Information Practices to Sustain Knowledge Building:
The Case of the Virtual Math Teams Online Community

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The sustained knowledge building of virtual groups and online communities requires that co-participants overcome a wide range of gaps in their interactions, especially in the context of long-term activity across multiple episodes and collectivities. Here we present an analysis of the collective information practices of virtual teams engaged in collaborative problem-solving as part of the Virtual Math Teams (VMT) online community. Our analysis aimed at understanding the information practices that teams employed to *bridged* the apparent discontinuity of their collaborative interactions (e.g. multiple collaborative sessions, teams, and problem tasks) and exploring the role that such *bridging activity* plays in their knowledge building over time.

Knowledge Building and Collective Information Practices

Knowledge Building has been defined as the creation, testing, and improvement of conceptual artifacts (Scardamalia & Bereiter, 2006). In this sense, *knowledge building* is primarily information activity (individual and collective) carried out through a set of practices aimed at developing and advancing a person or a group's understanding of a question, a problem, a decision, or any other knowledge gap. Knowledge building is at the core of many human contexts including, for example, educational settings (Scardamalia, 2002; Stahl, 2006a) digital libraries (e.g., Bearman, 2007; Fox & Urs, 2002) and virtual communities (e.g., Barab, Kling, & Gray, 2004; Ellis, Oldridge, & Vasconcelos, 2004; Renninger & Shumar, 2002). Online contexts, in particular, make knowledge-building more visible and, as such, represent very unique opportunities to advance our understanding of how individuals, small groups and the larger community build, evolve, and expand knowledge.

Naturally, knowledge building is a complex and challenging enterprise. Divergent perspectives often lead to problems of understanding; different work styles can result in interactional breakdowns, while the distributed nature of joint action over time usually leads to gaps of awareness and problems of coordination. Discontinuities emerging from long-term knowledge building have been studied from a number of different perspectives. The gaps that arise among events, perspectives, and participants have been an area of investigation in the study of individual and group creativity (e.g. Amabile, 1983; Sawyer, 2003) as well as in fields such as Small-group Research (Arrow et al., 2000; Bluedorn & Standifer, 2004), Computer-supported Cooperative Work (CSCW) and Knowledge Management (Greenberg & Roseman, 2003; Ishii et al., 1993). Despite their interest in this crucial topic, most studies have concentrated solely on characterizing the outcomes of groups and communities who successfully overcome discontinuities but few descriptions have been offered of the information practices that lead to such outcomes. Among these outcomes we can list the existence of "information bridgers" in group-to-group collaboration (Mark, Abrams, & Nassif, 2003), the use of boundary objects in interdisciplinary collaboration (Star, 1989), the emergence of "shifting epistemologies" (Bielaczyc & Blake, 2006), and the growing orientation to collective knowledge

advancement in communities (Scardamalia, 2002). Our interest lies in characterizing how specific information practices are used to overcome relevant gaps in collective knowledge building.

Case Study: The Math Forum and the Virtual Math Teams (VMT) online communities

The Math Forum (http://mathforum.org) is an online community, active since 1992. It promotes technology-mediated interactions among teachers of mathematics, students, mathematicians, staff members and others interested in learning, teaching and doing mathematics. As the Math Forum continues to evolve, the development of new interaction supports becomes essential for sustaining and enriching the mechanisms of community participation. As an example, the Virtual Math Teams (VMT) project investigates the innovative use of online collaborative environments to support effective mathematical work by small groups. In the VMT project, small groups of students come together to work through a special online environment that provides them with an array of tools to conduct their collaborative problem-solving activity, sustain it over time, and interact with other interested individuals and groups (Wessner *et al.*, 2006).

During the spring of 2005 and 2006 we conducted two case studies of VMT activity to explore issues of continuity and sustainability of collaborative knowledge building. In each case, five virtual teams were formed with about four non-collocated secondary-school students selected by volunteer teachers at different schools across the United States. The teams engaged in online math discussions for four hour-long sessions over a two-week period. They used the VMT virtual room environment (Wessner et al., 2006) which combines a persistent chat tool with a shared whiteboard in addition to some other interactional supports. At the start, the teams were given a brief description of an open-ended mathematical situation and were encouraged to generate and pursue their own questions about it. Later on, the teams were given feedback on their prior work and the work of other teams and were encouraged to continue their work.

The goals of our analysis were to understand how teams of participants in the VMT online community managed the apparent discontinuity of their interactions (e.g. multiple collaborative sessions, teams and tasks), and to explore the relationship between such activity and the teams' knowledge building over time. We employed the approach of ethnomethodology (Garfinkel, 1967) to examine the sequences of events by using recordings and artifacts from each team sessions. As part of the phenomenological perspective, ethnomethodology is based on naturalistic inquiry to inductively and holistically understand human experience in context-specific settings (Patton, 1990). For our purposes, we examined each of the 37 sessions recorded, paying special attention to the sequential unfolding of the problem-solving episodes in which each team participated. Constant comparison through the entire dataset led to our refinement of the structural elements that define the information practices presented below.

Information Practices: Local, Longitudinal and Expansive Continuity

Our study of bridging practices revealed a series of information practices which allowed the teams to cross over the boundaries of time and link together different episodes of collective action. The three most significant practices documented in our analysis are: *Framing Narratives of past activity as resources for new tasks, Collective remembering*, and *Projective Memory*.

By *framing narratives of past activity as resources for new tasks*, teams were able to construct and use "*reportables"* such as rules, procedures, or results that had been discovered in prior activities and construct new tasks for their current activity. In doing this, participants seemed to contribute to the creation of a team history constructed out of episodes of interaction and the relevant team members' biographies. *Projective Memory*, the least common of the three practices documented, involved the planning and configuration of future work out of incomplete work (e.g. missing explanations), further challenges (e.g. more complex problems), or possible new tasks. Finally, through *Collective Remembering*, participants and non-participants of prior activities engaged in reconstructing past results by juxtaposing past and present resources and, in many cases, advancing the frontiers of prior results.

These information practices seemed to have one interesting structural feature in common. They were deployed by interweaving three central aspects of the groups' interactions: *time and sequences of activity*, *participation frameworks*, and *knowledge artifacts*. The *temporal or sequential organization of experience* (i.e. what was done in a different episode of activity or at a different time, how does one action relates to something done before, etc.) provided the underlying structure for the teams to construct a sense of continuity that was "*local*" within an episode of interaction, "*longitudinal*" as it related to the history of the team, and "*expansive*" as it projected towards the past and future activities of other groups in the online community. By enacting specific *participation frameworks* (e.g. positioning participants as being or not involved in a specific past present or future activity, as those who can or should speak about a particular matter, etc.) teams managed their ongoing dynamic interactions and the creation and management of *knowledge artifacts* such as tasks and other problem-solving resources. These three elements were central to the information practices related to continuity.

In summary, bridging activity allowed the teams to cross over the boundaries of time, activities, collectivities, or perspectives. Bridging then seems to define a set of information practices through which participants deal with the discontinuities relevant to their joint activity. Another way to describe bridging might be to say that they are concerned with what Roschelle and Teasley (1995) described as the construction and maintenance of a "joint problem space." Originally this space was theorized as a "shared knowledge structure" that integrated goals, descriptions of the current problem state, and the awareness of available problem solving actions. In our case, we have seen that this joint problem space is significantly distributed over time, across participants and artifacts, and also that specific information practices are related to its construction, maintenance and use.

The successful construction and maintenance of a joint problem space constitutes a central challenge of effective collaborative knowledge building (Roschelle & Teasley, 1995; Stahl, 2006b; Suthers, 2005). Several studies in the field of computer-supported collaborative learning have shown that the interactional manner in which this intersubjective problem space is created and used determines the success of the collaborative experience (e.g., Barron, 2003; Chi, 2000; Dillenbourg *et al.*, 1995; Hausmann, Chi, & Roy, 2004; Koschmann *et al.*, 2005; Wegerif, 2006). Our present analysis has shown that this challenge escalates in contexts characterized by longitudinal activity across multiple collectivities but that specific information practices can be deployed for teams to manage this complexity. To establish continuity and sustainability, virtual teams and online communities "bridge" multiple elements of their interactions continuously a very consequential undertaking that lies at the core of effective collective knowledge building.

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