solutions. But I’m not sure how to explain how we got to the solutions, although it makes perfect sense to me.” If the solutions make perfect sense to Aznx, why does he feel that he cannot explain how they got the solutions? As noted above, this points to a fundamental problem in mathematics education. Students are trained to compute solutions, but they have difficulty articulating explanations. Some educational theories point to explanation as the core of “deep understanding” (Moss & Beatty, 2006).

Proponents of collaborative learning point to the importance of opportunities to explain math thinking to others as being important even for the development of one's own higher-order learning skills (Wegerif, 2006).

We may still wonder what the significance is of the fact that Aznx seems ready to post an explanation at line 1421 despite his repeated disclaimer at line 1401. Does line 1421 signal that the ensuing interaction is being taken as an adequate account or is the fact that things made perfect sense to Aznx now taken as adequate although it was not previously? Aznx does say in line 1403 that he can explain "the second formula." Does this entail that all that is needed is such an explanation of the second formula? Note that Aznx's line 1421 says, "So we're technically done with all of it, right?" What does the "So" respond to as an uptake? What has suddenly made the group ready to post an explanation? This line follows the extended effort to overcome the confusion of referencing, and it is hard to trace the "So" back to some clear point that it is building on. Furthermore, what is the significance of the hedge, "technically"? In fact it is not even clear what "it" refers to. Is Aznx just saying they are done with the repair, rather than with the whole explanation? Line 1423/1425 with its "all right" response seems to take line 1421 as saying that the group is ready to post their solution. It then proceeds to propose the logical next step, "let's put it on the wiki…. And let's clearly explain it." Aznx no longer resists, but in line 1426 he proposes that Bwang do the posting. In previous sessions, Aznx has requested that Bwang do the wiki postings, using precisely the same wording. Bwang has done previous wiki postings for the group. In this way, Aznx' statements leave ambiguous whether or not he still expresses doubt about his ability to explain the group's solution path and the extent to which he indicates understanding that path.

It not only remains ambiguous how much Aznx can explain, but also what exactly he was referring to as "the second formula." The repair of confusion shifted from distinguishing the second from the third formula to distinguishing Team C's formula from Team B's. Quicksilver and Aznx clearly pointed to two different text boxes in the whiteboard containing formulae as "ours" and "theirs." But the text box called "ours" contained three formulae: for the big square, for the 4 corners and for the diamond pattern as the difference. Did Aznx originally mean that he could only explain the second of these three—which was based on the formula for triangle numbers? Did Quicksilver's mention of triangle numbers in line 1402 and more general review of their solution path help Aznx to feel that they could put together an explanation of how all the formulae fit together? The discourse in this excerpt does not seem to provide complete answers to some of these questions. While careful analysis of small group discourse often reveals much about the problem-solving work of the group and its members, many other issues remain ambiguous, missing and even contradictory. The group did its work without resolving or explicating all of the issues that researchers may want to know about.

METHODS OF INTERSUBJECTIVE MEANING MAKING

We have seen that an understanding of the intersubjective meaning-making process of a small group in a text-chat environment involves paying attention to an intricate web of connections among the items in the interaction record and items from the context that are made relevant in the discourse. There is a *threading* of the flow, with a particular posting following up on a preceding one (that may not be immediately adjacent in the chat log) and opening the possibility of certain kinds of postings to follow. There is *up-take* of one phrase or action by another, carrying the work of the group ahead. There are often important *continuities* from one posting of a particular individual to the same person's subsequent postings. Various sorts of communication problems can arise—from typos to confusion—and *repairs* can be initiated to overcome the problems. Lines of chat can *reference* items outside the chat, such as whiteboard drawings, formulae learned in the past or notions raised earlier. Terms and phrases in a posting can serve as *citations* of previous statements, making the former meanings once more present and relevant. One could easily draw arrows on a record of the chat excerpt to indicate several dozen of these connections of threading, uptake, continuity, repair, reference and citation. The postings can be separated into columns by poster to reflect continuity (see Stahl, 2006d, p. 100), and a column added for referenced items external to the immediate discourse. The intricate web of arrows would indicate how interwoven the postings are and how the postings of the different participants are tied together, creating an overall flow to the group discourse. *The meaning of the interaction is co-constructed through the building of this web of contributions and consists in the implicit network of references*. The point is not to reify this network as the answer to the question, *what* is meaning, but to see it as a way of understanding *how* meaning is co-constructed, i.e., how people *make sense* together.

There are many methods that members of a group, community-of-practice or culture employ to accomplish meaning-making moves in small-group interactions. In face-to-face interactions, certain typical "adjacency pairs" (like question/answer or greeting/response) form common "member methods" (Garfinkel, 1967). In chat, the two postings that belong to an adjacency pair may not be directly adjacent, but they retain the basic structure of forming a meaningful interaction through their combination. In looking at collaborative problem-solving extracts in VMT logs, I defined a typical pattern of "math-proposal adjacency pairs" (Stahl, 2006d). Here, one participant proposes an approach for the group to take to a problem or current sub-problem and someone else must either accept or decline the proposal on behalf of the group. If it is declined, then some kind of argument or alternative proposal is expected. If the proposal is accepted, then the group can continue working on the proposal, often by considering a follow-up proposal pair. There are a number of conditions that must be met by a proposal for it to be successful. These involve its timing and relevance in the flow of the discourse. A bid at a proposal that does not satisfy these conditions is likely to fail to be taken up as a proposal. The bid/acceptance pair may be temporarily interrupted by clarification questions or repairs to the bid's formulation. These, in turn, can lead to discussions of indeterminate length. Math proposal adjacency pairs provide a social order for discussions of mathematical problems in small groups. In the excerpt of Table 1, the students are no longer solving a math problem, but reflecting on their solution, trying to recall the steps that they went through and to explain how they solved it in a way that will be meaningful for an audience of their peers (the other teams who read the wiki) and their facilitators (who provide feedback and judge the winning teams). Here, there is a similar process of making proposals and responding to them, but the proposals are formulated more as declarative statements that recall past actions and the responses are rather oblique. In addition, Quicksilver and Aznx tend to continue their presentations in multiple postings, creating parallel threads. While there is an underlying social order that makes this excerpt meaningful, as we have seen it takes some analysis to uncover this order.

Even in this brief excerpt, we have seen many member methods or social practices that the participants use to co-construct meaning. Mostly, they respond to each other, making suggestions and posing questions. In addition, they work on repairing problems, such as the confusion about references to formulae. In resolving the confusion, they called upon the referencing tool in the VMT environment. This was the equivalent for the online context of pointing with a physical gesture when face-to-face. Different media provide different affordances and impose different constraints. In new media like this specific chat environment, participants have to be creative in adapting traditional meaning-making methods or inventing new ones. Students may be very inventive and this may impose extra effort on analysts who want to study the meaning-making processes and practices in innovative settings.

The foregoing analysis of meaning making in the excerpt is purely preliminary. A fuller analysis would depend upon one's research interests and specific questions. The excerpt would have to be understood within its larger context, including: the four full sessions, which are being reflected on here; the feedback from the facilitators, as it developed in response to the different sessions and based on the original task instructions; the various postings to the whiteboard and to the wiki; and even some of the work of the other teams. But perhaps this preliminary analysis is enough to indicate some of the methods of meaning making that take place in CSCL settings like the VMT sessions. There are phenomena observable at many granularities of analysis. The interactions among brief sequences of postings such as those in Table 1 may be considered the cell-form or elements of the meaning making that underlies computer-supported collaborative learning.

PRECONDITIONS FOR COGNITIVE PROCESSES BY GROUPS

Now that we have a general sense of how meaning making takes place in CSCL (its *conditions*), what are the implications for design? What do we need to consider when attempting to support effective meaning making in CSCL? One approach to this question is to consider the logical and practical *preconditions* for students to get together and engage in joint meaning making to accomplish group cognitive tasks. In philosophical terms, this is to specify the preconditions for the possibility of group cognition. Based on our empirical experiences in the VMT project, here is a tentative list of some necessary—though not sufficient—preconditions for small groups of students to collaborate on math problems and other high-order cognitive tasks. The particular number, order and description of these preconditions is, of course, open to debate, extension and refinement. Nevertheless, it may be helpful to consider them when organizing CSCL environments and activities. Here are some preconditions (with examples from the analyzed excerpt):

1. *Intersubjectivity*. Participants must be willing and able to interact with others as peers. They must recognize others as active subjects with their own agency and be willing to relate to them as such. (human sociability)
2. *Opening of interaction space*. There must be a "world" in which people can come together and interact. The world must provide a network of meanings and possibilities for action. This situation defines deictic (Hanks, 1992), semiotic and semantic relations. (a virtual world, such as those created in the VMT project)
3. *Object of activity*. There must be a reason for interacting, a goal to work for, a topic to discuss, a problem to solve or an outcome to reach. (the math topic and motivating context)

4. *Shared intentionality*. It must be possible for participants to orient in common to objects, to focus their comments and activities on the same items, to "be-there-together" at a topic of joint concern, to "construct and maintain a shared conception of a problem." (e.g., the students' focus on the same formulae and tasks)
5. *Historical interpretive horizon*. Meanings of artifacts, words, domain concepts, etc. evolve through history and local pasts. Participants must have lived histories that overlap enough to share understandings of historically evolved meanings. (the term "triangular numbers" brought in from classroom background experience)
6. *Shared background culture*. Participants must share a language, a set of member methods, a vast tacit background knowledge of domain information and of ways of being human. (including how to "do" math)
7. *Member methods for social order*. Participants inherit and are socialized into an endless variety of member methods for conducting interaction and creating social order. However, small groups must also constantly adapt and enact methods to meet unique situations and innovative technologies. New methods must be fluidly negotiated and adopted for shared use *in situ*. (such as pointing from a chat message)
8. *Designed affordances of infrastructure*. The technological features of a CSCL medium define many features of the world which is opened up for interaction. These features are enacted by the participants to provide affordances for their activities. The enacted affordances are often quite different from the features imagined by the designers and can only be discovered through analysis of actual usage. (e.g., the pointing tool)
9. *Dialogic inter-animation of perspectives*. A key source of creativity, meaning making, problem-solving vitality—but also ambiguity—is the interaction of participants with essentially different interpretive perspectives (Wegerif, 2006). The power of CSCL is largely dependent upon its ability to bring different perspectives together effectively. (Bwang's math skills, Aznx' questioning, Quicksilver's recall)
10. *Creation & interpretation of group meaning*. The meaning-making process discussed in this paper lies at the core of computer-supported collaborative learning. It must be supported by CSCL environments. (pointing)
11. *Group-regulation & group meta-cognition*. Small groups of learners working on wicked problems that have no fixed solution path must have methods for proposing, negotiating, discussing, adopting and reflecting upon their path of inquiry. Methods of explaining their work are part of this. Scripting and other forms of scaffolding may help groups develop skills of self-regulation. (feedback about reflection on what to post to the wiki)
12. *Individual learning & interpretation*. The establishment of shared group meanings takes place through interactive processes like those we have noticed in this paper, involving the contribution of proposal bids by individual participants and the interpretation of meanings from individual perspectives (Stahl, 2006b, Ch. 16). Individual learning may result indirectly from the group cognitive processes that establish understanding by all participants. (the wiki posting done by Bwang later)
13. *Motivation and engagement*. Small groups and communities-of-practice determine their own interests and involvements through the particulars of what they work on and how they approach it. Individuals tend to become caught up in the group process through their contributions and participations in the interactions. Small-group processes appeal to the social inclinations of people, although they can also engender fears and pressures. In groups of several participants, the interactions can become quite complex, and engagement by different individuals in different activities may ebb and flow. (Bwang kept quiet, but entered strategically)

This paper has identified several interaction methods and group-cognitive processes that contribute to meaning making in CSCL settings. The interactions that constitute shared meaning are the elements of collaborative learning—as the co-construction of shared understanding, which includes individual interpretation. A number of preconditions for such interaction have also been proposed. An understanding of the conditions and preconditions of the small-group meaning-making process may aid in the design and analysis of CSCL activities.

REFERENCES

Cakir, M., Xhafa, F., Zhou, N., & Stahl, G. (2005). *Thread-based analysis of patterns of collaborative interaction in chat.* Paper presented at the international conference on AI in Education (AI-Ed 2005), Amsterdam, NL.

Clark, H., & Brennan, S. (1991). Grounding in communication. In L. Resnick, J. Levine & S. Teasley (Eds.), *Perspectives on socially-shared cognition* (pp. 127-149). Washington, DC: APA.

Dillenbourg, P., Baker, M., Blaye, A., & O'Malley, C. (1996). The evolution of research on collaborative learning. In P. Reimann & H. Spada (Eds.), *Learning in humans and machines: Towards an interdisciplinary learning science* (pp. 189-211). Oxford, UK: Elsevier.

Fuks, H., Pimentel, M., & de Lucena, C. J. P. (2006). R-u-typing-2-me? Evolving a chat tool to increase understanding in learning activities. *International Journal of Computer-Supported Collaborative Learning (ijCSCL), 1* (1), 117-142.

Garfinkel, H. (1967). *Studies in ethnomethodology*. Englewood Cliffs, NJ: Prentice-Hall.
Hanks, W. (1992). The indexical ground of deictic reference. In C. Goodwin & A. Duranti (Eds.), *Rethinking context: Language as an interactive phenomenon*. Cambridge, UK: Cambridge University Press.
Herring, S. (1999). Interactional coherence in CMC. *Journal of Computer Mediated Communication, 4* (4).
Hutchins, E. (1996). *Cognition in the wild*. Cambridge, MA: MIT Press.
Kilpatrick, J., Hoyles, C., Sokovsmose, O., & Valero, P. (Eds.). (2005). *Meaning in mathematics education*. New York, NY: Springer.
Koschmann, T. (1999). Meaning making: Special issue. *Discourse Processes, 27* (2).
Koschmann, T. (2002). Dewey's contribution to the foundations of CSCL research. In G. Stahl (Ed.), *Computer support for collaborative learning: Foundations for a CSCL community: Proceedings of CSCL 2002* (pp. 17-22). Boulder, CO: Lawrence Erlbaum Associates.
Koschmann, T., & LeBaron, C. (2003). *Reconsidering common ground: Examining Clark's contribution theory in the operating room.* Paper presented at the European Computer-Supported Cooperative Work (ECSCW '03), Helsinki, Finland. Proceedings pp. 81-98.
Koschmann, T., & Zemel, A. (2006). *Optical pulsars and black arrows: Discovery's work in 'hot' and 'cold' science.* Paper presented at the International Conference of the Learning Sciences (ICLS 2006), Bloomington, IN. Proceedings pp. 356-362.
Moss, J., & Beatty, R. A. (2006). Knowledge building in mathematics: Supporting collaborative learning in pattern problems. *International Journal of Computer-Supported Collaborative Learning (ijCSCL), 1* (4), 441-466.
Mühlpfordt, M., & Stahl, G. (2007). *The integration of synchronous communication across dual interaction spaces*. Paper presented at the international conference on Computer Support for Collaborative Learning (CSCL 2007), New Brunswick, NJ.
Roschelle, J., & Teasley, S. (1995). The construction of shared knowledge in collaborative problem solving. In C. O'Malley (Ed.), *Computer-supported collaborative learning* (pp. 69-197). Berlin, Germany: Springer Verlag.
Stahl, G. (2006a). Analyzing and designing the group cognitive experience. *International Journal of Cooperative Information Systems (IJCIS), 15*, 157-178. Retrieved from http://www.cis.drexel.edu/faculty/gerry/pub/ijcis.pdf.
Stahl, G. (2006b). *Group cognition: Computer support for building collaborative knowledge*. Cambridge, MA: MIT Press.
Stahl, G. (2006c). Supporting group cognition in an online math community: A cognitive tool for small-group referencing in text chat. *Journal of Educational Computing Research (JECR) special issue on Cognitive tools for collaborative communities, 35* (2), 103-122. Retrieved from http://www.cis.drexel.edu/faculty/gerry/pub/jecr.pdf.
Stahl, G. (2006d). Sustaining group cognition in a math chat environment. *Research and Practice in Technology Enhanced Learning (RPTEL), 1* (2), 85-113. Retrieved from http://www.cis.drexel.edu/faculty/gerry/pub/rptel.pdf.
Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning: An historical perspective. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 409-426). Cambridge, UK: Cambridge University Press.
Suthers, D. D. (2006a). A qualitative analysis of collaborative knowledge construction through shared representations. *Research and Practice in Technology Enhanced Learning (RPTEL), 1* (2), 1-28. Retrieved from http://lilt.ics.hawaii.edu/lilt/2006/Suthers-2006-RPTEL.pdf.
Suthers, D. D. (2006b). Technology affordances for intersubjective meaning making: A research agenda for CSCL. *International Journal of Computer-Supported Collaborative Learning (ijCSCL), 1* (3), 315-337.
Wegerif, R. (2006). A dialogical understanding of the relationship between CSCL and teaching thinking skills. *International Journal of Computer-Supported Collaborative Learning (ijCSCL), 1* (1), 143-157.

ACKNOWLEDGMENTS

The ideas in this paper are indebted to many sources, most directly to the team of the VMT project at the Math Forum and Drexel. Detailed documentation of the VMT session: mathforum.org/wiki/VMT?VMTGroupB. The idea of preconditions of possibility for interaction was suggested by Rupert Wegerif in a discussion at Intermedia in Oslo. The theoretical and methodological focus on joint meaning making has prospered through interactions with Tim Koschmann and Dan Suthers, most recently in workshops at Freiburg and Tübingen. The research reported here was supported in part by grants to the author from the NSF programs for digital library services (NSDL), innovative technologies (ITR/IERI) and the science of learning (SLC).