Bridging: Interactional mechanisms used by online groups to sustain knowledge building over time

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Abstract: In naturalistic settings, the sustained knowledge-building and collaborative learning of small virtual groups and online learning communities require that co-participants overcome a wide range of gaps in their interactions. We present an analysis of sequences of online collaborative problem-solving sessions held by teams of non-collocated mathematics students as part of the Virtual Math Teams (VMT) online community. Our analysis is aimed at understanding how teams of participants in VMT "bridge" the apparent discontinuity of their interactions (e.g. multiple collaborative sessions, teams, tasks, and perspectives) and exploring the role that such "bridging activity" plays in their knowledge building over time. In particular, we examine how bridging allows participants to construct and maintain a joint problem space over time and to manage participation based on it. In addition, we reflect on how these insights might inform the design of appropriate computational supports for long-term collaborative knowledge building.

Introduction

The construction and maintenance of a joint problem space—the intersubjective space of interaction emerging from the active engagement of collectivities in problem solving—represents one of the central challenges of effective collaborative knowledge building and learning (Roschelle & Teasley, 1995; Stahl, 2006b; Suthers, 2005). Furthermore, several CSCL studies have suggested that it is the interactional manner in which this intersubjective problem space is enacted that determines the success of the collaborative learning experience (Barron, 2003; Dillenbourg et al., 1995) (Chi, 2000; Hausmann et al., 2004; Koschmann et al., 2005; Wegerif, 2006). The challenge of maintaining a joint problem space is magnified when, as in many naturalistic settings, joint activity is dispersed over time (e.g. multi-session problem-solving engagements, long-term projects, etc.) and distributed across multiple collectivities (e.g. multiple teams, task forces, communities, etc.). As a result of these gaps, sustained collaborative learning in small virtual groups and online communities of learners requires that co-participants "bridge" multiple elements of their interactions continuously as they interact over time— a non trivial and possibly very consequential undertaking.

The discontinuity of the interactional space and its relationship to collective action has been a subject of study in multiple fields. The theory of knowledge building(Scardamalia & Bereiter, 1996), for instance, explores the progressive and communal nature of collective-knowledge development. The gaps that arise among events, perspectives, and people have also been an area of investigation in the study of individual and group creativity (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 the research interest in this crucial topic, most studies have concentrated on characterizing the visible outcomes of groups and communities overcoming such discontinuities. For instance, the existence of "information bridgers" in group-to-group collaboration (Mark et al., 2003), the use of boundary objects in interdisciplinary collaboration (Star, 1989), and the emergence of "shifting epistemologies" (Bielaczyc & Blake, 2006) and an orientation to knowledge advancement in knowledge-building communities (Scardamalia, 2002). It remains as an open challenge to characterize the interactional aspects of how participants overcome such discontinuities and sustain their knowledge building through their joint participation over time. Here, we concentrate on this type of "bridging activity."

The notion of *bridging*, as a relevant phenomena of study, has emerged in several areas of research. From the perspective of pragmatics, bridging has been studied mostly as an inferential aspect of the practical use of language. Clarck (H. Clark) coined the term when referring to certain types of implicature proceses (e.g., anaphora) where new information is linked to already given information as part of the collaborative process of comprehension that relates speakers and listeners. Clark's model of grounding (Herbert Clark & Brennan, 1991) is widely used to explain how participants sustain mutual understanding in an interaction but, to our knowledge, his concept of bridging has never been used to attempt to investigate how continuity of communication is established beyond a single interaction. Bridging has also been used in instructional science as a mechanism to scaffold conceptual change. Here, the instructor attempts to use the indigenous or alternative conceptions of a phenomena held by learners and guides them in using comparative and analogical reasoning so that learners "bridge" or reach a target conceptualization of the phenomena (e.g., (Brown & Clement, 1989). In a different context, bridging has also been used in the study of social networks and the theory of social capital to distinguish the two types of social capital (Putnam, 2002). Bonding social capital is theorized to be produced through social networks between homogeneous groups of people, while bridging social capital emerges thanks to the linkages between socially heterogeneous groups. Bridging social capital is expected to produce the highest benefit for communities, societies, and individuals. In all cases, the dynamics of "bridging" as an interactional phenomena remain to be more thoroughly described so that the mechanisms through which bridging is achieved (communicatively, conceptually or socially) and their role in the continuity of knowledge-building collectivities can be further understood.

From our perspective, bridging defines interactional phenomena that cross over the boundaries of time, activities, collectivities, or perspectives. This type of activity is achieved through a set of methods through which participants deal with the discontinuities relevant to their collective engagement. Bridging thereby might tie events at the local small-group unit of analysis to interactions at larger units of analysis (e.g. online communities, multi-team collectivities, etc.) as well as between the individual and small-group levels. Studying bridging may reveal linkages among group meaning-making efforts across collectivities or interactional episodes over time. In addition to the need to understand the interactional nature of bridging, there is also a crucial need to learn more about which aspects of the computer tools provided to support collaborative knowledge building attend to these types of activities, and how such designs might be enacted in particular contexts. This paper investigates the nature of bridging activity in small groups and the ways in which bridging mechanisms contribute to sustaining the collaborative knowledge building of small groups in an online learning community.

Bridging in the Virtual Math Teams community: A case study

The Math Forum is an online math community, active since 1992. It promotes technology-mediated interactions among teachers of mathematics, students, mathematicians, staff members and other interested parties interested in learning, teaching, and doing mathematics. As the Math Forum community continues to evolve, the development of new forms of interaction becomes increasingly essential for sustaining and enriching the mechanisms of community participation available(Renninger & Shumar, 2002). 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 (Stahl, 2005). 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. VMT implements a multidisciplinary approach to research and development that integrates the quantitative modeling of students' online interactions, ethnographic and conversation analytical studies of collaborative problem solving, and an iterative process of software design.

Central to the VMT research program are the investigation of the nature and dynamics of group cognition (Stahl, 2006a) as well as the design of effective technological supports for quasi-synchronous small-group interactions, and its linkages with distributed, asynchronous interactions at the level of the online community. During the Spring of 2005, we conducted a pilot experiment to explore issues of continuity and the sustainability of collaborative knowledge building over time. In this design experiment, five virtual teams were formed with about four non-collocated upper middle-school and high-school students selected by volunteer teachers at different schools across the USA. The teams engaged in online math discussions for four hour-long sessions over a two-week period. They used the ConcertChat virtual room environment (Wessner et al., 2006) with new rooms provided for each one of the sessions so that participants did not have direct access to the persistent records of the interactions. In the first session, the teams were given a brief description of a non-traditional geometry environment: a grid-world where one could only move along the lines of a grid (Krause, 1986). The students were encouraged to generate and pursue their own questions about the grid-world, such as questions about the shortest distance between two points in this world. In subsequent sessions, the teams were given feedback on their prior work and the work of other teams and were encouraged to decide on which problems to pursue. The chats were facilitated by a member of our research project team. In each session, the facilitator welcomed students to the chat, introduced the task, and provided technical assistance regarding the special features of the collaboration environment. The facilitator did not actively participate in the team's mathematical collaboration.

Figure 1 depicts the trajectory of participation and team composition of team five. Participation was voluntary in order to better resemble naturalistic interactions and this factor may have motivated the changes in team membership and variations in attendance recorded in our dataset. Two of the teams were highly stable (with 2 or more participants attending at least 3 of the 4 sessions), one was highly unstable and the others had mixed patterns of attendance. Team five is particularly interesting for our purposes given the fact that for each intermediate session (excluding the first and last), there is at least one participant from the previous session and one newcomer joining the team (in two cases the newcomer was a transfer from another team as signal by the dotted lines in Figure 1). Although we will use this team in particular to illustrate our findings, even stable teams exhibited similar interactional processes.

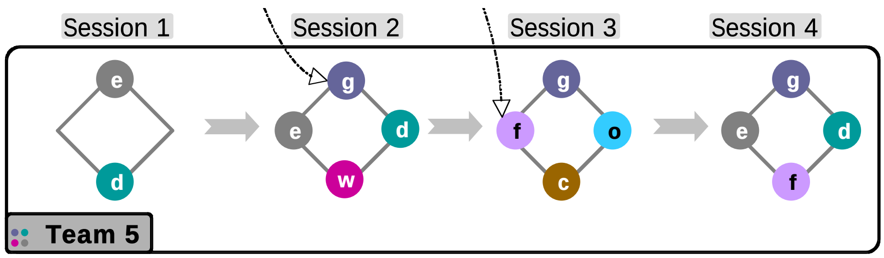
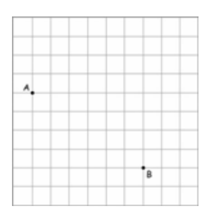


Figure 1. Team five's composition over the four problem-solving sessions.

The analysis presented in the following sections is aimed at understanding how teams of participants in the VMT online community "bridge" the apparent discontinuity of their interactions (e.g. multiple collaborative sessions, teams and tasks) and exploring the role that such bridging activity plays in their knowledge building over time. We employ the approach of ethnomethodology (Garfinkel, 1967) to examine the sequences of events by using recordings and artifacts from the team sessions in order to describe the ways in which participants established their knowledge-building interactions over time. Ethnomethodology is a phenomenological approach to qualitative sociology which attempts to describe the methods that members of a culture use to accomplish what they do, such as carrying on conversations (Sacks, 1992), using information systems (Button, 1993; Button & Dourish, 1996) (Suchman, 1987) or doing mathematics (Livingston, 1986). 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 current purposes, we examined each of the 18 sessions recorded, paying special attention to the sequential unfolding of the sets of four problem-solving episodes in which each team participated. Constant comparison through different instances of bridging in the entire dataset led to our refinement of the structural elements that define bridging activity.

"… last time, me and estrick came up that …"

It is the second time that team five meets online to work on figuring out the mathematics of the "grid-world," a world where one could only move along the lines of a rectangular grid. In their previous session, a few days ago, *drago* and *estrick* worked on exploring the grid-world and attempted to create a formula for the shortest distance between two points A and B. This time, they are joined by two new team members; *gdo* —who had worked on this problem with another team once before— and *mathwiz* —who is new to the task and to the team—.



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

After the initial greetings and a discussion on what to do in this session, the following exchange takes place via the chat interface available in the virtual meeting environment:

302	gdo:	now lets work on our prob (*Points to Whiteboard*)
303	**drago:**	**last time, me and estrick 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 *(Points to line 314)*
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 *(Points to line 317)*
322	gdo:	ok *(Points to line 314)*

This excerpt illustrates how the participants of this interaction chose to start a current collaborative task. Elements of their collaborative discourse signal to us that they are also engaged in using prior interactions as relevant resources in initiating their current work. Understandably, when teams sustain their collaborative work over multiple individual sessions, this task of recommencing knowledge-building activity becomes an issue that participants have to address. A close examination of this passage—by attending to the ways that the participants demonstrably orient to the interaction moment-by-moment—can help us construct ideas about how some aspects of such "bridging" activity get done and guide us in the process of articulating relevant questions about collaborative knowledge building. Furthermore, what participants do to "bridge" the discontinuity of their interactional episodes might have an impact on the ways collectivities evolve and the methods used to advance the development of group ideas.

One way in which we can approach our analysis of this sequence of postings is to consider the characteristic question of ethnomethodology-oriented studies: "*why this now?*" In other words, what purpose do these particular textual postings serve at this point of the interaction of this virtual team? How is it that the ways in which *drago* designed and presented his postings (e.g. the way they were segmented in the multiple postings, the way they were positioned after line 302, etc.) indicate their interactional role and their effects? 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*"). The juxtaposition between these two postings indicates to us the beginnings of the collective orientation of the group to the problem-solving task. The contrast of *drago's* "*last time*" with *gdo's* "*now*", seems to constitute a particular kind of episodic continuity or "relevant history" for the team, while at the same time positioning *gdo* and *mathwiz* as newcomers and opening up the possibility for *gdo* and *estrick* to orient to them as such. This initial analysis indicates that bridging work combines both temporal organization and the management of participation as current relevant aspects of the interaction. Continuing our inquiry as this interactional sequence unfolds, we could pursue these observations and investigate how *drago* and the rest of the small group of co-participants orient toward this reported history and how this orientation evolves. In addition, we might be able to inquire about how bridging elements influence and are influenced by the way the collaborative knowledge-building task is being approached by this team.

"*would you want to keep as close to the hypotenuse as possible?"*

Turning now to the unfolding of the sequence which begins with *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*") we can explore further the relationship between bridging work and knowledge building. The posting itself has the structure of a rule-like statement which typically represents a generalized understanding about a set of particular cases. However, as we pointed out earlier, this generalization is the result of exploratory work done previously by *gdo* and *estrick* and not directly shared by the other two participants. 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 problematical 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 the collectivity to successfully bridge prior work into the present, additional collaborative engagement seemed necessary. In the subsequent lines we can see the beginnings of an instance of the kind of interactional work that seems to be required for the team to engage with the reported past that *drago* has presented. 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…"). In this way, *drago* continues to use past resources to organize a potential present for the problem-solving task of the team and in doing so, attempts to project that past history on the current interaction. We will come back to further inquire about line 306 after exploring in more detail its uptake.

M*athwiz*'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 unique way. *Mathwiz*'s posting suggests an active way of orienting towards *drago*'s presentation of how the grid-world had been found to work, while at the same time re-positioning *drago* as the one who is to assess this suggestion (i.e. testing whether this case "*works against you*"). In this way, *mathwiz*' posting seems to actively situate *drago*'s narrative of the past by ratifying its relevance for their current problem solving and assessing its practical comprehensibility. The presentation of a "test case" by *mathwiz* follows *gdo*'s presentation of a general rule in a way that signals the sustainability of the team's knowledge building. It is precisely because of this type of engagement that we do not see this interaction simply as a peer explanation nor do we label the relationship between prior members of the team and newcomers as an entirely asymmetrical one of explainer–audience. 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 us with significant evidence of the nuanced aspects of this type of activity. Other researchers have pointed out that the management of attention and knowledge proposals as well as the roles of the co-participants in establishing join attention are consequential for the collective achievements of small groups (Barron, 2000) (Stahl, 2006b). Here we see how these interactional processes are especially important for the establishment of continuity of knowledge building over time.

"…it's like, you can't walk in water, and the lines are dry lines …"

One further aspect of this interactional sequence is worth exploring. The excerpt below follows the one from session two presented earlier. It allows us to observe how this collectivity dealt with some of the challenges in the uptake of *drago*'s presentation of the past finding about short distances in the grid-world.

323	drago:	ok....
324	drago:	so
325	gdo:	square root of 45
326	mathwiz:	but you have to move on the grid lines, right?
327	gdo:	3^2+6^2=c^2 right?
328	drago:	no
329	drago:	you can't go diagonal
330	gdo:	ok
331	drago:	the problem before said so, but you weren't here
332	gdo:	so the hypotenuse is not square root of 45?
333	gdo:	i was on team 2
334	drago:	I mean
335	drago:	it is
336	gdo:	but moved to team 5
337	gdo:	since u guys didn't have enough people
338	drago:	but, we can't move diagonally since that would be cutting through the grid
339	**mathwiz:**	**the hypotenuse is fine, but for the problem, you have to go on the grid lines**
340	gdo:	ok
341	drago:	so
342	**mathwiz:**	**it's like, you can't walk in water, and the lines are dry lines**
323	drago:	ok....

Despite *drago*'s orientation to the recommencement of the prior work that he and *estrick* did before (and to a narrator-explainer framework of participation), *gdo* departs partially from that orientation in line 325 by making a solution proposal for the shortest path between the points they are currently examining ("*square root of 45*"). Consequently, the sequence of postings from 325 to 330 seems to indicate a local engagement with the problem as the present matter and no longer as a bridging move to re-use prior findings. However, in the sequence starting at line 331 *drago* uses, once again, elements of prior interactions ("the problem before said so but you weren't here") to address what appears to be a problem in *gdo*'s understanding (i.e. that you can't go on the diagonal). This alternation between present and bridged resources for problem solving indicates a dynamic engagement by the group with its distributed history and its current problem-solving activity.

Also particularly interesting in this sequence are *mathwiz*'s postings in lines 339 and 342: "*the hypotenuse is fine, but for the problem, you have to go on the grid lines…it's like, you can't walk in water, and the lines are dry lines.*" These postings seem to do the unique work of ratifying *gdo*'s use of the hypotenuse —as well as his participation in the task— while at the same time offering him a new "rule" or perspective to manipulate the grid. It seems to us that this interactional move bears resemblance with the types of activities we have analyzed before and deserves the label of bridging work. By offering this new perspective on how to imagine and manipulate the grid, *mathwiz* identifies a boundary between different perspectives or forms of understanding (i.e. being able to use diagonals or not in the grid world) and goes beyond simply refuting it by offering a link or bridge between the two. This bridging of perspectives can naturally occur between different problem-solving episodes or collectivities but here we see it happening within the flow of a team's interactions. With the dynamic changes in team membership that characterize naturalistic environments and the diversity of points of view among individuals and teams that are typical of online communities, sustained problem-solving work seems to require that co-participants also engage in this type of bridging of perspectives. Additional research is necessary to explore the range of resources produced by individuals and groups to overcome these types of perspectival boundaries which emerge as relevant during their interactions and which relate to overcoming challenges of continuity, coordination or affiliation. It is possible that the methods and processes of doing this kind of boundary work could characterize effective collaborative learning interactions, but this remains a notion to be investigated.

So far, we have explored a few instances of bridging activity in the trajectory of a particular virtual math team in our experiment. In doing so, we have offered a preliminary analysis of how the collective engagement with past work is constituted across different interactions or episodes, how changes in the alignment of the participants signal various aspects of the sustained knowledge work of the teams, and how problem-solving perspectives are subject to bridging as well. Furthermore, our analysis seems to suggest that these attempts to establish continuity in collaborative problem solving involve the recognition and use of discontinuities or boundaries as resources for interaction (e.g. temporal or episodic discontinuity), changes in the participants' relative positioning toward each other as a collectivity (e.g. narrators and interactive audience), and also the use of particular orientations towards specific knowledge resources (e.g., the problem statement, prior findings, what someone professes to know or remember, etc.). This initial analysis demonstrates that in interactional contexts where there are continual sequences of discrete problem-solving episodes and where the membership of a team might change over time, sustaining continuity of the team's knowledge work becomes a particular challenge for which teams need to develop particular interactional strategies. In fact, the analysis of other instances of this type of activity could lead us to uncover a range of bridging mechanisms used as part of the teams' engagement in this online learning community.

"I remember that I proved this once but I forgot..."

In addition to following the prospective unfolding of the particular instance of a team's recommencement, we can also investigate retrospectively *drago*'s "bridging posting" (306: "*you always have to move a certain amount to the left/right and a certain amount to the up/down*"). We could do this by analyzing his prior work with *estrick* a few days back and explore the genesis of the reported finding. This approach would allow us to stretch the scope of our analysis not only from one problem-solving episode into another but also from one particular collectivity (*drago-estrick-gdo-mathwiz*) into a different one (the dyad *drago-estrick*). In essence, line 306 in session two appears as a re-statement of something that *drago* and *estrick* discovered in the first session that they held as a team. The following excerpt illustrates how this idea was articulated then:

168	estrick:	well, judging by my calculations, any root that does not go along a diagonal is the same length	
169	drago:	it should be	(Points to line 168)
170	drago:	except if you go some extra long way for no reason	
171	estrick:	haha, precisely	
172	drago:	but why are they the same? I remember that I proved this once but I forgot...	
173	**estrick:**	**because you will alsways have to go down and to the right the same amount of times**	

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174    drago:      oh, seems reasonable      (Points to line 173)
175    drago:      so...any more questions you can think of?
176    estrick:    but i am not sure of the correct proof
177    drago:      well...I guess its because whatever path you take, you will make
                   tiriangles   (Points to line176)
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The relationship between line 173 in this excerpt of session one and line 306 of session two appears significant. On the one hand, the use of the adverb "*always*" in both postings seems to suggest a rule-like statement (or a conjecture) aimed at capturing a constructed understanding about the way the grid-world works (from the participants' perscpective). The fact that the creator of this text changes from *estrickm* in session one to *drago* in session two could be taken as an indicator that this rule is a collaborative understanding achieved by the dyad which is, later on, projected into a new collectivity and a "bridged" problem-solving context. Based on this observation, we could construe the re-statement of prior findings and the change in authorship as indicators of sustainability in the co-construction of knowledge as the history of multiple teams in an online community evolves. Although not entirely conclusive, these two conditions certainly seem to point in that direction despite the fact that in small-group interactions the notion of authorship needs to be analyzed critically. For instance, if line173 is a response to line 172 and proceeds from the flow of the interaction, isn't it really the dyad who should be credited with having produced the original rule about the grid-world? These kinds of interactions point to the need to carefully redefine the notion of authorship as we navigate individuals, small-groups and larger collectivities engaged in knowledge building.

Beyond the apparent changes in authorship, it is interesting to note how *drago*'s text in line 306 of session two, differs from *estrickm*'s original posting from session one. Originally, there was only mention of moving "*down and to the right*," but in *drago*'s restatement, one has to move a certain amount "*to the left/right and a certain amount to the up/down.*" Why has *drago* modified the original rule by adding the "*/up*" and "*left/*" elements? At this point, we need to mention that the environment in which these teams are interacting is much more complex than what is captured by the transcripts we have presented. In addition to the chat interface, a shared whiteboard is available to the participants in the virtual room provided. At the moment in session two when the exchanges that we have presented took place, the whiteboard in this team's meeting room contains the picture in Figure 2. We can see in this snapshot the points that they selected to explore the grid-world and also some elements of how they have graphically presented their reasoning about it. Interestingly, a very similar diagram was used by *estrick* and *drago* in session one, as can be seen in Figure 3. However, in that case the diagram only included two points similar in their arrangement to points A and B in the diagram from session two. The arrangement of points used in session one matches *estrick*'s original rule that "*you will always have to go down and to the right.*" On Figure 2, there are two arrangement of points being considered: The one involving points A and B where the shortest path would be achieved by going *down* and to the *right* and another in which the movement would be *up* and to the right (linking the points labeled with circles). One can then read *drago*'s modification to the original rule as indication that he has adapted it to make it applicable to all arrangements of points based on the cases used by the team in this session.

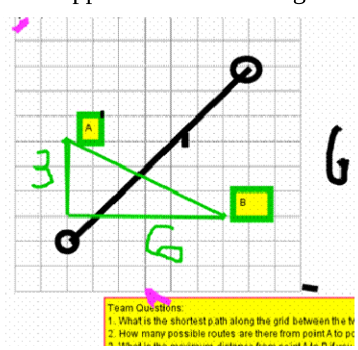

Figure 2. Snapshot of Team 5's whiteboard, Session 2.

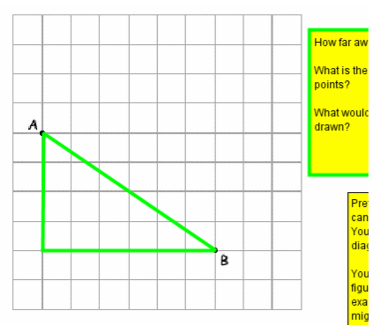

Figure 3. Snapshot of Team 5's whiteboard, Session 1

It is possible that *drago* realized this generalization via further individual work in between team sessions, or that the position on the grid of the points that the team has selected in session two provided the need for the generalization to happen. Whatever the actual motive, *drago* is presenting in session two a modified version of the finding previously constructed suited to the current circumstances. Beyond simply citing prior findings, *drago* has in fact bridged two problem-solving contexts in an attempt to construct continuity To further qualify this observation, we can contrast *drago*'s tentative reasoning for why the rule works presented in line177 of session one (*well...I guess its because whatever path you take, you will make tiriangles*) with the sense of confidence that his presentation conveys in session two. This subtle change could illustrate a change in the strength of his understanding of the grid-world. Observations like these, although requiring further verification through triangulation and further analyses, start to point to critical interactional aspects of how knowledge work is sustained over time and hint towards longitudinal aspects of collaborative learning interactions. Furthermore, they reveal the need to understand how bridging interactions span across the individual and the different collectivities involved in an online community.

Summary and conclusions

The analysis presented in the previous sections has defined bridging activity as the interactional overcoming of certain discontinuities relevant for the small groups engaged in collaborative knowledge building sustained over time. Three main elements appear as the structural components of bridging activity: *temporal references*, *management of participation*, and *knowledge claims*. These three elements provide for the structural relevance of bridging as a set of members' methods to sustain the teams' knowledge building over time. As we have presented it, bridging is not an individual undertaking but the concerted and situated achievement of collectivities.

Although we have used one particular team to guide our analysis, the systematic review of our dataset indicates that this type of bridging activity is highly pervasive. The changes in team membership and the sequential nature of the problem-solving episodes and tasks in our data provided a propitious setting for this type of activity in our experiment. Other factors may trigger bridging work as well. All teams in our experiment exhibited this orientation to continuity in different degrees but those that engaged in bridging work more actively were able to better overcome the instability of their membership and the sustainability of their problem-solving enterprise (as represented by the depth of exploration and number of problems attempted). This preliminary observation points to the consequential aspect of bridging work in long-term collaborative problem solving. Different degrees of success can be inferred across instances of bridging work, an aspect of this type of work that remains to be more fully investigated. Interestingly, bridging was also attempted by moderators when trying to inform teams of other teams' work and provide feedback, but such attempts were often taken normatively by the teams resulting in a framework of participation that appears to be more driven by the authority of the moderators than by the self-directed agency of the team. In other cases, moderator-initiated bridging attempts appeared unsuccessful because the knowledge claims made were not perceived as appropriate by the teams resulting in no direct engagement with the alleged prior work being presented.

Our subsequent work has attempted to use an additional interactional space implemented through a Wiki in order to better support continuity and cross-team knowledge building with preliminary results indicating that such bridging spaces do in fact promote the continuity of knowledge building across teams by engaging them in activities such as exploring, testing, and advancing other teams' ideas as well as projecting their own ideas towards future action. We expect these findings to help expand the scope of analyses of long-term collaborative interactions and enhance our understanding of collaborative knowledge building in naturalistic settings. In fact, in a recently proposed framework to assess the quality of collaborative processes in single-episode encounters (Spada et al., 2005), some of the proposed dimensions (e.g. "sustaining commitment," "sustaining mutual understanding," and "time management") appear to be amenable to expansion in order to accommodate the long-term dynamics of cross-team collaboration.

Finally, we would like to offer a few reflections regarding the collaboration supports used by the participants while engaged in the activities that we have presented. For the experimental design used, the virtual room that the teams used for each session was not available either to the same team nor to other teams who were working on the same problem (despite the potential usefulness of these cross-team interactions). However, even if these resources would have been made available, it seems to as as if special interfaces are needed so that "raw" recordings of interactions can be effectively used in promoting and supporting bridging work. The reappearance of findings across sessions of teamwork, expressed in text or through pictorial diagrams, could suggest that computational supports for the teams to annotate and mark their own resources for future work and for others to inspect them might be useful, but the structure of such resources needs to be carefully consider. The three elements of bridging work identified (temporal structure, management of participation, and knowledge claims) might provide a tentative framework for such annotation mechanisms. Further research is needed to develop our understanding of how continuity of collaborative knowledge work is achieved by multiple participants and how to translate such knowledge into design principles. This theoretical and applied enterprise would contribute significantly to the pressing need to better understand how the power of virtual distributed teams and online communities can be harnessed to realize the potential of these new forms of interaction to generate and advance learning and knowledge in organizations, communities of interest, academic disciplines, societies, and other types of collectivity.

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