Group Creativity in Virtual Math Teams: Interactional Mechanisms for Referencing, Remembering and Bridging

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ABSTRACT
In this paper, we present a qualitative case study of group creativity online in the domain of mathematics. We define creative work broadly, ranging from the micro-level co-construction of novel resources for problem solving to the innovative reuse of ideas and solution strategies across virtual teams. We analyze the collaborative interactions of virtual math teams with an emphasis on describing the relationship between "*synchronic*" aspects of creative work (i.e. single episode interactions) and their "*diachronic*" evolution across time and across collectivities. Our analysis indicates that the synergy between these two types of interactions and the resulting creative engagement of the teams relies on three fundamental processes: (1) referencing and the “configuration of indexicals”, (2) collective remembering, and (3) bridging across discontinuities. In addition we also reflect on the aspects of the online environment used by these virtual teams which promote, support or hinder diachronic and synchronic interactions and creativity as aspects of group cognition.

Keywords
Group creativity, group cognition, case study, virtual teams

INTRODUCTION

We take a social and interactional view of creativity. We study creative accomplishments of small groups working together online. It may be that one can see the mechanisms and practices that are constitutive of creativity in the observable interactions of groups and then understand individual creativity as forms of “internalization” of these interactional processes.

Although the social dimension of individual creativity has been studied extensively in creativity research [e.g., 1, 2, and 3], collective creativity is a recent topic of study. In fact, understanding collective creativity as interactional phenomena of groups evolving over time can help us understand better the creative process itself. For instance, recent conceptual models of group creativity [5] propose that collective creative work can be better understood as the synergy between *synchronic* interactions (i.e., in parallel and simultaneously) and *diachronic* exchanges (i.e., interaction over long time spans, and mediated indirectly through creative products). In this paper we attempt to explore the interdependency between the synchronic and diachronic interactions and analyze its relationship with creative work, broadly defined. In our study of mathematics collaboration online we observe collective creative work as manifested in a wide range of interactions extending from the micro-level co-construction of novel resources for problem solving to the innovative reuse and expansion of ideas and solution strategies across multiple teams. This paper presents a case study of such collective creativity.

We start by describing the Virtual Math Teams project, the context from which our observations originate. Then we turn our attention to describing incrementally some central interactional aspects of online collectivities engaged in creative work. Our main goal is to better understand the synergy between single-episode collaboration and the creative work of multiple collectivities engaged together over time. In particular, we describe three interactional processes which appear to be fundamental for collective creativity: (1) referencing and the “configuration of indexicals”, (2) collective remembering, and (3) bridging across discontinuities.

The emergence of computational environments that support collaborative work has opened up the opportunity for researchers to go beyond studies of “solo” action and investigate distributed systems of cognition and creativity that situate artifacts, tasks and knowing in the interactions of co-participants and activity systems over time. In addition to describing the interactions that the virtual teams observed engage in, we also reflect on the particular aspects of the online environment employed which promote, support or hinder *synchronic* and *diachronic* interactions.

THE VIRTUAL MATH TEAMS (VMT) PROJECT

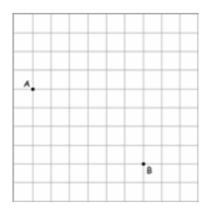
The Math Forum (http://mathforum.org) is an online community, active since 1992. It promotes technology-mediated interactions among teachers of mathematics, students, mathematicians, staff members and other interested parties committed to learning, teaching and doing mathematics. As the Math Forum community continues to evolve, the development of new interaction supports becomes increasingly essential for sustaining and enriching the mechanisms of community participation available. As an example of these endeavors, the Virtual Math Teams (VMT) project at the Math Forum investigates the innovative use of online collaborative environments to support effective secondary mathematics learning in small groups. The VMT project is an NSF-funded research program designed to investigate sustained collaborative problem-solving in computer-supported environments and to characterize how members of the Math Forum's community of learners constitute their interactions over time to foster their development as learners of mathematics.

Central to the VMT research program are the investigation of the nature and dynamics of group cognition [6] as well as the design of effective technological supports for quasi-synchronous small-group interactions. In addition, we investigate the linkages between synchronous interactions (e.g. collaborative chat episodes) and distributed asynchronous interactions at the level of the online community. We are currently studying how upper middle school and high school students do mathematics collaboratively in online chat environments. We are particularly interested in the methods that they develop to conduct their interactions in such an environment. Taken together, these methods define a culture, a shared set of ways to make sense together. The methods are subtly responsive to the chat medium, the pedagogical setting, the social atmosphere and the intellectual resources that are available to the participants. These methods help define the nature of the collaborative experience for the small groups that develop and adopt them.

In our iterative design-based research approach, we started by conducting chats in a variety of commercially available environments. Based on these early investigations, we concluded that we needed to add a shared whiteboard for drawing geometric figures and for persistently displaying notes. We also found a need to minimize "chat confusion" by supporting explicit referencing of conversation threads. We decided to try ConcertChat [4], a research collaboration environment combining persistent chat with a shared whiteboard and a set of referencing tools. By collaborating with the software developers, our educational researchers have been able to successively try out versions of the environment with groups of students and to gradually modify the environment in response to our research. Some of ConcertChat's interactional supports include:

* Chat conversations are persistent during and after each session. Latecomers automatically receive the last ten messages when joining a session and can load all previous messages at will.
* A chat user can post a new message with an explicit graphical link pointing to one or more previous messages. The graphical link between the two messages is displayed until a new message gets posted in the chat, but can be shown again by a user clicking on the linking message.
* The shared whiteboard allows chat participants to create drawings and shared graphic information with each other. Every whiteboard action is recorded as part of the evolving history of the whiteboard. Users can manipulate a slide bar to navigate through all changes made in the whiteboard since the creation of the chat room.
* When someone types a new chat message, they can also select and point to a rectangular area in the whiteboard. When that message appears in the chat as the last posting, a bold line appears connecting the text to the area of the drawing (see Figure 1).

In the Spring of 2005 and 2006, we conducted a series of pilot studies using ConcertChat. In each study we formed five virtual math teams, each containing about four middle-school students selected by volunteer teachers at different schools across the USA or abroad. The teams engaged in online math discussions for four hour-long sessions over a two-week period. They were given a brief description of an open-ended mathematical situation and were encouraged to explore this world, create their own questions about it, and work on those questions that they found interesting. For example, the teams participating in the 2005 study (and whose work we will use to illustrate our observations about collective creativity) worked in exploring a non-Euclidian world where the concept of distance between two points in space had to be redefined. The initial task as presented to the students is displayed in Figure 2.



Pretend you live in a world where you can only travel on the lines of the grid. You can't cut across a block on the diagonal, for instance. Your group has gotten together to figure out the math of this place. For example, what is a math question you might ask that involves these two points?

Figure 2.Grid-world task

The observations that we will present in the following sections come from our qualitative analysis of resultant interaction logs. We will present these reflections starting at the micro-level of collaborative creative work and expanding towards more global interactional processes across collectivities and time spans.

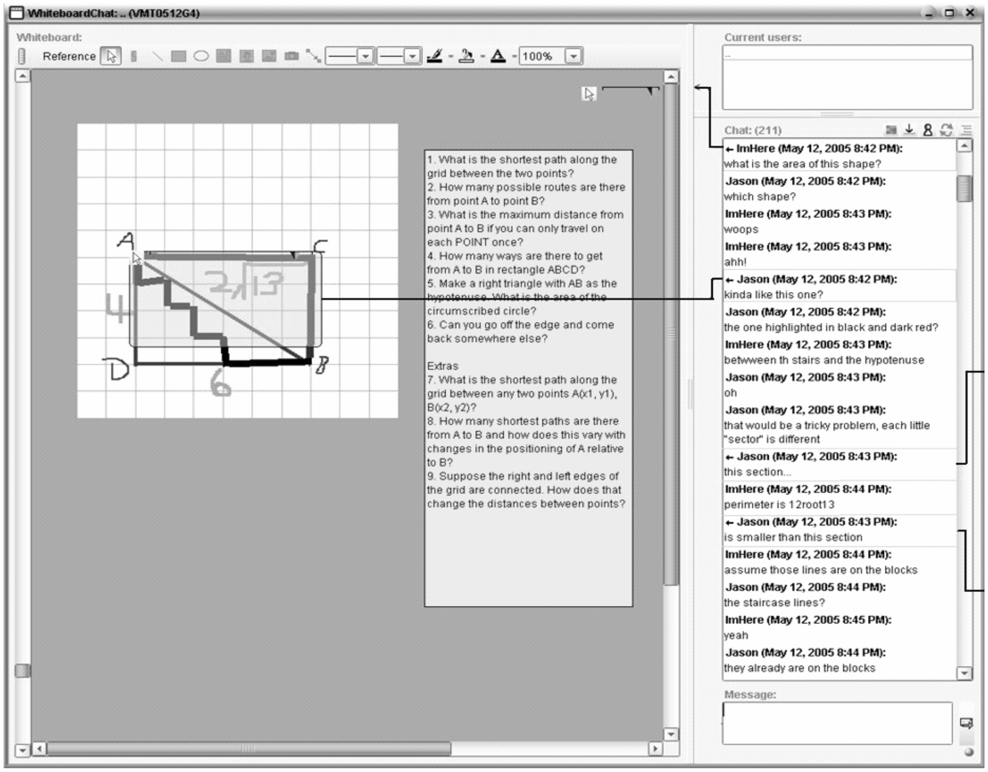


Figure 1. VMT/ConcertChat collaboration environment

REFERENCING AND INDEXICALITY

Indexicality, the referencing or symbolic pointing achieved through language and other means, is one of the unique aspects of group creativity which Sawyer [5] has described in his analysis of creative collaboration in music and theater groups. The role of indexicality is that of joining—in elaboration, contrast, reframing, etc.—the individual elements that the participants of a collectivity produce and reuse as part of their creative work. From this perspective, it is through a complex "configuration of indexicals" that the creative product is conceived to emerge through synchronous interactions. In our analysis of virtual math teams, we have been able to observe this primordial level of synchronous creative work promoted and supported by the online environment and its explicit referencing tools. Below, we describe an instance of such referencing work embedded in the collaborative mathematical work of one of the teams analyzed and offered as an initial and fundamental mechanism of creative work.

The chat log excerpt visible in Figure 1 is reproduced in Figure 3 (with line numbers added for referencing in this paper). In this interactional sequence, two team members discuss parts of a drawing that has already been constructed in the shared whiteboard. The students had created the drawing as part of discussions about shortest paths between points A and B in a grid-world were you can only travel along the lines of the grid (see Figure 2). In particular, a red triangle, ABD, was drawn with sides of length 4, 6 and 2√13. A thick black staircase line was drawn as a path on the grid from A to B. In this excerpt, the students propose a math problem involving this drawing.

1 ImH: what is the area of this shape? [REF TO WB]
2 Jas: which shape?
3 ImH: woops
4 ImH: ahh!
5 Jas: kinda like this one? [REF TO WB]
6 Jas: the one highlighted in black and dark red?
7 ImH: between th stairs and the hypotenuse
8 Jas: oh
9 Jas: that would be a tricky problem, each little "sector" is different
10 Jas: this section [REF TO WB]]
11 ImH: perimeter is 12root3
12 Jas: is smaller than this section [REF TO WB]
13 ImH: assume those lines are on the blocks
14 Jas: the staircase lines?
15 ImH: yea
16 Jas: they already are on the blocks

Figure 3. Chat log. Line numbers added; names anonymized. Graphical references to the whiteboard indicated by [REF TO WB].

The message in line 1 of the chat excerpt (see Figure 3) proposes a mathematical question for the group to consider: "What is the area of this shape?" This is accompanied by a graphical reference to the whiteboard. The reference does not indicate a specific area—apparently ImH did not completely succeed in using this new referencing tool. Line 2 raises the question, "Which shape?" pointing out the incompleteness of the previous message's reference.

Lines 5 and 6 offer a repair of line 1's problem. First, line 5 roughs in the area that may have been intended by the incomplete reference. It includes a complete graphical reference that points to a rectangular area that includes most of the upper area of rectangle ACBD in the drawing. The graphical referencing tool only allows the selection of rectangular areas, so line 5 cannot precisely specify a more complicated shape. The text in line 5 ("kinda like this one?") not only acknowledges the approximate nature of its own referencing, but also acknowledges that it may not be a proper repair of line and accordingly requests confirmation from the author of line 1. At the same time, the *like* reflects that this act of referencing is providing a model of what line 1 could have done.

Line 5 is accompanied by line 6, which provides a textual reference or specification for the same area that line 5 pointed to: the one highlighted in black (the staircase line) and dark red (lines AC and CB). The inexact nature of the graphical reference required that it be supplemented by this more precise textual reference. Note how the sequence of indexical attempts in lines 1, 2, 5 and 6 successively focuses shared attention on a more and more well-defined geometric object. This is an interactive achievement of the group (the interaction between ImH and Jas, observed by others and situated among the math objects co-constructed by all).

Lines 5 and 6 were presented as questions calling for confirmation by ImH. Clarification follows in line 7 from ImH: "between the stairs and the hypotenuse." Line 8's "Oh" signals a shift in the understanding of the evolving reference. Now that a complete reference has been co-constructed to a math object that is well enough specified for the practical purposes of carrying on the chat, Jas continues the problem-solving activity by raising an issue that must first be dealt with. Line 9 says that calculating the area now under consideration is tricky. The tricky part is that the area includes certain little "sectors" whose shapes and areas are non-standard. Line 9 textually references "each little 'sector'." *Little* refers to sub-parts of the target area. *Each* indicates that there are several such sub-parts and *sector*, put in scare quotes, is proposed as a name/description of these hard-to-refer-to sub-parts.

Lines 10 through 16 illustrate the kind of highly interactive work in which groups engage when creating and defining their problem space. Beyond simply clarifying an ambiguity in their vocabulary, this interaction represents the contingent and ongoing sense making that leads to the emergence of a fully meaningful math object that the group has created, started to specify and is about to start investigating.

In this example, the group has creatively produced a new mathematical object: a geometric area with interesting features that the group can explore and discuss. The ability of group members to discuss the new object relies on their establishment of a *configuration of indexicals* in terms of which features of the object ("this shape", "the stairs", "those lines") can be referenced. The intersubjective being-there-together in a chat is structured as a world of future possible activities with shared meaningful objects within this referential network. The possibilities for collaborative action are made available by the social, pedagogical and technical context of the VMT environment, but the group must creatively enact this by co-constructing a shared system of indexicality (its Heideggerian world of being-with, the situation, activity structure, network of relevant significance). The group creativity thereby consists in its establishment of the conditions and preconditions of its ability to engage in shared meaning making [7].

Next, we expand this synchronic characterization of the role of interactional referencing and indexicals to consider diachronic aspects of collective remembering and its role in creative work and knowledge building.

COLLECTIVE REMEMBERING

The virtual teams involved in our studies demonstrated across its sessions a variety of methods for producing and managing relevant resources for their mathematical work. In each session they used the chat conversation and the shared whiteboard extensively to achieve this. In the previous section we analyzed how the chat conversation and the resources on the whiteboard where used to establish a new math object and begin its exploration. These textual and graphical resources and their co-constructed meaning allowed teams to create visualizations of strategies and ideas, to contrast several different representations of a problem situation, to coordinate different problem-solving paths among different team members, and to reconstruct collectively past work so that it can be continued in the present moment. We turn our attention now to this last aspect, which seems particularly interesting when considering the relationship between single-episode interactions (synchronic) and longer sequences of interaction (diachronic).

As an example, in the last session of one of the teams studied, the facilitator produces a summary of the teams' prior work and suggests that they continue from that point. However, the team has some new members and others who had missed the previous sessions, so this recommencement of the prior work was problematic. One of the participants who attended the last session attempts to remember what they were doing, and by doing so engages the group in the collective remembering of that prior work as can be seen in the following chat log (Figure 4).

121 MFmod: I think that the above section I wrote is where the group last was
122 MFmod: yes?
123 drago: well
124 gdog: i dont remember that
125 drago: actually, my internet connection broke on Tuesday
126 drago: so I wasn't here
127 MFmod: so maybe that is not the best place to pick up
128 estrickmcnizzle: i wasnt able to be here on tuesday either
129 gdog: how bout u meets
130 meets: uh...
131 meets: where'd we meet off....
132 meets: i remember
133 gdog: i was in ur group
134 meets: that we were trying to look for a pattern
135 gdog: but i didn't quite understand it
136 gdog: can u explain it to us again meets
137 meets: with the square, the 2by 2 square, and the 3by2 rectangle
138 meets: sure...
139 meets: so basically...
140 gdog: o yea
141 gdog: i sort of remember
142 meets: we want a formula for the distance between poitns A and B
143 drago: yes...
144 meets: ill amke the points
145 MFmod: since some folks don't remember and weren't here why don't you pick up with this idea and work on it a bit
146 meets: okay
147 meets: so there are those poitns A and B
148 meets: (that's a 3by2 rectangle
149 meets: we first had a unit square
150 meets: and we know that there are only 2 possible paths......

Figure 4. Chat excerpt from session 4 of Team 5.

One of the things that are remarkable about the way this interaction unfolds is the fact that although it might appear as if it is Meets who remembered what they were doing last time, the actual activity of remembering unfolds as a collective engagement in which different team members participate dynamically. In fact, later in this sequence there is a point where Meets remembers the fact that they had discovered that there are 6 different shortest paths between the corners of a 2-by-2 grid but he reports that he can only "see" four at the moment. Even though Drago did not participate in the original work leading to that finding, he was able to see the six paths when Meets presented the 2-by-2 grid on the whiteboard and proceeded to invent a method of labeling each point of the grid with a letter so that one can name each path and help others see it (e.g., "from B to D there is BAD, BCD …"). After this, Meets was able to see again why it is that there are six paths in that small grid and together with Drago, they proceeded to investigate, in parallel, the cases of a 3-by-3 and a 4-by-4 grid using the method just created. The result can be seen in Figure 4.

Despite the fact that Figure 5 is a restrictively static representation of the team's use of the whiteboard, it allows us to illustrate some unique aspects of this remarkable creative organization of their collective activity. First, we see again the crucial role of indexicals and referencing activity in the collective construction of the mathematical ideas of the team (e.g., through the use of labels, the witnessing of actions on the whiteboard, and the coordination of parallel activity).

The use of the whiteboard represents an interesting way of making visible the procedural reasoning behind a concept (e.g., shortest path). The fact that a newcomer can use the persistent history of the whiteboard to re-trace the team's reasoning seems to suggest a possible strategy towards preserving complex results of problem-solving activities. However, the actual meaning of these artifacts is highly situated in the doings of the co-participants, a fact that challenges the ease of their reuse despite the availability of detailed records such as those provided by the whiteboard history.

Despite these technical limitations, we could view the artifacts created by this team as "bridging" objects which, in addition to being a representation of the teams' moment-to-moment joint reasoning, could also serve for their own future work and for other members of the VMT online community. These particular objects are constructed *in situ* as a complex mix of resources that "bridge" different points in their own problem-solving and, potentially, those of others. As can be seen in Figure 4, the two team members combined the depiction of the cases being considered, the labeling and procedural reasoning involved in identifying each path, a summary of results for each case (i.e., the list of paths expressed with letter sequences) and a general summary table of the combined results of both cases. The structure of these artifacts represents the creative work of the team but also documents the procedural aspects of such interactions in a way that can be read retrospectively to document the past, or "projectively" to open up new possible next activities.

Despite the fact that the problem-solving artifacts and conversations are the result of the moment-by-moment interactions of a set of participants and, as such, require a significant effort for others to reconstruct their situated

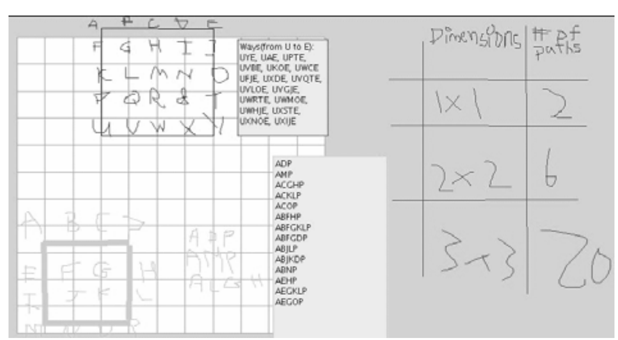


Figure 5. Shared whiteboard of Team 5, session 4.

meaning, they can serve as one of the resources used to "bridge" problem-solving episodes, collectivities or even conceptual perspectives. Here, we use the term "bridging" to characterize interactional phenomena that cross over the boundaries of time, activities, collectivities, or perspectives as relevant to the participants themselves. Bridging thereby might tie events at the local small-group unit of analysis to interactions at larger units of analysis (e.g., the community). Bridging may reveal linkages among group meaning-making efforts, across collectivities or events in time, diachronically.

Next, we will present an instance of this type of interactional phenomena that is closely related to these diachronic aspects of group creativity.

BRIDGING THE PAST: PROJECTING TO OTHERS

So far, we have explored two aspects of the creative dimension of the work that virtual teams engaged in as part of our studies. We have seen that the use of referencing and the configuration of indexicals are necessary elements of the "synchronic" interactions of these teams but that they can also play a central role in processes such as those that we have labeled "group remembering." As a matter of fact, we can see the central role of referencing as that of overcoming boundaries in joint activity. Deictic expressions such as "*the one highlighted in black and dark red*" are sometimes used to overcome gaps in perception, while temporal deictic terms (e.g., last time, next time, etc.) can be used as part of the process of doing memory work and engaging with prior activities. In fact, in the contexts of extended sequences of collaborative knowledge work, where the membership of a team might change over time and where the trajectory of problem solving needs to be sustained over time, overcoming such boundaries might be especially challenging. We define this type of purposeful overcoming of boundaries through interaction as "bridging" work and turn our attention now to interactional strategies that virtual teams utilized to engage in these kinds of activity.

In order to investigate the dynamics of bridging we designed our studies so that a number of teams worked on the same task for a series of four sequential sessions. In our 2005 study, teams used a different ConcertChat room for each session and had no direct access to archives of their previous interactions. Despite this apparent limitation, they demonstrated several strategies to reconstruct their sense of history and to establish the continuity of their interactions.

The following excerpt represents an example of this, recorded during the second session of one of the participating teams, where two new team members, Gdo and Mathwiz, are joining the dyad that had collaborated in the first session, Drago and Estrickm.

302	gdo:	now lets work on our prob [Points to Whiteboard]
303	drago:	last time, me and estrickm came up
304	drago:	that
305	gdo:	……
306	drago:	you always have to move a certain amount to the left/right and a certain amount to the up/down
307	gdo:	what?
308	drago:	for the shortest path
309	drago:	see
310	drago:	since the problem last time
311	drago:	stated that you couldn't move diagonally or through squares
312	drago:	and that you had to stay on the grid
313	*gdo leaves the room*	
314	mathwiz:	would you want to keep as close to the hypotenuse as possible? or does it actually work against you in this case?
315	drago:	any way you go from point a to b
316	*gdo joins the room*	
317	drago:	is the same length as long as you take short routes
318	gdo:	opps
319	gdo:	internet problem
320	gdo:	internet problem
321	drago:	you always have to go the same ammount right, and the same ammount down

Figure 6. Excerpt from session two of Team 3.

This excerpt illustrates how the participants of this interaction chose to start a current collaborative task. Understandably, when teams sustain their collaborative work over multiple individual sessions, the task of recommencing knowledge-building activity becomes an issue that participants have to address. We can see that Drago's posting in line 303 ("last time, me and estrickm came up") stands as an uptake of the proposal for collective action put forward by Gdo in line 302 ("now lets work on our prob"). By contrasting "last time" with Gdo's "now", Drago attempts to establish a particular kind of episodic continuity or "relevant history" of the team (unavailable elsewhere in the collaboration environment), while at the same time categorizing Gdo and Mathwiz as newcomers and opening up the possibility of orienting to them as such.

Drago's posting in line 306 ("you always have to move a certain amount to the left/right and a certain amount to the up/down") completes the initiation of his bridging move, not only in a temporal sense but also as far as the problem-solving trajectory, since a prior discovery ("you always have to go…") is presented as relevant to re-start the problem-solving task of the team.

Naturally, it is not a simple task for the new members of the team to fully understand the meaning of Drago's summary but they engage in doing the situated work of making sense of it and using it. In fact, the reply posted in line 307 by Gdo ("what?") and the subsequent elaboration attempted by Drago suggest that the posting in 306 was taken as a problematic response to the proposal to initiate the problem-solving work. Perhaps additional work was necessary for line 306 to be fully sensible for the team—in other words, for Drago to successfully bridge prior work into the present. In the subsequent lines we can see the beginnings of an instance of the kind of interactional work that seems to be necessary for the team to engage with the reported past that Drago is presenting.

Even without a thorough understanding of the mathematical task at stake, one can see that Drago elaborates on his initial posting by providing additional problem information (308, "for the shortest path") and adding further references to elements of the past problem-solving activity (310-312, "since the problem last time stated that you couldn't…"). Furthermore, Mathwiz's posting in line 314 ("would you want to keep as close to the hypotenuse as possible? or does it actually work against you in this case?") engages with the bridging activity opened up by Drago in a particular way. Mathwiz seems to suggest a specific way of clarifying Drago's presentation of how the grid-world works while at the same time doing the interesting work of positioning Drago as the one to assess this suggestion (i.e., testing whether this case "works against you"). This short sequence signals only the beginnings of the type of interactional work necessary to fully bridge prior knowledge-work into present joint activity, and yet it is sufficient to provide significant evidence of the nuanced aspects of this type of activity.

This scenario of change in membership and continuity of task work is a clear example of the need for persistent supports in collaboration environments. However, simply providing Drago, Mathwiz, Gdo, and the rest of the team direct access to raw recordings of the team's prior sessions would probably be an inefficient solution. Even if the team was reusing the same persistent room for each session, the interactional ground that is so essential to the meaning of the chat and whiteboard records is not easily recovered and certainly not easily transferred or summarized. On the other hand, the successful bridging achieved by this team can be partially linked to the sophistication of their problem-solving work in the last session, especially when compared with other teams, which did not establish such a strong sense of continuity of their problem-solving trajectory.

At the moment, our analysis suggests that these attempts to establish continuity in collaborative problem solving involve: (a) the recognition and use of discontinuities or boundaries as resources for interaction, (b) changes in the participants' relative alignment toward each other as members of a collectivity, and (c) the use of particular orientations towards specific knowledge resources (e.g., the problem statement, prior findings, what someone professes to know or remember, etc). Bridging activity defines the interactional phenomena that cross over the boundaries of time, activities, collectivities, or perspectives. It defines a set of methods through which participants deal with the discontinuities relevant to their joint activity.

As a result of our initial findings, we designed in our 2006 study a setting in which "bridging" could be investigated more conspicuously. We arranged for the teams to reuse the same persistent chat rooms so that they had direct access to the entire history of their conversations and their manipulations on the whiteboard across the four sessions. In addition, mentors provided explicit feedback by leaving a note on the whiteboard of each team's room in between sessions. Finally, we also provided a wiki space to help the teams share their explorations (e.g., formulae found, new problems suggested by their work, etc.). We have just begun to analyze the results of this study in which we hope to better analyze the interrelationship between synchronic and diachronic interactions. Below, we provide some of our initial observations.

The reuse of the same room by teams that were much more stable in their membership over time proved effective in stimulating the constructive establishment of continuity in the creative and problem-solving activity of the teams. The feedback provided by the external mentors, however, was in several cases problematic since it re-framed past experiences in ways that seemed unfamiliar or curious to the participants themselves. In addition, the use of the wiki space provided us with a set of interesting examples of new "bridging" activity being conducted by the teams.

Through the wiki postings, teams working on the same or similar task were made aware of the parallel work being conducted by their counterparts. In several cases, the wiki acted as an effective third workspace from which materials generated by one team could be used, validated, and advanced by other teams. The authors of the postings also used them to sustain their own problem-solving across the four sessions. Postings and trajectories of use in the wiki also showed a structure that was very different from the conversational and interactional style of the chat room artifacts. Some postings were purposively vague and others resembled highly elaborate summaries of the teams' findings. In a few cases, postings included a narrative structure abstracted from the chat sessions (e.g., "So in session 3, our team tried to understand Team C's formula …").

In one instance, the wiki presented evidence of cross-team asynchronous interactions: Team B found a new problem generated by another team in addition to a possible solution. Team B proceeded to work on the problem, found a mistake in the solution formula originally reported, and proceeded to re-work the original solution and post the corrected result back to the wiki.

These preliminary findings seem to suggest both the potential of explicit bridging spaces to promote continuity and sustain creativity in problem-solving work, especially in the context of an online community formed of multiple virtual teams with overlapping interests and activities. Naturally, the availability of bridging resources like the wiki does not by itself shape the ways participants interact over time. In addition, the fact that certain social practices were promoted (e.g. reporting to others, imitating, reflecting, etc.), also influenced the way these resources were used.

CONCLUSIONS

When one looks seriously at the interactional activity that goes into the formulation and communication of creative ideas, one sees the limitations of traditional, ahistorical views of creativity. Creativity involves extended efforts to articulate, critically consider, and communicate notions that are not already part of the taken-for-granted life-world. Even when accomplished largely by an individual person, this generally involves sequences of trials with physical and/or textual artifacts [8]. Such internal monologue generally incorporates skills learned from dialogues in dyads or small groups [9]. The study of creative accomplishments in groups, where their interactions can be made visible for analysis, may provide insights about individual as well as group creativity.

Several models have been proposed to characterize features of individual creativity, such as the ability to concentrate efforts for long periods of time, to use "productive forgetting" when warranted, and to break “cognitive set” [1]. We expected that these individual skills could also play a role that is distinctively critical in the context of long-term collective knowledge building. In our analysis, we have seen that in fact, some of these individual accomplishments can be characterized as fundamentally social and interactional. The virtual math teams we have studied rely for their creative work on basic interactional mechanisms such as referencing, group remembering and the bridging of discontinuities.

Recent models of group creativity [5] argue that collective creative work has to be understood as the synergy between synchronic interactions (i.e. parallel and simultaneous) and diachronic exchanges (i.e. interaction over long time spans, and mediated by ostensible products). Our analysis validates this model in the context of the creative and problem-solving work of virtual math teams and starts to provide an interactional description of some of the processes underlying these two types of interaction.

Because continuity in itself is important to the success of virtual teams, we have observed how participants develop a series of interactional methods to co-construct mathematical knowledge within single collaborative episodes as well as over time. The co-configuration of indexicals and the use of referencing methods allowed a collectivity to create new mathematical objects that gained their meaning through interaction and opened up new possibilities for next possible steps within a synchronous episode. Collective remembering and the bridging of interactional discontinuities allowed the teams to expand the referential horizon so that the objects created by themselves or by other teams could be expanded, reconsidered, or challenged. These methods allowed the teams to evolve a sense of collectivity engaged in building new knowledge and made it possible for them to interlink their collaborative interactions with those of other teams.

Just as we have argued that cognition should not be conceptualized solely or even predominantly as a fundamentally individual phenomenon [6], so we claim that creativity is often rooted in social interaction and that innovative creations should often be attributed to collectivities as a feature of their group cognition.

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