Can shared knowledge exceed the sum of its parts?

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Abstract. We are investigating the nature of shared knowledge under distributed circumstances. In particular, we are exploring the possibility that a small group of students collaborating online on math problems can construct group knowledge that exceeds the knowledge of the individual group members.

Overview of the Problem

The term “shared knowledge” is ambiguous. It can refer to:

- **Similarity of individuals’ knowledge**: The knowledge in the minds of the members of a group happen to overlap and their intersection is “shared.”
- **Knowledge that gets shared**: Some individuals communicate what they already knew to the others.
- **Group knowledge**: Knowledge is interactively achieved in discourse and may not be attributable as originating from any particular individual.

Collaboration theory argues that “common ground” – a form of shared knowledge – is required for successful communication. But it is not always clear which of the above forms authors are referring to, or whether repairs to breakdowns in such common ground comes from ideas that existed in someone’s head and are then passed on to others until a consensus is established, or whether the common ground might be constructed in the interaction of the group as a whole. It is possible that shared knowledge can sometimes be explained in one way, sometimes another. At any rate, it seems that the question of the source of shared knowledge in a given case might best be treated as an empirical question.

At Drexel University, we are undertaking a research project to investigate empirically whether knowledge sharing under distributed conditions can construct group knowledge that exceeds the individual knowledge of the group’s members. Our hypothesis is that precisely such a result is, in fact, the hallmark of collaborative learning, understood in an emphatic, visionary sense.

We are investigating not only whether computer-supported collaborative learning under distributed conditions can construct novel group knowledge, but what conditions are favorable to fostering such an outcome. We will do this by designing and implementing an experimental service in the Math Forum @ Drexel (www.mathforum.org), a popular online site with resources and problems related to K-12 school mathematics. Students visiting the site will be invited to join small virtual teams to discuss and solve math problems collaboratively online. We will analyze the interactions in these teams to determine how they build shared knowledge under distributed circumstances.

A Conflict of Paradigms

Our work is motivated by the following circumstance: Research on learning and education is troubled to its core by a conflict of paradigms. Sfard (1998) reviewed some of the history and consequences of this conflict in terms of the incompatibility of the acquisition metaphor (AM) of learning and the participation metaphor (PM). AM conceives of education as a transfer of knowledge commodities and their subsequent possession by individual minds. Accordingly, empirical research in this paradigm looks for evidence of learning in changes of mental contents of individual learners. PM, in contrast, locates learning in intersubjective, social or group processes, and views the learning of individuals in terms of their changing participation in the group interactions. AM and PM are as different as day and night, but Sfard argues that we must learn to live in both complementary metaphors.

The conflict is particularly pointed in the field of CSCL (computer-supported collaborative learning). The term "collaborative learning" can itself be seen as self-contradictory given the tendency to construe learning as taking place in individual minds. Having emerged from a series of paradigm shifts in thinking about instructional technology (Koschmann, 1996), the field of CSCL is still enmeshed in the paradigm conflict between opposed cognitive and sociocultural focuses on the individual and the group (Kaptelinin & Cole, 2002). In a keynote at the CSCL '02 conference, Koschmann argued that even exemplary instances of CSCL research tend to adopt a theoretical framework that is anathema to collaboration (Koschmann, 2002a). Koschmann recommended that talk about "knowledge" as a thing that can be acquired should be replaced with discussion of "meaning-making in the context of joint activity" in order to avoid misleading images of learning as mental acquisition and possession.

Although Koschmann's alternative phrase can describe the intersubjective construction of shared meanings achieved through group interaction, the influence of AM can re-construe meaning-making as something that must perforce take place in individual human minds, because it is hard for most people to see how a group can possess mental contents. In a paper at CSCL '03 responding to Koschmann's earlier keynote, (Stahl, 2003b) argued that both Koschmann's language and that of the researchers he critiqued is ambiguous and is subject to interpretation under either AM or PM. A simple substitution of wording is inadequate; it is necessary to make explicit when one is referring to individual subjective understanding and when one is referring to group intersubjective understanding – and to make clear to those under the sway of AM how intersubjectivity is concretely possible.

The problem with recommending that researchers view learning under both AM and PM or that they be consistent in their theoretical framing is that our common sense metaphors and widespread folk theories are so subtly entrenched in our thinking and speaking. The languages of Western science reflect deep-seated assumptions that go back to the *ideas* of Plato's *Meno* and the *ego cogito* of Descartes' *Meditations*. It is hard for most people to imagine how a group can have knowledge, because we assume that knowledge is a substance that only minds can acquire or possess, and that only physically distinct individuals can have minds (somewhere in their physical heads).

Evidence to Overcome the Conflict

We are addressing this central research issue head-on by studying online collaborative learning in the specific context of Math Forum problems, with the aim of presenting empirical examples of concrete situations in which groups can be seen to have knowledge that is distinct from the knowledge of the group members. By analyzing these situations in detail, we will uncover mechanisms by which understanding of mathematics passes back and forth between the group as the unit of analysis and individual group members as units of analysis.

One example might be a group of 5 high school students collaborating online over a two week period. They solve an involved algebra problem and submit a discussion of their solution to the Math Forum. By looking carefully at the computer logs of their interactions in which they collaboratively discussed, solved and reflected upon the problem, we can see that the group solution exceeds the knowledge of any individual group members before, during or after the collaboration. For instance, there may be some arguments that arose in group interaction that none of the students fully understood but that contributed to the solution. Or a mathematical derivation might be too complicated for any of the students to keep "in mind" without reviewing preserved chat archives or using an external representation the group developed in an online whiteboard. By following the contributions of one member at a time, it may also be possible to find evidence of what each student understood before, during and after the collaboration, and thereby to follow individual trajectories of participation in which group and individual understandings influenced each other,

While we do not anticipate that group knowledge often exceeds that of all group members under generally prevailing conditions, we hypothesize that it can do so at least occasionally under particularly favorable conditions. We believe that we can set up naturalistic conditions as part of a Math Forum service and can collect sufficient relevant data to demonstrate this phenomenon in multiple cases. The analysis and presentation of these cases should help to overcome the AM/PM paradigm conflict by providing concrete illustrations of how knowledge can be built through group participation as distinct from – but intertwined with – individual acquisition of part of that knowledge. It should also help to clarify the theoretical framing of acts of meaning-making in the context of joint activity.

We believe that the theoretical confusion surrounding the possibility of group knowledge presents an enormous practical barrier to collaborative learning. Because students and teachers believe that learning is necessarily an individual matter, they find the effort at collaborative learning to be an unproductive nuisance. For researchers, too, the misunderstanding of collaborative learning distorts their conclusions, leading them to look for effects of pedagogical and technological innovation in the wrong places. If these people understood that groups can construct knowledge in ways that significantly exceed the sum of the individual contributions and that the power of group learning can feed back into individual learning, then we might start to see the real potential of collaborative learning realized on a broader scale. This project aims to produce rigorous and persuasive empirical examples of collaborative learning to help bring about the necessary public shift in thinking.

The Range of Views on this Issue

CSCL grows out of research on cooperative learning that demonstrated the advantages for individual learning of working in groups (e.g., Johnson & Johnson, 1989). There is still considerable ambiguity or conflict about how the learning that takes place in contexts of joint activity should be conceptualized. While it has recently been argued that the key issues arise from ontological and epistemological commitments deriving from philosophy from Descartes to Hegel (Koschmann, 2002b; Packer & Goicoechea, 2000), we believe that it is more a matter of focus on the individual (cognitivist) versus group (sociocultural) as the unit of analysis (Stahl, 2003a, 2003b). Positions on the issue of the unit of learning take on values along a continuous spectrum from individual to group:

- Learning is always accomplished by individuals, but this individual learning can be assisted in settings of collaboration, where individuals can learn from each other.
- Learning is always accomplished by individuals, but individuals can learn in different ways in settings of collaboration, including learning how to collaborate.
- Groups can also learn, and they do so in different ways from individuals, but the knowledge generated must always be located in individual minds.
- Groups can construct knowledge that no one individual could have constructed alone by a synergistic effect that merges ideas from different individual perspectives.

- Groups construct knowledge that may not be in any individual minds, but may be interactively achieved in group discourse and may persist in physical or symbolic artifacts such as group jargon or texts or drawings.
- Group knowledge can be spread across people and artifacts; it is not reducible to the knowledge of any individual or the sum of individuals' knowledge.
- All human learning is fundamentally social or collaborative; language is never private; meaning is intersubjective; knowledge is situated in culture and history.
- Individual learning takes place by internalizing or externalizing knowledge that was already constructed inter-personally; even modes of individual thought have been internalized from communicative interactions with other people.
- Learning is always a mix of individual & group processes; the analysis of learning should be done with both the individual and group as units of analysis and with consideration of the interplay between them.

In this project, we take a rather strong position on collaborative learning as our working hypothesis:

- H0 (**collaborative learning hypothesis**): A small online group of learners can (on occasion and under favorable conditions) build knowledge and understanding that exceeds that of its individual members.

The different positions listed above are supported by a corresponding range of theories of human learning. Educational research on small group process in the 1950's and '60's maintained a focus on the individual as learner (Johnson & Johnson, 1989; Stahl, 2000). Classical cognitive science in the next period continued to view human cognition as primarily an individual matter – internal symbol manipulation or computation across mental representations, with group effects treated as secondary boundary constraints (Simon, 1981; Vera & Simon, 1993). In reaction to these views, a number of sociocultural theories have become prominent in the learning sciences in recent decades. To a large extent, these theories have origins in much older works that conceptualized the situated-ness of people in practical activity within a shared world (Bakhtin, 1986; Heidegger, 1927/1996; Husserl, 1936/1989; Marx, 1867/1976; Schutz, 1967; Vygotsky, 1930/1978). Here are some representative theories that focus on the group as a possible unit of knowledge construction:

- **Collaborative Knowledge Building**. A group can build knowledge that cannot be attributed to an individual or to a combination of individual contributions (Bereiter, 2002; Fuks, Gerosa, & Pereira de Lucena, 2001; Hakkarainen & Lipponen, 2002; Scardamalia & Bereiter, 1996; Wasson & Morch, 2000).
- **Social Psychology**. One can and should study knowledge construction at both the individual and group unit of analysis, as well as studying the interactions between them (Daradounis, Xhafa, & Marques, 2003; Fischer & Granoo, 1995; Palen, 1999; Resnick, Levine, & Teasley, 1991).
- **Distributed Cognition**. Knowledge can be spread across a group of people and the tools that they use to solve a problem (Hutchins, 1996; Hutchins & Palen, 1998; Solomon, 1993; Wasson & Morch, 2000).
- **Situated Cognition**. Knowledge often consists of resources for practical activity in the world more than of rational propositions or mental representations (Hewitt, Scardamalia, & Webb, 1998; Polanyi, 1966; Schön, 1983; Suchman, 1987; Winograd & Flores, 1986).
- **Situated Learning**. Learning is the changing participation of people in communities of practice (Chaiklin & Lave, 1993; Graether & Prinz, 2001; Hewitt, 1997; Lave & Wenger, 1991; Prinz, 1999; Schlager, Fusco, & Schank, 2002; Shumar & Renninger, 2002).
- **Zone of Proximal Development**. Children grow into the intellectual life of those around them; they develop in collaboration with adults or more capable peers (Brown & Campione, 1994; Goldman-Segall, 1998; Hmelo-Silver, 2004; Lemke, 1990; Vygotsky, 1930/1978).
- **Activity Theory**. Human understanding is mediated not only by physical and symbolic artifacts, but also by the social division of labor and cultural practices (Engeström, 1999; Gay & Bennington, 1999; Kaptelinin, 1996; Nardi, 1996a; Nardi, 1996b).

- **Ethnomethodology**. Human understanding, inter-personal relationships and social structures are achieved and reproduced interactionally (Dourish, 2001; Garfinkel, 1967; Hall, 1999; Heritage, 1984; Koschmann & LeBaron, 2003; Stahl, 2002b; Streeck, 1996; Streeck & Mehus, 2003).

One does not have to commit to one of these theories in particular in order to gain a sense from them of the possible nature of group knowledge. We have selected a working hypothesis that is in line with these theories in general without opting for one specifically. Based on our previous empirical work, we believe that we can study the issues raised by these theories without circularity by structuring collaborative activities, varying their parameters and critically evaluating the results. By reflecting on the theoretical issues within our work, we believe we can avoid the pitfalls of theory-laden research without claiming unattainable value neutrality.

Empirical Study of Group Knowledge

We previously conducted a pilot study involving a group of five middle school students collaborating on a problem involving data from a computer simulation. Like many studies of collaborative learning (e.g., Hmelo-Silver, 2004; Koschmann & LeBaron, 2003) (but unlike the new study), this one involved face-to-face interaction with an adult mentor present. Close analysis of student utterances during an intense interaction suggested that the group developed an understanding that certainly could not be attributed to the utterances of any one student (Stahl, 2002b). In fact, the utterances themselves were meaningless if taken in isolation from the discourse and its activity context.

There were a number of limitations to the pilot study: (1) Although the mentor was quiet for the specific interaction analyzed, it might be possible to attribute something of the group knowledge to the mentor's guiding presence. (2) The digital videotape was limited in capturing gaze and even some wording. (3) The data included only two sessions, too little to draw conclusions about how much individual students understood of the group knowledge before, during or after the interaction. To overcome such limitations, in our current study: (1) Mentors are not active in the collaborative groups – although the group will work on problems that have been carefully crafted to guide student inquiry and advice can be requested by email from Math Forum staff. (2) The online communication is fully logged, so that researchers have a record of the complete problem-solving interaction. (3) Groups will be studied over a period of a couple weeks – and longer for several groups that work on a sequence of problems.

Despite its limitations, the pilot study clearly suggests the feasibility of studying group knowledge. It shows that group knowledge is constructed in discourse and that discourse analysis can "make visible" that knowledge to researchers. Student discourse is increasingly recognized as of central importance to science and math learning (Atkins, 1999; Bauersfeld, 1995; Lemke, 1990; Schifter, 1996). Discourse analysis is a rigorous human science, going under various names: conversation analysis, interaction analysis, micro-ethnography, ethnomethodology (Coulthard, 1977; Duranti, 1998; Garfinkel, 1967; Heritage, 1984; Jordan & Henderson, 1995; Mehan, 1979; Sacks, 1992; Sinclair & Coulthard, 1975; Streeck & Mehus, 2003).

The focus on discourse suggests a solution to the confusion between individual and group knowledge, and to the conceptual conflict about how there can be such a thing as group knowledge distinct from what is in the minds of individual group members (Stahl, 2003a). One way of putting it is that meaning is constructed in the group discourse. The status of this meaning as shared by the group members is itself something that must be continually achieved in the group interaction; frequently the shared status "breaks down" and a "repair" is necessary. In the pilot study, the interaction of interest centered on precisely such a repair of a breakdown in shared understanding among the discussants (Stahl, 2002b). While *meaning* inheres in the discourse, the individual group members must construct their own *interpretation* of that meaning in an on-going way. Clearly, there are intimate relationships between the meanings and their interpretations, including the interpretation by one member of interpretations of other members. But it is also true that language can convey meanings that transcend the understandings of the speakers and hearers. It may be precisely through divergences among different interpretations or among various connotations of meaning that collaboration gains much of its creative power (Stahl, 2003b). These are questions that we will investigate as part of our micro-analytic studies of collaboration data, guided by our central working hypothesis. We believe that such an approach can maintain a focus on the ultimate potential in CSCL, rather than losing sight of the central phenomena of collaboration as a result of methods that focus exclusively on statistical trends (Stahl, 2002a).

Related Issues for Investigation

Collaborative success is hard to achieve and probably impossible to predict. CSCL represents a concerted attempt to overcome some of the barriers to collaborative success, like the difficulty of everyone in a group effectively communicating their ideas to all the other members, the complexity of keeping track of all the inter-connected ideas that have been offered or the barriers to working with people who are geographically distant. As appealing as the introduction of technological aids for communication, computation and memory seem, they inevitably introduce new problems, changing the social interactions, tasks and physical environment. Accordingly, CSCL study and design must take into careful consideration the social composition of groups, the collaborative activities and the technological supports.

In order to observe effective collaboration in an authentic educational setting, we are adapting a successful math education service to create conditions that will likely be favorable to the kind of interactions that we want to study. We must bring together groups of people who will work together well, both by getting along with and understanding each other and by contributing a healthy mix of different skills. We must also carefully design mathematics curriculum packages that lend themselves to the development and display of deep math understanding through collaborative interactions – open-ended problems that will not be solved by one individual but that the group can chew on for a week or two of online interaction. Further, the technology that we provide to our groups must be easy to use from the start, while meeting the communicative and representational needs of the activities. As part of our project, we will study how to accomplish these group formation, curriculum design and technology implementation requirements. This is expressed in three working hypotheses of the project: H1, H2 and H3. Two further working hypotheses define areas of knowledge building that the project itself will engage in on the basis of our findings. H4 draws conclusions about the interplay between group and individual knowledge, mediated by physical and symbolic artifacts that embody knowledge in persistent forms. H5 reports on the analytic methodology that emerges from the project:

- H1 (**collaborative group hypothesis**): Small groups are most effective at building knowledge if members share interests but bring to bear diverse backgrounds and perspectives.
- H2 (**collaborative curriculum hypothesis**): Educational activities can be designed to encourage and structure effective collaborative learning by presenting open-ended problems requiring shared deep understanding.
- H3 (**collaborative technology hypothesis**): Online computer support environments can be designed to facilitate effective collaborative learning that overcomes limitations of face-to-face communication.
- H4 (**collaborative cognition hypothesis**): Members of collaborative small groups can internalize group knowledge as their own individual knowledge and they can externalize it in persistent artifacts.
- H5 (**collaborative methodology hypothesis**): Quantitative and qualitative analysis and interpretation of interaction logs can make visible to researchers the online learning of small groups and individuals.

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