Computer-Supported Academically Productive Discourse

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Studies of computer-supported collaborative learning have begun to explore processes of online group cognition, such as small-group methods of problem solving, and how they can be mediated by various technological and interactional mechanisms to promote academically productive discourse. This chapter first presents an analysis of *copresence* as a foundational aspect of online interaction in an excerpt of chat discourse. On the basis of how the students in this excerpt actually interact, I develop a notion of *intersubjective shared understanding* as necessary for the possibility of collaborative knowledge-building dialogue. The chapter concludes with a discussion of consequences for the design of computer support of academically productive online *group cognition*.

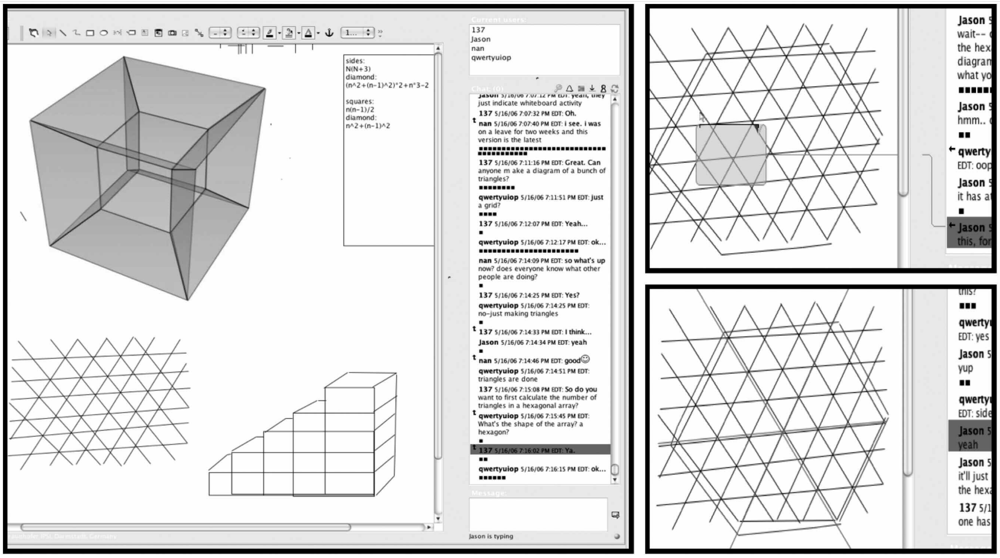
An Excerpt of Computer-Supported Discourse

The studies of digital interaction by virtual math teams presented in Stahl (2009) adopt an ethnomethodological interest in how interaction is actually carried out in particular online contexts. They assume that the member methods or group practices of computer-mediated interaction developed by small groups of students may differ significantly from commonsense assumptions of researchers on the basis of experience with face-to-face interaction. If this is true, then it is important to explore actual instances of digital interaction before designing interventions in such settings.

This section reviews how a team of three students collaboratively achieved a cognitive accomplishment as a distributed online group. The log of their interaction makes visible mechanisms by which academically productive discourse can arise naturally in settings of "computer-supported collaborative learning" (CSCL; Stahl, Koschmann, & Suthers, 2006). The data analysis presented in this initial section is not intended as an illustration of preexisting theories; rather, the theory in the next section emerges from this and similar data.

"Wait…I Don't Really See": Establishing Copresence

Figure 1 (left-hand section) shows a screenshot of the Virtual Math Teams (VMT) software environment, being used by three middle school students. They volunteered to participate in this online, synchronous math activity with other students from around the world. The students collaboratively investigated mathematical patterns (*combinatorics*) related to sequences of geometric figures. At the lower right of the whiteboard was a stair-step pattern of blocks remaining on the board from their previous day's session. The students were considering



sides:
N(N+3)
diamond:
(n^2+(n-1)^2)*2+n*3-2

squares:
n(n-1)/2
diamond:
n^2+(n-1)^2

137
Jason
nan
qwertyuiop

just indicate whiteboard activity
137 5/16/06 7:07:32 PM EDT: Oh.
nan 5/16/06 7:07:40 PM EDT: i see. i was on a leave for two weeks and this version is the latest
137 5/16/06 7:11:16 PM EDT: Great. Can anyone m ake a diagram of a bunch of triangles?
qwertyuiop 5/16/06 7:11:51 PM EDT: just a grid?
137 5/16/06 7:12:07 PM EDT: Yeah...
qwertyuiop 5/16/06 7:12:17 PM EDT: ok...
nan 5/16/06 7:14:09 PM EDT: so what's up now? does everyone know what other people are doing?
137 5/16/06 7:14:25 PM EDT: Yes?
qwertyuiop 5/16/06 7:14:25 PM EDT: no-just making triangles
137 5/16/06 7:14:33 PM EDT: I think...
Jason 5/16/06 7:14:34 PM EDT: yeah
nan 5/16/06 7:14:46 PM EDT: good☺
qwertyuiop 5/16/06 7:14:51 PM EDT: triangles are done
137 5/16/06 7:15:08 PM EDT: So do you want to first calculate the number of triangles in a hexagonal array?
qwertyuiop 5/16/06 7:15:45 PM EDT: What's the shape of the array? a hexagon?
137 5/16/06 7:16:02 PM EDT: Ya.
qwertyuiop 5/16/06 7:16:15 PM EDT: ok...

Jason is typing

Figure 1. The VMT interface near the beginning (left), middle (upper right), and end (lower right) of the excerpt.

a pattern of regular hexagons, which they would eventually visualize in a grid of triangles they had constructed at the lower left.

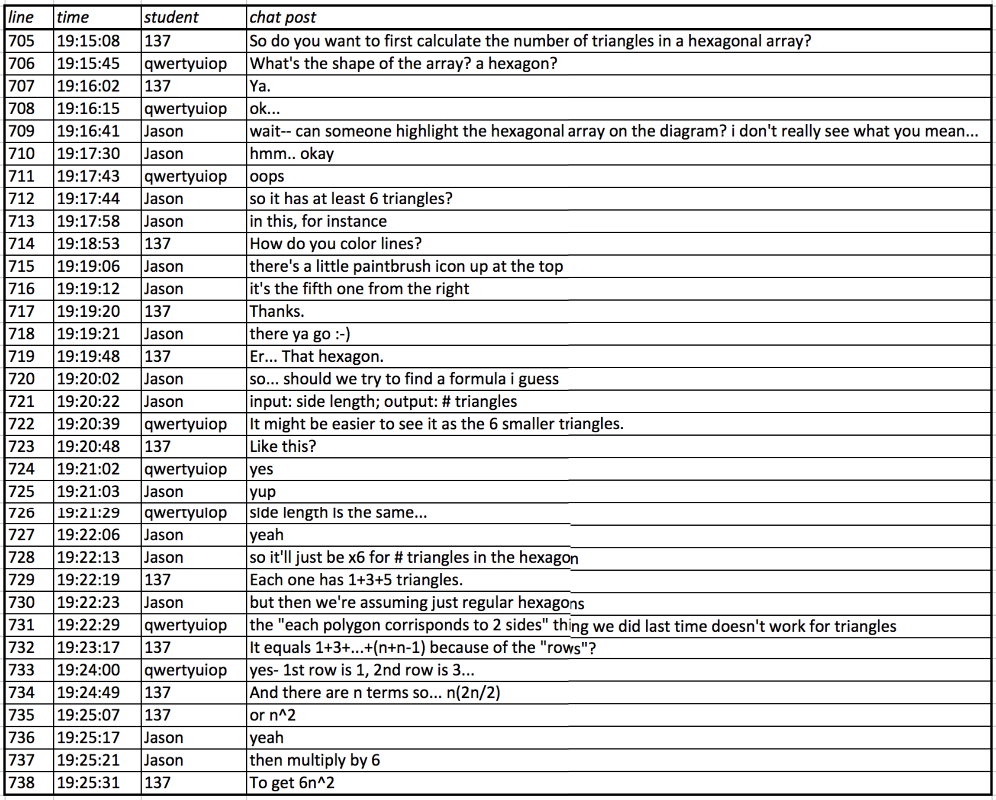
VMT is a prototypical CSCL environment, with a text-chat tool integrated with a shared whiteboard. Figure 2 shows a chat excerpt. Three students—whose online names are 137, Qwertyuiop, and Jason—were chatting.

In line 705, student 137 posed a math question of potential interest to the small group. Then Qwertyuiop sought to understand the math shape that 137 proposed. Qwertyuiop next drew the grid of triangles to see if he understood what 137 meant by "hexagonal array."

Jason effectively halted the discussion (line 709) to seek help in seeing the hexagonal form that 137 and Qwertyuiop saw. Jason's posting was designed to bring the group work to a halt, because he did not see what 137 and Qwertyuiop were talking about. This was an important collaboration move, to ask the others to clarify what they meant. Jason referred to the group meaning-making process and halted it so he could fully participate.

Jason phrased his request in terms of "seeing" what the others "mean." This way of seeing should be taken literally, in terms of vision and graphics. Jason asked the others to "highlight the hexagonal array on the diagram" so he could see it in the graphics.

Student 137 outlined a large hexagon with extra lines, as shown at the upper right of Figure 1. This provided what Jason needed to be part of the group problem-solving effort. Jason not only said, "Okay," but he contributed a next step (line 712) by proposing a math result and giving a visible demonstration of it with a highlighted small hexagon. Giving a next step shows understanding and takes the idea further. Jason pointed from his chat posting to the hexagon. Note in the figure the green rectangle highlighting a small hexagon and the connecting line to Jason's chat posting (line 713); this is an important feature of the



line	*time*	*student*	*chat post*
705	19:15:08	137	So do you want to first calculate the number of triangles in a hexagonal array?
706	19:15:45	qwertyuiop	What's the shape of the array? a hexagon?
707	19:16:02	137	Ya.
708	19:16:15	qwertyuiop	ok...
709	19:16:41	Jason	wait-- can someone highlight the hexagonal array on the diagram? i don't really see what you mean...
710	19:17:30	Jason	hmm.. okay
711	19:17:43	qwertyuiop	oops
712	19:17:44	Jason	so it has at least 6 triangles?
713	19:17:58	Jason	in this, for instance
714	19:18:53	137	How do you color lines?
715	19:19:06	Jason	there's a little paintbrush icon up at the top
716	19:19:12	Jason	it's the fifth one from the right
717	19:19:20	137	Thanks.
718	19:19:21	Jason	there ya go :-)
719	19:19:48	137	Er... That hexagon.
720	19:20:02	Jason	so... should we try to find a formula i guess
721	19:20:22	Jason	input: side length; output: # triangles
722	19:20:39	qwertyuiop	It might be easier to see it as the 6 smaller triangles.
723	19:20:48	137	Like this?
724	19:21:02	qwertyuiop	yes
725	19:21:03	Jason	yup
726	19:21:29	qwertyuiop	side length is the same...
727	19:22:06	Jason	yeah
728	19:22:13	Jason	so it'll just be x6 for # triangles in the hexagon
729	19:22:19	137	Each one has 1+3+5 triangles.
730	19:22:23	Jason	but then we're assuming just regular hexagons
731	19:22:29	qwertyuiop	the "each polygon corrisponds to 2 sides" thing we did last time doesn't work for triangles
732	19:23:17	137	It equals 1+3+...+(n+n-1) because of the "rows"?
733	19:24:00	qwertyuiop	yes- 1st row is 1, 2nd row is 3...
734	19:24:49	137	And there are n terms so... n(2n/2)
735	19:25:07	137	or n^2
736	19:25:17	Jason	yeah
737	19:25:21	Jason	then multiply by 6
738	19:25:31	137	To get 6n^2

Figure 2. Chat Excerpt Log

VMT system supporting online pointing, or *deixis*. Pointing is a critical function for shared understanding, and it must be supported explicitly in a digital environment, in which bodily gestures are not visible to others.

After Jason drew the visual attention of the other participants to a particular example of a smaller hexagon consisting of six triangles, 137 asked Jason how to change the color of lines in the whiteboard. In line 715, Jason responded, and 137 changed the color of the lines outlining the larger hexagon. Color becomes an effective method for orienting the team to a shared object. This use of colored lines to help one another see focal things on the whiteboard became an important group practice in the team's continuing work. In line 719, 137 outlined a larger hexagon, with an edge of three units.

At this point, the group had established an effective *copresence* at a mathematical object of interest. Through a variety of interactional practices—which the group members adapted from past experiences or constructed on the spot—the group regulated its interaction and focused its common vision into a "being-there-together" (Stahl, Zhou, Çakir, & Sarmiento-Klapper, 2011) with the object that they constituted as a hexagonal array. The group was now in a position to explore this object mathematically.

"Like This…": Building Intersubjective Shared Understanding

In line 720, Jason explicitly proposed finding a formula for the number of elemental triangles in a hexagonal array with side length *N*. Qwertyuiop suggested a way of seeing the hexagonal array as consisting of six identical sectors, which he ambiguously referred to as "the 6 smaller triangles." Student 137 checked what Qwertyuiop meant by asking him, "Like this?" and then divided the large hexagon with three red lines, which formed six triangular forms inside of the blue outline (see Figure 1, lower right; unfortunately the colors cannot be seen in this black-and-white figure). This was a move by Qwertyuiop to *see* the representation of their problem as a much simpler problem. As Jason noted, now they only had to compute the number of elemental triangles in each of the six identical triangular sectors and then multiply that result by 6 to get the total. Furthermore, the simpler problem could be solved immediately by just looking. As Jason said, each sector has 1 + 3 + 5 triangles. The human eye can recognize this at a glance, once it is properly focused on a relevant sector.

The important mathematical problem-solving move here is to see the problem in a new way. Qwertyuiop saw the hexagon *as* a set of six symmetrical sectors. The important discourse move was to share this new view with the team. This was accomplished collaboratively in lines 722 to 725: Qwertyuiop proposed a new way of seeing the array, 137 outlined it using their new technique of colored lines, and Jason aligned with them. They each participated in seeing the same thing (seeing the hexagon as composed of six triangles), in demonstrating to one another that they saw in this new way, and then in building on one another to count the small triangles visually. They thereby collectively went beyond the copresence of seeing the same thing to actually building knowledge about the object. This group knowledge is *intersubjective shared understanding* of the mathematical structure of the object. Through the sequence of steps outlined above, the members of the group articulated an understanding that they shared because of their copresence and their shared textual and graphical actions.

"To Get 6n^2": Accomplishing Group Cognition

Note in the chat how the three students built on one another to construct the general formula for any size array: $6n^2$. Having collaboratively deconstructed the complicated problem into visually simple units, they took turns reconstructing the problem symbolically and for any size hexagon. They were able to work on this together because of their copresence, which allowed them to orient to the same objects with a shared understanding of the terms (e.g., "hexagonal array," "side length"), graphics (colored border lines), procedures (divide into 6, then multiply by 6), and goals ("find a formula").

Having counted the number of triangles in the array during this excerpt, the students will next want to count the number of line segments. This is more complicated, but the group will extend the methods we have just observed to accomplish their task. Taking advantage of multiple symmetries, they will use colored lines to break the pattern down into visually simple patterns, outline specific focal areas, and attend to shared objects, where their optical systems can do the counting. Some of the smaller units are harder to visualize, and there are issues of possible overlap among the sectors. But using the skills we observed and developing those skills incrementally, the group will succeed in achieving a sequence of cognitive accomplishments (for a detailed analysis, see Çakir & Stahl, 2013).

Intersubjective Shared Understanding in Computer-Supported Discourse

The establishment of shared understanding in a small group through coattending to shared objects is essential for collaboration (Evans, Feenstra, Ryon, & McNeill, 2011; Mercer & Wegerif, 1999). However, in an online context, the usual techniques of body positioning, gaze, and explicit pointing with fingers are not available for creating and maintaining shared attention. Virtual teams must invent new methods to coordinate attention or make use of special tools in the software that may be provided to support this.

Previous VMT studies have analyzed cases in which small groups of online students have developed methods for creating, maintaining, and repairing shared understanding—similar to what was seen in the previous section. For instance, small groups working in the VMT environment have

- coexperienced a shared world (Stahl et al., 2011) by developing shared group practices (Medina, Suthers, & Vatrapu, 2009; Stahl, 2011b);
- used the posing of questions to elicit details needed to establish and confirm the sharing of understandings (Zhou, Zemel, & Stahl, 2008);
- built a "joint problem space" (Teasley & Roschelle, 1993) (i.e., a shared understanding about a set of topics) with ways of referencing them—an "indexical ground" (Hanks, 1992)—that is shared and supports coattending (Sarmiento & Stahl, 2008);
- developed group methods for bridging across temporal breaks in interaction to reestablish a group memory or shared understanding of past events (Sarmiento & Stahl, 2007);
- repaired their shared understanding in the face of breakdowns (Stahl, Zemel, & Koschmann, 2009);
- Integrated text chat and sequences of whiteboard actions to communicate complex mathematical relationships (Çakir, Zemel, & Stahl, 2009); and
- solved math problems by proceeding through logical sequences of steps collaboratively (Stahl, 2011a).

The analysis of the excerpt of interaction presented above and these other studies of VMT have identified the following features of the mediation of digital interaction: copresence, intersubjective shared understanding, and group cognition. I now review the theoretical articulation of these three features as foundations that make possible the goals of academically productive discourse.

Copresence

A small group's copresence, through coattending as a basis for shared understanding, by a small group includes many of the basic features of an individual's attending to and interpreting an object of interest. Attending to something involves focusing on it as the foreground object, assigning everything else to its background context (Polanyi, 1966). For instance, the students in the excerpt above foregrounded a specific hexagon against the background of the larger array of lines by coloring its outline or highlighting it with the pointing tool. Attending to an object involves seeing it "as" something or some way (Goodwin, 1994; Heidegger, 1927/1996; Wittgenstein, 1953). Coattending supports a shared interpretation, viewing, or understanding by creating copresence in attending to a shared object in a shared world in a shared way. For instance, the students viewed the larger hexagon "as" a set of six triangular sectors by visually dividing the hexagon with red lines that outlined the sectors and by texting, "it might be easier to see it as the 6 smaller triangles." (Note that the terminology Qwertyuiop naturally uses here explicitly involves "to see it as….")

Intersubjective Shared Understanding

One can distinguish two paradigms of shared understanding. A rationalist paradigm assumes that individuals each have a stock of propositions in their minds that represent their current beliefs or opinions. The corresponding conception of shared understanding starts from individual understanding of two people and tries to establish equivalence of one or more propositions they hold. This is sometimes called "cognitive convergence," in which the goal is the convergence of the two mental models: sharing as mutual giving.

The alternative paradigm of shared understanding, exemplified by the analysis in this chapter, starts from the shared world and a view of intentionality as consciousness of an object, rather than as a mental construct by an ego. This is the view of situated and distributed cognition, whereby individuals are situated in and active with a shared, intersubjective world consisting of meaningful objects for which they care: sharing as doing together.

Nineteenth- and 20th-century philosophy from Hegel (1807/1967) and Husserl (1936/1989) through Marx (1858/1939), Heidegger (1927/1996), Sartre (1968), Merleau-Ponty (1945/2002), and Wittgenstein (1953) has rejected the starting point of a transcendental ego in favor of consciousness as a social and fundamentally shared phenomenon. Now, even at the neuron level, the discovery of mirror neurons points to a physiological, specifically human, basis for shared cognition (Gallese & Lakoff, 2005). We can immediately experience the world through the eyes and bodies of other people. We can feel the pain if we see another person's body hurt. As Wittgenstein (1953) argued in other ways, there is no such thing as private feelings of pain or of private meanings of language: We are copresent in an intersubjectively shared and commonly understood world. The discourse of the three students collaborating in VMT does not reference and try to converge purported private representations in the students' individual minds; it references features of the mathematical representation of the shared whiteboard, features that the students worked hard to make visible, relevant, shared, and intersubjectively understood.

Group Cognition

Vygotsky (1930/1978) claimed that intersubjective (group) cognition precedes intrasubjective (individual) cognition. He conducted controlled experiments to show that children were able to accomplish cognitive tasks in collaboration with others at an earlier developmental age than they were able to accomplish the same tasks on their own. Individual-cognitive acts are often preceded by and derivative from group-cognitive acts. For instance, individual reasoning or action (dividing a figure, coloring a border) by a student in the VMT data may be based on earlier group practices. According to Vygotsky, individual mental thinking is fundamentally silent self-talk. Thus, individual-student reasoning can often be seen as reflective self-talk about what the group accomplished. In such cases, self-reports about individual cognition—through think-aloud protocols, survey answers, or interview responses—are what Suchman (2007) referred to as post hoc rationalizations. They are reinterpretations by the individual (responsive to the interview situation) of group cognitions. In this reading of Vygotsky, group cognition has a theoretical priority over individual cognition. If one accepts this, the theoretical analysis of shared understanding and the practical promotion of it become priorities. The emerging technologies of networked digital interaction provide promising opportunities for observing and supporting the establishment of shared understanding in online educational environments.

On the basis of experiments in computer support of small-group knowledge building from 1995 to 2005, I proposed the construct of *group cognition* (Stahl, 2006) to begin to define the relevant focus on group-level cognitive achievements; analyses of studies from 2006 to 2009 (Stahl, 2009) continued to explore the practicalities of supporting group-level cognition.

Group cognition is not a physical thing, a mental state, or a characteristic of all groups. It is a unit of analysis. Researchers who are studying digital interaction should look at the small-group unit of analysis (Stahl, 2010). Too often, collaborative learning researchers reduce group-level phenomena either to individual psychological constructs or to societal institutions and practices (Stahl, 2013b). But, as we have seen in the excerpt, there are group methods and processes taking place at the small-group unit of analysis that are not reducible to the mental behaviors of an individual or to the institutions of a community. For instance, the three students collaboratively solved their problem through a sequence of postings that elicited and responded to one another. Qwertyuiop proposed the view of the hexagon as six sectors; 137 summed the series of triangles in one sector to n^2; Jason provided the answer by multiplying the value for one sector by the number of sectors. The result was a group product of the group interaction. If one student had derived this result, we would call it a cognitive achievement of that student. Because the group derived it, it can be called an achievement of group cognition. This does not mean there is some kind of "group mind" at work or anything other than the interaction of the three students. Rather, it means that the analysis of that cognitive achievement is most appropriately conducted at the group unit of analysis, in terms of the interplay of the posting and drawing actions shared by the group.

The absolute centrality of public discourse and shared understanding to the success of group cognition—successful knowledge building at the group level—in the context of digital interaction implies the need for productive forms of talk within the group. Digital environments to support collaborative knowledge building must be carefully designed to foster copresence, intersubjective shared understanding, and group cognition by supporting academically productive talk.

Consequences for Computer Support of Discourse

The theory of academic talk has been oriented primarily toward affecting individual cognition in contexts of face-to-face instruction. Accordingly, it is based on the paradigm of cognitive convergence, trying to guide individual students to converge their individual understandings with the understandings of other students, the teacher, or the community. In the alternative paradigm presented in this chapter for group cognition in online contexts, one tries to maintain and build on intersubjective shared understanding and then guide the group of students to articulate clearly, explicitly, and scientifically its largely tacit shared group understanding.

Computer technology suggests many tools for supporting group cognition. Computers can provide computational supports, such as spreadsheets and graphing calculators, for assisting individuals and groups in computing tasks. They can provide digital media for communication (text, audio, video, drawing, mapping, etc.). They can provide domain-specific visualizations and work environments, such as the multiuser dynamic-geometry system that VMT has recently incorporated (Stahl, 2013c; Stahl & Powell, 2012). Perhaps most important, computers allow people to interact with others around the world.

A particularly intriguing potential of computer technology is to have software agents that interact directly with groups of people, in analogy with human teachers or tutors who support face-to-face groups (see chapters by Gillies and Webb et al., this volume). For instance, an Accountable Talk agent could interact with students to prompt them to engage in Accountable Talk moves. As promising as this sounds, it is equally problematic. Detailed studies of online interaction by small groups of students in the VMT environment show that students are creative at adapting their subtle linguistic skills to the characteristics of online media. They are able to achieve impressive accomplishments of group cognition in exploring mathematical phenomena through dialogic interaction. However, this interaction is fragile and easily disrupted by external interventions of educators and surrogate educators. In particular, software agents, designed to guide groups of students to maintain focus and to engage in productive discourse, can be particularly distracting.

This concluding section of the chapter addresses three issues related to the potential of using software agents to promote Accountable Talk within small online groups of students—invasiveness, automated agency, and overscripting—which respectively threaten to disrupt copresence, shared understanding, and group cognition.

Invasiveness

We have seen that a primary cognitive need is to maintain focal attention; for group cognition, this means maintaining shared attention. Software agents and other scaffolds can distract attention from what the group has created as its focus. An automated agent might raise issues at inopportune moments, interrupting the flow of discourse and group problem solving. We call this possibility "invasiveness."

If software agents are introduced as participants in a group interaction and their status is left ambiguous in order to catch the fancy of students, this will likely raise false expectations. Students may assume that the agent knows answers, has teacher powers, or understands student intentions. The agent can itself become the focus of attention, distracting from both the peer interaction and the problem solving.

Collaboration involves following the lead of the students (individually and as a group), but software agents are not good at understanding student thinking. In experiments investigating the use of software agents in the VMT environment to scaffold and guide group cognition, we have seen how problematic Accountable Talk agents can be (Stahl, 2013a). Agents were sometimes distracting, confusing, and disruptive. The agents did not always listen well to the students or follow their lead. Although some of the problems in our initial experiments with agents were substantially reduced through reprogramming the agents in response to detailed analyses of the results by multiple researchers (Suthers, Lund, Rosé, & Law, 2013), agents may be ultimately incapable of being well "situated" in a group's shared world. Because they are not copresent, attending to the shared object of attention in human ways, but are following generic algorithms designed outside of the current context of interaction, their contributions can disrupt the delicate focus of situated group co-attention.

Automated Agency

Agents and other automated techniques for guiding student groups to achieve academic goals are often modeled on the role of an excellent teacher. But even trained, experienced teachers find the task of orchestrating student discussion overwhelming. Teachers should ideally anticipate students' misconceptions, monitor their ideas, and have them presented to the class in a strategic sequence (Stein, Engle, Smith, & Hughes, 2008). This requires a shared understanding by the teacher of the students' articulations of ideas.

It is unlikely that software agents will soon be able to engage in anticipating effectively, monitoring, selecting, sequencing, and making connections between student responses. It is not just a matter of the required high level of sophistication in understanding the students. In theory, it is questionable whether software agents can ever participate as human peers in small-group interaction. They cannot be situated in the world or understand meaning like humans, largely based on human bodily presence in the physical world (Lakoff, 1987) and intersubjective experiences (Vygotsky, 1930/1978).

Suchman (2007) derived "three outstanding problems for the design of interactive machines" (p. 179) in her empirical study of interactions with intelligent help systems in copier machines. These focused on the lack of a shared understanding between the machines and the humans. Suchman stressed that the limits of software supports should be made very clear to users, to avoid unrealistic expectations that lead to problems of interaction with the systems. Although it is possible to address some of these concerns, it is probably important to make explicit to the users the limits of agents and other software functions. For instance, anthropomorphizing an agent with a human-sounding name and having the agent use colloquial-sounding speech forms may be counterproductive.

Overscripting

A danger of automated guidance and software-embedded scripts for discourse support (Kobbe et al., 2007), such as prompts to be answered, is that they miss the engagement of when a listener really wants an explanation. Dillenbourg (2002) noted the problem of scripted agents' distracting from the student-centered nature of collaborative learning. Interactions may appear superficially collaborative but may fail to trigger the cognitive, social, and emotional mechanisms that are expected to occur during genuine, naturally occurring collaboration. If academic discourse moves are not well situated in student discourse, the effect may be disruptive to authentic group-cognitive processes.

Implications

The following implications for research on the computer support of academically productive discourse and for the design of effective supports follow from the discussion in this chapter:

- It is possible to observe and analyze in chat logs how online small groups establish copresence, maintain intersubjectivity, and accomplish group-cognitive tasks. This can often reveal cognitive processes and the effects on them of different media more clearly than in studies of individuals or face-to-face groups.
- Digital collaboration environments can support coattention, shared understanding, and group cognition in online modes that are essentially different from situations of physical embodiment. However, this requires careful design of technology, pedagogy, and interventions on the basis of iterative trials.
- Usage analysis is needed to compare the results of different approaches to the use of mechanisms such as software agents or other scaffolding. The results are often unintuitive, because they may differ from analogous effects in the context of individual cognition or face-to-face interaction.

References

Çakir, M. P., & Stahl, G. (2013). The integration of mathematics discourse, graphical reasoning and symbolic expression by a virtual math team. In D. Martinovic, V. Freiman, & Z. Karadag (Eds.), *Visual mathematics and cyberlearning* (Vol. 1, pp. 49–96). New York: Springer. Retrieved from http://GerryStahl.net/pub/visualmath.pdf

Çakir, M. P., Zemel, A., & Stahl, G. (2009). The joint organization of interaction within a multimodal CSCL medium. *International Journal of Computer-Supported Collaborative Learning*, *4*, 115–149. Retrieved from http://GerryStahl.net/pub/ijCSCL_4_2_1.pdf

Dillenbourg, P. (2002). Over-scripting CSCL: The risks of blending collaborative learning with instructional design. In P. Kirschner (Ed.), *Three worlds of CSCL: Can we support CSCL?* (pp. 61–91). Heerlen: Open University of the Netherlands.

Evans, M. A., Feenstra, E., Ryon, E., & McNeill, D. (2011). A multimodal approach to coding discourse: Collaboration, distributed cognition, and geometric reasoning. *International Journal of Computer-Supported Collaborative Learning*, *6*, 253–278.

Gallese, V., & Lakoff, G. (2005). The brain's concepts: The role of the sensory-motor system in conceptual knowledge. *Cognitive Neuropsychology*, *21*, 455–479.

Goodwin, C. (1994). Professional vision. *American Anthropologist*, *96*, 606–633.

Hanks, W. (1992). The indexical ground of deictic reference. In A. Duranti & C. Goodwin (Eds.), *Rethinking context: Language as an interactive phenomenon* (pp. 43–76). Cambridge, UK: Cambridge University Press.

Hegel, G.W.F. (1967). *Phenomenology of spirit* (J. B. Baillie, Trans.). New York: Harper & Row. (Original work published 1807)

Heidegger, M. (1996). *Being and time: A translation of* Sein und Zeit (J. Stambaugh, Trans.). Albany: State University of New York Press. (Original work published 1927)

Husserl, E. (1989). The origin of geometry (D. Carr, Trans.). In J. Derrida (Ed.), *Edmund Husserl s origin of geometry: An introduction* (pp. 157–180). Lincoln: University of Nebraska Press. (Original work published 1936)

Kobbe, L., Weinberger, A., Dillenbourg, P., Harrer, A., Hämäläinen, R., Häkkinen, P., & Fischer, F. (2007). Specifying computer-supported collaboration scripts. *International Journal of Computer-Supported Collaborative Learning*, *2*, 211–224.

Lakoff, G. (1987). *Women, fire, and dangerous things*. Chicago: University of Chicago Press.

Marx, K. (1939). *Grundrisse der Kritik der politischen Oekonomie (Rohentwurf)* [*Foundations for the critique of political economy (rough draft)*]. Frankfurt, Germany: Europische Verlagsanstalt. (Original work published 1858)

Medina, R., Suthers, D. D., & Vatrapu, R. (2009). Representational practices in VMT. In G. Stahl (Ed.), *Studying virtual math teams* (pp. 185–205). New York: Springer. Retrieved from http://GerryStahl.net/vmt/book/10.pdf

Mercer, N., & Wegerif, R. (1999). Is "exploratory talk" productive talk? In K. Littleton & P. Light (Eds.), *Learning with computers: Analyzing productive interaction* (pp. 79–101). New York: Routledge.

Merleau-Ponty, M. (2002). *The phenomenology of perception* (2nd ed.) (C. Smith, Trans.). New York: Routledge. (Original work published 1945)

Polanyi, M. (1966). *The tacit dimension*. Garden City, NY: Doubleday.

Sarmiento, J., & Stahl, G. (2007). *Bridging and persistence in sustained, collaborative problem solving online*. Paper presented at the 40th Annual Hawaii International Conference on System Sciences (HICSS 2007). Retrieved from http://GerryStahl.net/pub/hicss07

Sarmiento, J., & Stahl, G. (2008). *Extending the joint problem space: Time and sequence as essential features of knowledge building. Paper presented at the International Conference of the Learning Sciences* (ICLS 2008), Utrecht, the Netherlands. Retrieved from http://GerryStahl.net/pub/icls2008johann.pdf

Sartre, J.-P. (1968). *Search for a method* (H. Barnes, Trans.). New York: Random House.

Stahl, G. (2006). *Group cognition: Computer support for building collaborative knowledge*. Cambridge, MA: MIT Press.

Stahl, G. (2009). *Studying virtual math teams*. New York: Springer.

Stahl, G. (2010). Group cognition as a foundation for the new science of learning. In M. S. Khine & I. M. Saleh (Eds.), *New science of learning: Cognition, computers and collaboration in education* (pp. 23–44). New York: Springer. Retrieved from http://GerryStahl.net/pub/scienceoflearning.pdf

Stahl, G. (2011a). How a virtual math team structured its problem solving. In *Proceedings From International Conference on Computer-Supported Collaborative Learning (CSCL 2011), Connecting Computer-Supported Collaborative Learning to Policy and Practice* (pp. 256–263). Retrieved from http://GerryStahl.net/pub/cscl2011stahl.pdf

Stahl, G. (2011b). Social practices of group cognition in virtual math teams. In S. Ludvigsen, A. Lund, I. Rasmussen, & R. Säljö (Eds.), *Learning across sites: New tools, infrastructures and practices* (pp. 190–205). New York: Routledge. Retrieved from http://GerryStahl.net/pub/cmc.pdf

Stahl, G. (2013a). Interaction analysis of a biology chat. In D. Suthers, K. Lund, C. P. Rosé, & N. Law (Eds.), *Productive multivocality*. New York: Springer. Retrieved from http://GerryStahl.net/pub/multivocal.pdf

Stahl, G. (2013b). Theories of collaborative cognition: Foundations for CSCL and CSCW together. In S. Goggins & I. Jahnke (Eds.), *CSCL@work* (Vol. 13, Springer CSCL Book Series). New York: Springer. Retrieved from http://GerryStahl.net/pub/collabcognition.pdf

Stahl, G. (2013c). *Translating Euclid: Designing a human-centered mathematics*. San Rafael, CA: Morgan & Claypool. Retrieved from http://GerryStahl.net/elibrary/euclid

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. Retrieved from http://GerryStahl.net/elibrary/global

Stahl, G., & Powell, A. B. (2012). *Multi-user GeoGebra for virtual math teams*. Paper presented at the GeoGebra ICME Pre-conference, Seoul, South Korea. Retrieved from http://GerryStahl.net/pub/ggbkorea.pdf

Stahl, G., Zemel, A., & Koschmann, T. (2009). *Repairing indexicality in virtual math teams*. Paper presented at the International Conference on Computers and Education (ICCE 2009), Hong Kong, China. Retrieved from http://GerryStahl.net/pub/icce2009.pdf

Stahl, G., Zhou, N., Çakir, M. P., & Sarmiento-Klapper, J. W. (2011). Seeing what we mean: Co-experiencing a shared virtual world. In *Proceedings From International Conference on Computer Supported Collaborative Learning (CSCL 2011), Connecting Computer-Supported Collaborative Learning to Policy and Practice* (Vol. I, pp. 534–541). Retrieved from http://GerryStahl.net/pub/cscl2011.pdf

Stein, M. K., Engle, R. A., Smith, M. S., & Hughes, E. K. (2008). Orchestrating productive mathematical discussions: Five practices for helping teachers move beyond show and tell. *Mathematical Thinking and Learning*, *10*, 313–340.

Suchman, L. A. (2007). *Human-machine reconfigurations: Plans and situated actions* (2nd ed.). Cambridge, UK: Cambridge University Press.

Suthers, D., Lund, K., Rosé, C. P., & Law, N. (2013). *Productive multivocality*. New York: Springer.

Teasley, S. D., & Roschelle, J. (1993). Constructing a joint problem space: The computer as a tool for sharing knowledge. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as cognitive tools* (pp. 229–258). Mahwah, NJ: Lawrence Erlbaum.

Vygotsky, L. (1978). *Mind in society*. Cambridge, MA: Harvard University Press. (Original work published 1930)

Wittgenstein, L. (1953). *Philosophical investigations*. New York: Macmillan.

Zhou, N., Zemel, A., & Stahl, G. (2008). *Questioning and responding in online small groups engaged in collaborative math problem solving*. Paper presented at the International Conference of the Learning Sciences (ICLS 2008), Utrecht, the Netherlands. Retrieved from http://GerryStahl.net/pub/icls2008nan.pdf