

**Sustaining Collaborative Knowledge Building:
Continuity in Virtual Math Teams**

A Thesis

Submitted to the Faculty

Of

Drexel University

by

Johann W. Sarmiento-Klapper

in partial fulfillment of the
requirements for the degree

of

Doctor of Philosophy

May 2009

TABLE OF CONTENTS

LIST OF TABLES	v
LIST OF FIGURES	vi
LIST OF LOGS.....	viii
LIST OF LOGS.....	viii
1. INTRODUCTION: THE SOCIAL ORGANIZATION OF SUSTAINING COLLABORATIVE KNOWLEDGE BUILDING ONLINE	1
1.1. Motivation and Objectives.....	2
1.2. Problem Statement and Research Questions.....	4
2. THEORETICAL FOUNDATIONS.....	11
2.1. Studying Interactional Mechanisms in CSCL	14
2.2. Situated and Group Cognition.....	29
2.3. Time and Change Small Group Research and Team Cognition.....	33
2.4. Discontinuities in Collaborative Work, Information Systems, and Organizations	47
2.5. Methodological perspectives in the study of interaction	58
3. CONTEXT AND RESEARCH APPROACH	63
3.1. Virtual Math Teams at The Math Forum Online Community	63
3.2. Research Framework: Design-based Research.....	67
3.3. Data Collection: Design Case One	68
3.3.1. Goals.....	68
3.3.2. The task.....	69
3.3.3. Team composition.....	70
3.3.4. Online Collaboration Environment.....	73
3.4. Data Collection: Design Case Two.....	73

3.4.1. Goals.....	73
3.4.2. The task.....	74
3.4.3. Team composition.....	75
3.4.4. Online Collaboration Environment.....	76
3.5. Case Selection.....	79
3.6. Data Analysis Method: Chat Interaction Analysis.....	83
4. RESEARCH RESULTS.....	87
4.1. Four interactional bridging methods.....	87
4.1.1. Method I: Reporting prior activity to frame current problem solving.....	88
4.1.2. Method II: Collective re-membering.....	110
4.1.3. Method III. Projecting to future activity.....	121
4.1.4. Method IV. Cross-team Bridging.....	127
4.1.5. Bridging Activity as Temporal Organization.....	139
4.2. The Organization of Participation in Sustained Collaborative Knowledge Building... 143	
4.2.1. Positioning Dynamics in VMT.....	145
4.2.2. Positioning and the Individual.....	150
4.2.3. Positioning and the Small Group.....	153
4.2.4. Positioning and the Collectivity of VMT Teams.....	159
4.2.5 Knowledge Artifacts in Positioning.....	163
4.3. Continuity in Sustained Collaborative Knowledge Building.....	168
4.3.1. Diachronic Continuity.....	169
4.3.2. Expansive Continuity.....	178
5. SUMMARY OF FINDINGS AND FURTHER DISCUSSION.....	182
5.1. Four Interactional Bridging Methods.....	182

5.2. Positioning dynamics in VMT	188
5.3. Continuity in Sustained Collaborative Knowledge Building	192
6. CONCLUSIONS AND CONTRIBUTION TO KNOWLEDGE.....	196
6.1. Emerging Theory: Sustaining Collaborative Knowledge Building in VMT	196
6.2. Future Research.....	207
References.....	211
Appendix A. Observed Instances of Reporting Bridging Activity	231
Appendix B. Observed Instances of Collective Re-membering Activity	235
Appendix C. Observed Instances of Projecting Activity	236
Appendix D. Observed Instances of Cross-team Bridging	237
Appendix E. Observed Instances of Positioning and the Individual.....	238
Appendix F. Observed Instances of Positioning and the Small Group	239
Appendix G. Observed Instances of Positioning and the Collectivity of VMT Teams	242

LIST OF TABLES

Table 1. Four Uses of the Term Bridging	14
Table 2. Three Paradigms of Research in Collaborative Learning. Summarized from (Dillenbourg <i>et al.</i> , 1996)	19
Table 3. Three Basic Discontinuities in Computer-Mediated Knowledge Communication. Adapted from (Bromme <i>et al.</i> , 2005)	20
Table 4. Three central claims of Situated Cognition.	31
Table 5. Modes and Functions in the Time, Interaction and Performance Model of Group Development. (Adapted from Figure 1 in McGrath, 1991, p. 154)	37
Table 6. Team Development Phases, Processes and Dimensions	42
Table 7. Five discourse analysis paradigms. Adapted from Herring (2004).....	60
Table 8. Design Cases, Elements and Goals	79
Table 9. Total and Selected Cases from each Design Case Study.....	82
Table 10. Summary of Reporting Cases	109
Table 11. Summary of Collective Re-membering Cases	119
Table 12. Summary of Projecting Cases.....	126
Table 13. Summary of Cross-Team Bridging Cases in Design Case Two.....	138
Table 14. Interactional Bridging Methods and Cases of Bridging Activity.....	140
Table 15. Dimensions of Positioning and the Individual Observed Across Cases	153
Table 16. Dimensions of Small Group Positioning Observed Across Cases	158
Table 17. Dimensions of Positioning and the Collectivity of VMT Teams Observed Across Cases.....	162
Table 18. Observed Cases by Positioning Type	163
Table 19. Summary of Positioning Dynamics in Bridging Activity	167
Table 20. Summary of Observed Aspects of Diachronic Continuity Across Cases	178
Table 21. Summary of Observed Aspects of Expansive Continuity Across Cases	180
Table 22. Observed Cases by Dimension of Continuity	180

LIST OF FIGURES

Figure 1. Trajectories of sustained collaboration.....	10
Figure 2. The Multidisciplinary Field of Computer-supported Collaborative Learning.	15
Figure 3. ConcertChat collaboration environment.	65
Figure 4. VMT re-player with playback toolbar.....	66
Figure 5. Two cycles of design experimentation employed.....	68
Figure 6. Grid-world task.	70
Figure 7. Patterns of Participation of Individuals and Teams in Case Study one.	72
Figure 8. Sticks and Squares task.....	74
Figure 9. Patterns of Participation of Individuals and Teams in Case Study Two.	76
Figure 10. Two pages of the Wiki environment provided in Design Case Two. Left: Front Page. Right: Collaborative Team Page.....	77
Figure 11. Arrangements of points considered by Team Five in session one (left) and session two (right) of Design Case One, as depicted on the shared whiteboard of their virtual room.	91
Figure 12. Three possible ways of seeing the problem's pattern grow.....	102
Figure 13. Whiteboard diagrams constructed by Team 5 when engaged in finding the number of shortest paths between two points on the grid world.	114
Figure 14. Two snapshots from the shared whiteboard in the Second Session of Team 5, Design Case One.....	122
Figure 15. Snapshot of the Wiki posting after the second session of Team C, Design Case Two.	130
Figure 16. Bridging activity linking the work of teams B and C in sessions 2 and 3 of Design Case Two.	135
Figure 17. Bridging activity linking the work of teams B and C in sessions 2 through 4 of Design Case Two.....	137
Figure 18. Three interrelated dimensions of bridging and continuity in knowledge building.	140
Figure 19. Schematics of group positions.	158
Figure 20. Sample Wiki page from Design Case Two.	161
Figure 21. Team Five's trajectory of work between sessions one and two, on Design Case One.	170
Figure 22. Team Five's trajectory of work across all four sessions, Design Case One.....	172
Figure 23. Team A's trajectory of work across all four sessions, Design Case Two.	174
Figure 24. Team B's trajectory of work across all four sessions, Design Case Two.	175
Figure 25. Team C's trajectory of work across all four sessions, Design Case Two.....	176
Figure 26. Mapping of Instances of Bridging Methods and Positioning.....	190
Figure 27. Team Two's bridging instances over time.....	193

Figure 28. Team A's bridging instances over time.....	193
Figure 29. Team B's and C's bridging instances over time.....	194
Figure 30. Tower of Hanoi's problem space.	197
Figure 31. Primary features of the process of achieving convergent conceptual change. From (Roschelle, 1992).	199
Figure 32. Snapshots of grid-world problem resources created by VMT groups.	200
Figure 33. Primary Barron's Dual Space Model of Joint Activity. From (Barron, 2003).	202
Figure 34. Three interrelated dimensions of the field.....	204

LIST OF LOGS

Log 1. Sample VMT chat	5
Log 2. Sample Feedback Note. Design Case Two, Team C, Session 2	75
Log 3. Design Case One, Team 4, Session 3	81
Log 4. Design Case One, Team 4, Session 4	81
Log 5. Design Case One, Team 5, Session 2	89
Log 6. Design Case One, Team 5, Session 1	94
Log 7. Design Case One, Team 2, Session 2	96
Log 8. Design Case One, Team 2, Session 1	98
Log 9. Design Case Two, Team B, Session 2.....	99
Log 10. Design Case Two, Team B, Session 2.....	100
Log 11. Design Case Two, Team B, Wiki posting for session 2	106
Log 12. Design Case Two, Team B, Session 2.....	106
Log 13. Design Case One, Team 5, Session 4	111
Log 14. Design Case Two, Team C, Feedback Note posted on Session 2	116
Log 15. Design Case Two, Team C, Session 2	116
Log 16. Design Case Two, Team C, Session 2	118
Log 17. Design Case Two, Team C, Wiki from Session 2	118
Log 18. Design Case One, Team 5, Session 2	121
Log 19. Design Case Two, Team B, Feedback Note posted on Session 2	123
Log 20. Design Case Two, Team B, Session 2.....	124
Log 21. Design Case Two, Team B, Wiki posting after Session 2.....	125
Log 22. Design Case Two, Team C, Session 2 – Whiteboard textbox.....	129
Log 23. Design Case Two, Team B, Feedback Note on Session 2.....	131
Log 24. Design Case Two, Team B, Session 2.....	133
Log 25. Design Case Two, Team B, Wiki after Session 4.....	136
Log 26. Design Case One, Team 3, Session 1	147
Log 27. Design Case One, Team 2, Session 4	156
Log 28. Design Case One, Team 5, Session 3.....	173

ABSTRACT

Sustaining Collaborative Knowledge Building: Continuity in Virtual Math Teams

Johann W. Sarmiento-Klapper
Gerry Stahl, Ph.D.

When groups engage in online collaboration, they can face significant challenges overcoming a wide range of gaps such as those related to understanding and integrating the activities of multiple participants, coordinating multiple sessions over time, and monitoring the ways in which ideas and contributions evolve. These gaps become especially challenging when multiple virtual groups engage together in sustained collective knowledge-building—the creation and improvement of knowledge artifacts such as theories, plans, and designs. These gaps seem to emerge precisely from the very factors that make collaborative knowledge building promising: diversity of actors, activities, and ideas engaged over time.

This dissertation explores the ways that virtual teams overcome gaps in their sustained knowledge building by analyzing sequences of online, collaborative, problem-solving sessions held by virtual teams of secondary students who participated in Virtual Math Teams (VMT) online community at The Math Forum. In particular, we focused on two sources of discontinuity in the teams' collective work: The discontinuity of their discrete *sequence* of collaboration sessions and those emerging from the changes in *group participation* over time. Our analysis aimed at understanding how the teams “bridged” the apparent discontinuity of their collaborative interactions and exploring the role that such bridging activity played in their knowledge building over time.

The following main findings were derived through qualitative interactional/chat analysis of data from 38 online sessions within two design studies in which 10 VMT teams worked on a open-ended knowledge building tasks: (a) *Bridging Methods*: Four types of bridging practices are central to how Virtual Math Teams overcome episodic and participation discontinuities to sustain the building of collaborative knowledge over time: Reporting, Collective Re-membering, Projecting, and Cross-team Bridging. (b) *Temporality*. VMT teams actively constitute and interconnect sequences of interaction and the temporality that characterizes such sequences as a resource to organize their

collective knowledge-building over time. (c) *Positioning*: VMT teams purposely place individual and collective participants, their history of interaction, and relevant knowledge resources relative to each other in a situated field of interaction. As part of bridging practices, teams use these positioning dynamics to sustain their jointly-produced knowledge over time. (d) *Knowledge Artifacts*. Each one of the bridging practices described involves the interactional co-construction of a bridging artifact which interlinks group knowledge building activity or discourse across different episodes or different collectivities. (e) *Continuity*. Bridging practices intertwine three central elements of Virtual Math Teams interactions: Temporality, Positioning, and Knowledge Artifacts. The interactional relationships among these elements are critical to constituting both the diachronic continuity of knowledge building for an individual virtual team over time as well as the expansive continuity of the larger collective of virtual teams.

These findings represent a novel framework for understanding how members of online collectivities recognize, constitute, and use the discontinuities emerging from sequences of interactions and from the fluid changes of participation over time to sustain collaborative knowledge building. Designers of similar activity systems integrating social and technical components will be able to use this knowledge toward better realizing the potential of new forms of collective interaction to generate and advance learning and knowledge in organizations, communities of interest, academic disciplines, societies, and many other types of collectivity.

1. INTRODUCTION: THE SOCIAL ORGANIZATION OF SUSTAINING COLLABORATIVE KNOWLEDGE BUILDING ONLINE

Emergent theories and designs for collaborative knowledge building in fields such as Computer-supported Collaborative Learning (CSCL), Social Computing, and Information Science, among others, continue to point to the pressing need to better understand how to harness the power of collectivities such as distributed or virtual teams and online communities for advancing the development of new knowledge (e.g., Ellis, Oldridge, & Vasconcelos, 2004; Koschmann, Suthers, & Chan, 2005; Putnam, 2002; Resnick, Levine, & Teasley, 1991; Salas & Fiore, 2004; Stahl, 2006a). The kind of research and design work called for should both further our understanding of the dynamics of collective action and contribute to realize the potential of new forms of human interaction to generate and advance learning and knowledge in organizations, communities of interest, academic disciplines, societies, and many other contexts. This represents a significant challenge both for the existing models and theories of human cognition as well as for design research in general. For instance, extant knowledge on individual cognition appears quite limited to model collective interactions in online settings of sustained collaborative knowledge building (e.g., Greeno, 2006; Schwartz, 1995; Suchman, 1987). Although significant progress has been made in understanding online collaboration in small groups engaged in episodes of joint action (e.g., Arrow, McGrath, & Berdahl, 2000; Hare, 1992; Koschmann, Suthers *et al.*, 2005; McGrath & Tschan, 2004a) and about knowledge creation in communities and organizations (Carlile, 2004; Gasson, 2005b; Ilgen *et al.*, 2005; Orlikowski, 2002; Renninger & Shumar, 2002; Scardamalia & Bereiter, 2006; Weick, 1995) challenges still remain in the understanding of the actual practices that small online groups of learners employ specifically to sustain their on-going knowledge-building discourse over time in ways that further their on-going problem-solving tasks and those of others (Marks, Mathieu, & Zaccaro, 2001; Mayer, 1999).

Participants in online collaborative interactions are often faced with numerous challenges related to overcoming a wide range of interactional gaps including, for example, those emerging from the need to attend to and integrate the activities of multiple people in different locations, monitoring multiple ideas and topics, coordinating sessions of work over time, or dealing with discrepancies in attention, perception, skill, participation, styles of work, phases of activity, and many more (e.g., Bromme, Hesse, & Spada, 2005; Greenberg & Roseman, 2003; Watson-Manheim,

Crowston, & Chudoba, 2002). In contexts in which learning and building collaborative knowledge is a central concern, collectively creating, testing, and improving 'conceptual artifacts' (Bereiter, 2002; Bereiter & Scardamalia, 2003 p. 13; Stahl, 2006a) relies precisely on the successful engagement of multiple actors and on the effectiveness of their strategies to manage their actions and resources over time. This particular aspect of the interdisciplinary study of computer-supported collaborative learning, however, represents an outstanding challenge to current theories and design practices struggling with understanding and supporting interactions which are dispersed over time (e.g., long-term projects, multi-session problem solving engagements, etc.) and which cut across different collectivities (e.g., sub-teams, teams, communities, etc.) engaged in collaborative knowledge building over time (Bereiter, 2002; Stahl, 2006a; Suthers, 2005). The present dissertation contributes to this area of research by investigating in detail the interactional mechanisms that multiple virtual teams undertake while participating in online knowledge building over time as part of a specific online community. (Note: Following the approach of Ethnomethodology (Garfinkel, 1967) and Conversation Analysis (ten Have, 1999) most of the findings presented here have been derived through team data sessions in which multiple members of the Virtual Math Teams research team participated. For a review of these data sessions see Section 3.6. Although I have chosen to use the first-person plural pronoun to write this dissertation report, the ideas and points of view expressed in it represent my intellectual responsibility unless otherwise explicitly acknowledged through citations)

1.1. Motivation and Objectives

The Virtual Math Teams project at The Math Forum

The first source of motivation for the work presented here comes from the potential applied benefits that the knowledge developed in this work could have in online communities such as the Virtual Math Teams (VMT) project at the Math Forum. The Math Forum at Drexel University (www.mathforum.org), an online community active since 1992, promotes interactions among teachers of mathematics, students, mathematicians, hobbyists, staff members and other interested parties involved in learning, teaching, and doing mathematics. As the Math Forum continues to evolve, support for more engaging and productive online interactions becomes increasingly essential for sustaining and enriching the mechanisms of community participation available. A step in this direction, the Virtual Math Teams (VMT) project investigates the innovative use of online collaborative environments to support effective secondary mathematics learning at the Math Forum. VMT promotes and

supports a community of virtual teams collaborating in solving open-ended mathematical problems and developing their interests and discoveries over time. Understandably, when virtual teams attempt to sustain their collaborative work over multiple individual sessions, challenges such as bringing new or returning members up to speed on collaborative work, recommencing prior activities, envisioning possible future work, and following up on such plans, among others, become issues that VMT participants may need to address. To the extent that the teams are able to sustain their work over time their success in developing their collaborative knowledge seems more attainable. For both the Math Forum and the VMT project, developing a solid understanding of the interactional dynamics of sustained online collaboration and of potential ways to support it, are of critical importance.

Computer-supported Collaborative Learning (CSCL)

In addition to such applied goal, a primary objective of this work has been to contribute to the existing body of knowledge in Computer-Supported Collaborative Learning (CSCL). As research in CSCL expands its understanding of joint knowledge building and the participation frameworks enacted by it, new perspectives on how social reality is constructed become necessary (Hmelo-Silver & O'Donnell, 2007; Koschmann, Suthers *et al.*, 2005). In particular, the need for detailed interactional studies that take the collectivity as the unit of analysis and investigate processes that go beyond single episodes of collaboration are salient challenges in CSCL (Dillenbourg *et al.*, 1996; Koschmann, Zemel *et al.*, 2005). This dissertation concentrated on the diachronic trajectories of online groups as part of the VMT project of The Math Forum and aimed at investigating how the small virtual teams who engaged in sustained knowledge work over time overcome the discontinuity of their multiple episodes of collaboration to constitute knowledge building as a sustained activity. A close examination of the collaborative knowledge building of virtual teams—attending to the ways that the participants demonstrably orient to the interaction moment-by-moment—was used to develop ideas about the methods or practices that co-participants enact in sustaining their collaboration over time and, at the same time, guide the process of expanding what is currently known about building collaborative knowledge.

In summary, the motivation for this work emerged from the need for furthering existing theories of collaborative knowledge building over time and the unique opportunity of exploring how teams of participants in VMT online community 'bridged'

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. As a result, this dissertation pursued two central objectives which, together, aimed at expanding the existing knowledge within the field of CSCL regarding continuity in building collaborative knowledge by small online groups and informing the practical application of such knowledge in the Virtual Math Teams project at the Math Forum. These objectives were:

(a) Defining how collaborative episodes and collectivities are bridged as part of the online interactions of Virtual Math Teams. In doing so, we attempted to document the interactional methods that allow small groups of participants in Virtual Math Teams to sustain their knowledge building and overcome or ‘bridge’ the discontinuities that emerge from interactions over time and across several different collectivities.

(b) Exploring the relationship of such bridging activity and the sustained knowledge work of virtual math teams. This second objective aimed at exploring the linkages between the interactional methods used to bridge discontinuities and the processes related to building collaborative knowledge over time.

1.2. Problem Statement and Research Questions

As we have argued, sustained collaborative knowledge building in small virtual groups and online communities might require that co-participants overcome or ‘bridge’ multiple discontinuities in their interactions as they engage over time— a non trivial and possibly very consequential undertaking. To illustrate more precisely the types of discontinuities which we are seeking to investigate and to illustrate the types of interactions that take place in the Virtual Math Teams project (VMT) we will briefly explore a passage of a VMT team’s interaction.

It is the second time that a few virtual teams of secondary students meet online to work on investigating the mathematics of a ‘grid-world’ —a world where one could only move along the lines of a rectangular grid. In a previous session, a few days ago, Drago and Estrickm worked on exploring the grid-world and attempted to create a formula for the shortest distance between two points A and B in this world. This time, they are joined by two new team members: Gdo, who had worked on this problem with another team in a previous session, and Mathwiz who is new to the task and the team.

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 VMT meeting environment:

Log 1. Sample VMT chat

302 gdo¹: now lets work on our prob
 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 (*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*)

From the point of view of an observer, it could seem that there are a number of pre-existing discontinuities that could come at play in this interaction. There are, for instance, multiple participants currently engaged in this passage who might differ based on their skills, their knowledge, and their history of previous participation in similar activities. However, if we focus on the ways that the participants themselves orient to these or any other discontinuities they find relevant for the task at hand we can uncover how groups constitute and deal with those features of their interaction. For example, this excerpt illustrates one way in which these VMT team chose to approach the recommencement of their collaboration. Elements of their discourse signal to us that they are engaged in using prior interactions as relevant resources for organizing their current work. For example, Drago in line 303 responds to Gdo's request for the team to work on a problem with a report that indexes a prior session, a prior problem, the participants of such session, and a report of something that was

¹ The names presented in all transcripts used in this dissertation correspond to anonymous system handles as per the procedures approved for the VMT project by Drexel's Internal Review Board.

discovered about the grid world —that you always have to move a certain amount to the left/right and a certain amount to the up/down. In responding to this report, the team as a whole appears to be visibly oriented to making sense and using such reported resources in a way that constitutes their current knowledge-building activity as a continuation of Drago and Estrickm's prior work. There is in this passage, from the interactional sense given by the participants, a unique orientation to the activities performed in the previous session and, possibly, to the changes in group membership that have taken place from the prior session to this one. (In fact, even within this brief interaction a change in group membership appears relevant when Gdo leaves the virtual room in line 313, re-joins in line 316 and finds it germane to provide a series of postings in lines 318 to 320 that orient to the gap created by this situation.)

Despite the fact that this type of interaction may appear, at least at first instance, as simple or unsurprising, there are a number of probing questions that can be asked about this and similar interactions which are left, at least partially unanswered, by current models of collaborative learning and knowledge building. For instance, classical information-processing models of human cognition and memory (Tulving & Donaldson, 1972) might treat this interaction as a case in which some of textual messages exchanged by the participants as well as elements of the diagrams they had been creating and manipulating 'triggered' the retrieval of stored episodic memories in Drago. The interaction that we observe would then correspond to Drago's communicative processes of expressing 'encoded' information as part of his attempt to represent the problem at hand (Newell & Simon, 1972). Situated perspectives on human cognition and memory which attend more directly to the social and material aspects of memory in action would challenge this view based on the empirical evidence that suggests that "neither the form of the activity of remembering, nor the detailed nature of what is remembered is straightforwardly or monocausally determined by any internally stored information" (Sutton, 2009). In addition, the situated perspective on cognition challenges us to explore "how much the machinery of inference, computation and representation is embedded in the social, cultural and material aspects of situations" (Kirsh, 2009). As we will see in our analysis of this and similar passages as part of collaborative encounters spread over time in VMT (Section 4.1.1 on Reporting and similar subsections in Chapter 4), a number of interactional methods constituted by the participants through interaction allow them to organize their collective orientation to multiple episodes of collaboration and constitute their trajectory of action as a continuous one. Even though some

theory frameworks exist that suggest the important of such situative perspective (Hutchins, 1995; Robbins & Aydede, 2009; Stahl, 2006a; Vygotsky, 1930/1978) the description of the actual methods by which collectivities achieve this through interaction remains an open enterprise (Kirsh, 2009).

The sample VMT interaction in Log 1 presents also a unique opportunity to inquire about the unique group processes which online peer-groups develop and use in order to link their synchronous episodes of collaborative knowledge building to their diachronic trajectory; a process that recently has been investigated as being fundamental to group creativity (Sawyer, 2003) and long-term task groups (Marks *et al.*, 2001). In our example, one might also inquire about whether the way that Drago has constructed and presented the report of their prior discovery exhibits unique properties in relation to both, whatever he and Estrickm had achieved in their previous session (retrospectively), and to the way that future interactions might unfold (projectively). In this case, it is interesting to note that the current relevance of what Drago has chosen to present, the rule-like discovery about the grid-world from “last time” is something that the group itself has started to work through and which, can be seen to slowly take shape in a combination of projective and retrospective pointers. Given the asymmetry that separates newcomers and old-timers in this current team, working out the relevance of Drago’s report implies, as we can start to see in the excerpt, building a unique organization of participation in which different parties might have different possibilities for action, different artifacts are manipulated, and markers of temporality are constituted. The dynamics of how this is accomplished constitute a central interest of this dissertation. In addition to inquiring about linkages between relatively close episodes of collaboration, explanation of the interactional mechanisms through which teams engage in activities that transition prior discoveries and other relevant aspects of their interactions across the trajectories of collaboration of other teams are also a unique challenge to theories of collaboration (Mark, Abrams, & Nassif, 2003; Stahl, 2005b; Weick & Sutcliffe, 2005). We will explore in more detail the relevant theoretical frameworks and the ways that they attempt to address discontinuities across episodes of collaboration and changes in participation in Chapter 2.

We have used the term ‘bridging’ to refer to the kinds of interactional situation and dynamics that we illustrated through the short passage of a VMT interaction explored in the previous paragraphs. In the sense we use it, the term ‘bridging’ denotes interactional phenomena that allows collectivities to signal and deal with

discontinuities of time, activities, and participation within their joint interaction. More concretely, we have used the term bridging to allude to the set of methods through which participants constitute and deal with the discontinuities they find relevant to their joint knowledge work. Within those, we intend to concentrate on two types of discontinuities which are unique to the Virtual Math Teams context —episodic and participation discontinuities, which, as we will explore in detail in Chapter 2 represent open challenges to current theories of collaborative knowledge building.

Taking bridging as the central interactional phenomena of interest of this research, our central aim was to characterize the ways in which bridging contributes to the establishment of continuity and discontinuity in the knowledge-building experience of online collaborative learning teams in the VMT online community. To achieve this, we defined the following three central research questions:

Q1. What interactional practices are used by teams participating in the Virtual Math Teams online community to overcome *episodic* discontinuities—multiple episodes of collaborative knowledge building, and *participation* discontinuities—changes in group participation over time?

Taking a strong interaction perspective, this research question inquires about the observable and demonstrable practices that the teams participating in Virtual Math Teams employ to constitute and deal with the discontinuities that emerge from their multiple collaborative sessions, teams and tasks. In particular, we attempt to understand the interactional dynamics of such team practices and their relationship with a team's trajectory of interaction over time. (See Section 4.1 for Results)

Q2. How are individual participants, small groups, and the overall collectivity of teams constituted in relation to episodic and participation discontinuities in the VMT online community?

Secondly, we aim to verify and describe the link between the interactional practices that characterized as “bridging methods” and the ways that individuals, small virtual groups, and collectivities of such groups organize their participation and their building collaborative knowledge. We hypothesize that bridging links events at the local small-group unit of analysis to interactions at larger units of analysis (e.g., sustained multi-team collectivities) as well as between the individual and small-group

levels. (See Section 4.2 for Results)

Q3. What forms of continuity are constituted by Virtual Math Teams through their building of collaborative knowledge over time?

Finally, we investigate the ways in which participants orient to specific aspects of the VMT activity system to constitute their online experience as a continuous or discontinuous one. In particular, we are interested in exploring whether the small virtual teams participating in VMT demonstrate an orientation to building collaborative knowledge that crosses over their multiple episodes of collaboration over time and across collectivities. (See Section 4.3 for Results)

In defining “bridging activity” as the interactional work performed by co-participants to establish continuity in a context in which virtual teams collaborate in learning and engaging with problem-solving tasks across multiple sessions and where multiple teams might form an online community, one our central conjectures was that bridging is highly consequential for the qualitative nature of the teams’ knowledge-building experience. As a result, we sought to understand how bridging is achieved in interaction and to explore its role as part of the collaborative learning activities conducted by the teams we propose to study. As indicated in Figure 1 bridging might operate at many social and temporal levels. The arrows in this diagram indicate expected bridging across interactions among individuals, teams and communities, and across time. A central underlying hypothesis that motivated our interactional approach is the fact that how bridging activity is conducted by the teams is strongly determined by the particulars of the participants, the activities that they orient to, and the resources at their disposal—all contextual factors which are made relevant in and through interaction and distributed across people and artifacts. As a result, we focused on understanding activity and changes in the activity systems in which knowledge is co-constructed and used jointly.

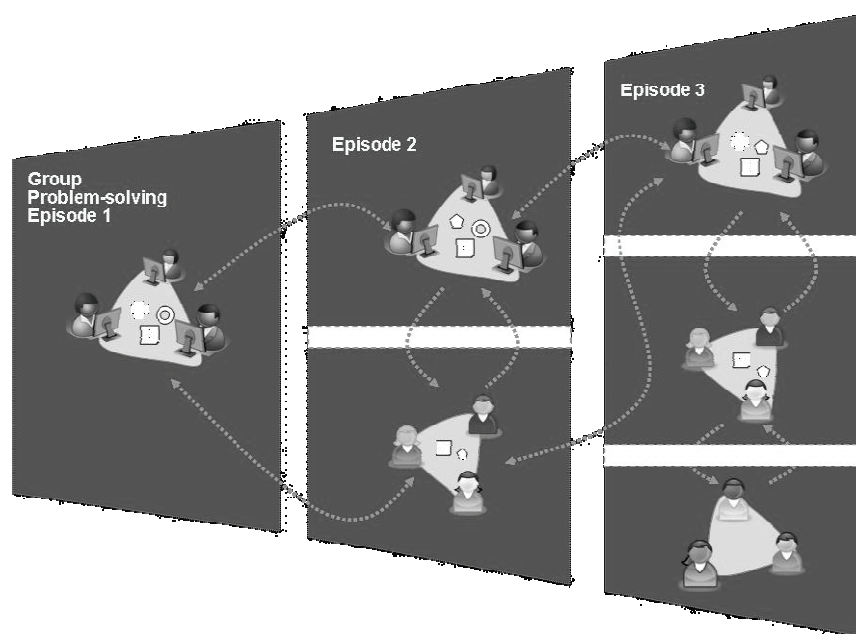


Figure 1. Trajectories of sustained collaboration.

As Figure 1 suggests, when individual teams engage in their episodes of knowledge building and collaborative-learning they might co-construct resources which can be – and often are designed by the participants to be – taken up as being connected with other episodes involving the same or different teams as part of a larger collectivity (e.g., an online community). The three research questions proposed investigate from different perspectives such uptake processes, the establishment of continuity and relevance and its relationship to the sustainability of knowledge-building work across individual episodes and across multiple collectivities in the VMT project. Central to our conceptual framework was the view that, to understand bridging and its functions, an interactional perspective was essential. As we will discuss in Chapters 2 and 3, the commitment to bridging as interactional phenomena was central to our theoretical framework. This commitment also guided our choice of naturalistic data and the use of micro-level methodologies as we will explore in subsequent sections.

Before presenting the details of the research methods used to answer the three central research questions presented before, we will first review the current state of the relevant literature in order to better ground our choice of problem in the larger research context, explore to what extent similar phenomena have been investigated in relevant research fields, and identify potential contributions of the work conducted.

2. THEORETICAL FOUNDATIONS

Although up to this point we have used the term *bridging* metaphorically to denote group interactions oriented to overcoming discontinuities of time, activities, and participation, the term *bridging* has been used in several different fields with various meanings worth exploring in some detail. We first present four of these uses of *bridging* before exploring in detail the gaps in the current state of the research literature on the study of *episodic* and *participation* discontinuities in the knowledge building activity of online groups from different theoretical perspectives.

The many faces of bridging

The term *bridging* has been independently introduced within different scholarly fields at least five times in the last few decades—each time to call attention different discontinuities of human interaction. The first of these uses of the concept of bridging dates back to 1975 when Psychologist Herbert H. Clark introduced it as one of the central mechanism to explain how humans comprehend natural language. For Clark, *bridging* is a semantic and mental process through which listeners draw inferences, establish connections, or derive implications (bridges) from what was “given” (previous knowledge) to completely new information based on what a speaker says (Clark, 1975). In formulating the concept of *bridging* in this form Clark was concerned with how listeners deal with the discontinuities of information that characterize single conversational encounters in which speakers imply significant portions of their intended message instead of communicating it explicitly. Although this type of inferential process is still studied within Linguistics (Cohen, 1996; Matsui, 2001), later on in the development of his theory of language comprehension, Clark moved away from this “given-to-new” model of individual inferential bridging, in order to formulate his widely used model of communication as *grounding* and building *common ground* (Clark & Brennan, 1991). Through the lens of grounding, language comprehension is seen as a cooperative process of coordinating mutual knowledge, mutual beliefs and mutual assumptions (p. 127) rather than solely a process of deriving inferences from what is said.

In the field of Instructional Science and its studies of conceptual change the concept of *bridging* has also been used to illustrate how analogies and certain types of diagrammatic representations can be used as transitional resources to aid learners in moving, for example, from misconceived to correct understandings, from concrete to abstract concepts, or between mechanistic and systemic views on processes. Brown and Clement (1989) introduced the term *bridging strategy* to illustrate a four-

step process through which an instructor attempts to use analogous cases to take learners from their indigenous or alternative conceptions of a phenomena to a target conceptualization of it. In this sense, *bridging* alludes to discontinuities between a learner's current mental model of a subject and a target or intended mental representation (Savinainen, Scott, & Viiri, 2005). Other researchers of conceptual change and human development have expanded this notion to explore ways in which learners themselves construct conceptual bridges, specially within collaborative interactions (e.g. Granott, Fischer, & Parziale, 2002) by "guiding the activity to gradual construction of the missing knowledge" (p. 142). Even in theories of learning that go beyond seeing cognition as a purely mental process of transforming defective or incorrect mental representations with target ones and consider the situated nature of skill development, the notion of bridging across discontinuities of competence and identity is present. For instance, as we will explore later, in Lave and Wenger's model of legitimate peripheral participation the discontinuities in a learner's competence are traced as he moves toward full participation in a community of practice (Lave & Wenger, 1991 p. 64)

In yet a different field—Management and Organization Science, the term *bridging* has been used by Carl Weick as part of his model of Sensemaking in Organizations (Weick, 1995). This model, a contrasting alternative to the prevalent rational model of organizational decision making, builds on Norbert Wiley's four symbolic levels: *intra-subjective* (individual), *inter-subjective* (interaction), *generic or collective subjective* (social structure), and *extra-subjective* (culture) (Wiley, 1988, 1994). Weick defines for organizations a variation of Wiley's *generic* or *collective subjective* level as '*generic intersubjective*' and argues that organizations are "entities that move continuously between intersubjectivity and generic intersubjectivity" (p. 75) while managing the 'tensions' between intersubjective innovation and the necessary control of such innovation which builds generic subjectivity (p. 72). In fact for Weick organizational forms are "the bridging operations that link the intersubjective with the generically intersubjective" (p.73), by creating, preserving, and implementing the innovations that arise from intimate contact, focusing and controlling "the energies of that intimacy" (p. 72). As such, Weick's model is centrally concerned with the discontinuities between intersubjective or "intimate" interaction as the source of innovation that facilitates changes and control or "generic-subjectivity" that "enforces stability." In doing this he portrays the act of organizing as "a mixture of vivid, unique intersubjective understanding and understandings that can be picked up, perpetuated, and enlarged by people who did not participate in the original

intersubjective construction.” This conception of *bridging* resonates highly with our research concerns despite the fact that Weick’s model is more directly concerned with structured contexts of organized and managed action rather than online peer groups involved in knowledge building. We will return to Weick’s model and its relevance to our research at a later point in this chapter.

Finally, *bridging* has made its most recent explicit appearance as one of two types of social capital (Putnam, 2002) in Social Science studies of modern society and its networks of trust and cooperation. Bridging social capital is theorized to be “outward looking” and emerging from linkages between heterogeneous groups—in contrast to bonding social capital which emerges from social networks that link homogeneous groups of people. Bridging social capital is expected to produce the highest benefit for communities, societies, and individuals (Gittel & Vidal, 1998) and has been studied as well in the online context (e.g., Yuan & Gay, 2006). Similarly, the concept of *bridging* has figured within studies of Interdisciplinary collaboration in Information Science and more specifically within the Bibliometric studies of disciplinary literatures (McCain, 1990; White & McCain, 1989). From this perspective, specific publications, concepts or authors are said to “*bridge*” different theoretical approaches, sub-disciplines or entire fields when they appeared in unique connecting positions within the networks of co-citations revealed through Bibliometric studies (e.g. White & McCain, 1998) (Diodato, 1994; Lancaster, Diodato, & Li, 1988). In this sense, *bridging* alludes to discontinuities of foci, concepts or perspectives between different fields of study or groups of authors and to the flow or “porting” of knowledge from one field or discipline to another, from one research team to another—a concern that goes well beyond Bibliometrics and involves fields such as CSCW and the study of corporate innovation (Burt, 2004; Mark *et al.*, 2003).

These four uses of the term bridging orient us to different types of discontinuity and shed light on different aspects of interactive knowledge building. Central elements of these four perspectives are summarized in Table 1. We will come back to some of these frameworks in more detail in the remaining sections of this Chapter while considering other relevant theories and frameworks which, even though they do not use the concept of bridging explicitly, provide foundational knowledge for the study of online peer groups building collaborative knowledge over time.

Table 1. Four Uses of the Term Bridging

	Linguistics - Semantics Clark (1975)	Instructional Science Brown and Clement (1989)	Organizational Science Weick (1995)	Social Capital (Putnam, 2002)
Context	<ul style="list-style-type: none"> Comprehension of Natural Language 	<ul style="list-style-type: none"> Teaching and Learning Processes 	<ul style="list-style-type: none"> Sensemaking in Organizations 	<ul style="list-style-type: none"> Networks of trust and cooperation in societies and other large groups
Discontinuity Addressed	<ul style="list-style-type: none"> Between what is known by a listener and unknown information inferred from the speakers message. 	<ul style="list-style-type: none"> Between a learner's indigenous or alternative concepts to a "target" concept 	<ul style="list-style-type: none"> Between inter-subjective knowledge (innovation in interaction) and "generic subjective" knowledge (control and stability) 	<ul style="list-style-type: none"> Between the individual members or subgroups of a large group, their beliefs interests, etc.
Concept of Bridging	<ul style="list-style-type: none"> A mental process of listeners inferring completely new information based on what a speaker says and in relation to what was already "given" (previous knowledge) 	<ul style="list-style-type: none"> A gradual process of constructing and modifying mental representations of a phenomena 	<ul style="list-style-type: none"> Organizational forms are the bridging operations that link the intersubjective with the generically intersubjective 	<ul style="list-style-type: none"> Bridging social capital emerges from linkages between heterogeneous groups Bridging leads to the highest benefits for communities, societies, and individuals.
Principles of Bridging	<ul style="list-style-type: none"> Semantic Mental Scope-based Inference Comprehension as a cooperative process 	<ul style="list-style-type: none"> Symbolic Mental Gradual and Transformative Constructivist 	<ul style="list-style-type: none"> Intersubjective interaction is the source of innovation Generic-subjectivity enforces stability and control Organizing links "vivid" intersubjective understanding and understandings that can be "picked up" by people who did not participate in the original intersubjective construction 	<ul style="list-style-type: none"> Heterogenous linkages lead to innovation through cooperation and trust Homogenous linkages lead to stability Network properties of a group empower or restrict it

2.1. Studying Interactional Mechanisms in Computer-supported Collaborative Learning

The types of research questions and the context in which our research was carried out situate our work in the multidisciplinary field of Computer-supported

Collaborative Learning (CSCL). CSCL has been defined as being primarily concerned with understanding “the practices of meaning making in the context of joint activity, and the ways in which these practices are mediated through designed artifacts” (Koschmann, 2002) as a way to understand “how people can learn together with the help of computers” (Stahl, Koschmann, & Suthers, 2006).

As illustrated Figure 2 CSCL attempts to integrate fields as diverse as Educational Psychology, Situated Cognition, Small-group Research, Groupware Design, and other research areas from which CSCL borrows (as well as builds on) theoretical models, analytical methods, and contexts of study. In this section we will review the CSCL literature relevant to the research questions proposed first while leaving more detailed discussions of some of the relevant foundational theories used in CSCL for the rest of the Chapter.

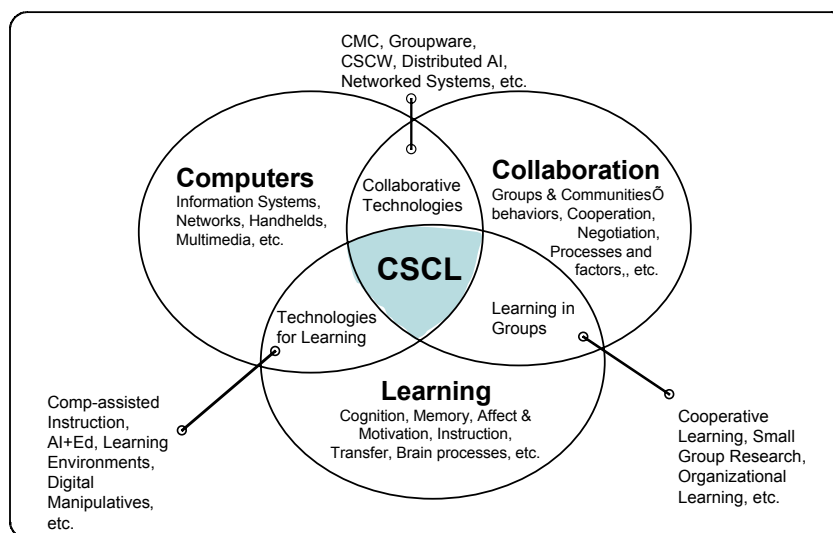


Figure 2. The Multidisciplinary Field of Computer-supported Collaborative Learning.

Effect, Conditions and Interactions

Significant progress has been made within CSCL in advancing the understanding of the nature of learning in small-groups and how to support it with designed artifacts (Koschmann, Hall, & Miyake, 2002; Koschmann, Suthers *et al.*, 2005; Stahl, 2002; Wasson, Ludvigsen, & Hoppe, 2003) but much remains to be discovered. In their comprehensive review of empirical research on collaborative learning, Dillenbourg and colleagues (1996) put forward a broad framework that illustrates the evolution of CSCL research and the current challenges in theory and

methods. According to the authors, research in this area has evolved through three phases or paradigms: The “*effect*” paradigm, the “*conditions*” paradigm, and the “*interactions*” paradigm.

In the initial “*effect*” paradigm there was an interest in comparing “together” versus “apart” scenarios of activity (mostly dyadic work compared to individual work) and measuring changes to individual performance to validate whether collaborative settings are more efficient than individual ones in, for example, leading to higher individual achievement and the development of new individual knowledge. Perhaps the best comprehensive review of this kind of research is the meta-analysis conducted by Slavin (1980; 1983; 1995; 1996) which synthesizes numerous empirical studies contrasting individual performance under individualistic or collaborative conditions. These reviews point to a generalized positive support for the value of collaboration for individual learning but also present some contradictory findings such as the increase, in some cases, of “confirmation bias” and negative social effects by which the motivation of lower-ability learners to participate in learning activities with higher-ability peers seems to decrease within collaboration (Salomon & Globeson, 1989). Some of these negative results resemble the long documented “process losses” of task groups (Steiner, 1972) where the ‘actual’ productivity of a group has been considered to be less than its ‘potential’ productivity (as measured by its pre-existing knowledge and skills) due to process losses (as represented by breakdowns in coordination, communication, motivation, etc.). In other cases, it was evident that not all participants seemed to respond equally to collaborative learning conditions with some benefiting more than others (Webb, 1991).

The complex and, in some cases, contradictory nature of some of the results obtained within the “*effect*” paradigm motivated the development of the “*conditions*” paradigm in which the central preoccupation has been to establish under what circumstances collaboration works. In this type of research factors such as the size of a group, its gender composition, prior achievement, task structure and others have been controlled as part of, mostly, short-span collaborative episodes while measuring general effects on dependent variables such as learning outcomes. Examples of research under this paradigm abound (see Johnson & Johnson, 1989 for a general review). For instance, Azmitia studied how groups composed of young novices and experts working on a model-building task provided the context for novices to improve much more than what groups of either all novices or experts did (Azmitia, 1988).

However, other types of task arrangements that include explicit rewards and the assessment of both individual and group outcomes have shown positive results for both mix-ability and same-ability groups (Slavin, 1980). Despite the significant contribution that these studies have brought to the studies of collaborative learning, Dillenbourg and colleagues argue that the wide diversity of factors tested and the lack of a common framework have challenged the very possibility of developing a unified theory of group collaboration from this research. Researchers have concluded that the factors studied do not have simple effects on learning outcomes but interact with each other in complex ways. For instance, group size, the distribution of expertise, and the structure of the task commonly interact with one another (Ibid, p. 189). In addition, laboratory effects very often were not verified in more naturalistic settings (Anderson *et al.*, 2005)

As a response to the problems exhibited by the two initial paradigms of collaborative learning research but also as a way to extend their results, the '*interactions*' paradigm in CSCL has attempted to conduct in-depth studies of collaborative interactions in which intermediate or process variables which describe group interactions are related to the conditions of learning and to learning outcomes. These studies often pursue two separate but related questions: What types of interactions are associated with specific aspects of a collaborative situation, and what effects do these interactions have on the overall outcomes of the collaboration. We will explore these most recent studies in more detail next.

Table 2 synthesizes the three research paradigms and their central elements.

Table 2. Three Paradigms of Research in Collaborative Learning. Summarized from (Dillenbourg *et al.*, 1996)

<p>The “Effect” Paradigm: “Together vs. Apart”</p> <ul style="list-style-type: none"> • Independent Variable: Collaborative Work vs. Work alone • Dependent Variables: Individual Performance, improvement in monitoring and regulation skills, etc. • Results: Contradictory but mostly positive. Some negative results document, for instance, that low achievers progressively become passive when collaborating with high achievers • Examples: Slavin (1980; 1983; 1995; 1996), Steiner (1972)
<p>The “Conditions” Paradigm: When does collaboration work?</p> <ul style="list-style-type: none"> • Independent Variable: Group composition (e.g., group size, gender distribution, prior knowledge, etc.) task structure, context, communication medium, etc. • Dependent Variables: Learning outcomes • Results: Variables do not have simple effects on learning outcomes but interact with each other in a complex way; for instance group composition interacts with the structure of the task • Examples: Anderson et al. (2005), Azmitia (1988), Slavin (1980)
<p>The “Interactions” Paradigm : How do effective collaborations work?</p> <ul style="list-style-type: none"> • Intermediate Variables: Variables that describe the interactions and that can be related to the conditions of learning and to learning outcomes • Results: Candidate interactional methods include elaboration, explanation, control, socio-cognitive conflict, negotiation, and argumentation. • Challenges: New analytical tools are needed to model interactions and understand the processes involved in joint activity and learning. • Examples: Andriessen, Baker, & Suthers (2003), Chi (2000), Danserau (1988), Stahl (2003), Vygotsky (1930/1978), Webb (1991)

Research under the ‘*interactions*’ paradigm has attempted to explore in detail diverse discontinuities emerging in collaborative knowledge creation—discontinuities between different stages of individual and group competency, between knowledge constructed in group interaction and that internalized by individual peers, or between online or face-to-face episodes of collaboration over time. These are, in fact, challenges that permeate, in general, “computer-mediated knowledge communication” in CSCL (Computer-supported Collaborative Learning) and CSCW (Computer-supported Cooperative Work) contexts. Bromme, Hesse and Spada (2005) argued this position when proposing that the extant research literature suggests three main ‘barriers’ or discontinuities which groups have to be overcome in

order to succeed in such collaborative contexts. First among the discontinuities proposed by these researchers are those related to meaning and meaning-making such as the gaps among the ways that each participant understands an idea or an interaction ('common ground' gaps), the gaps between each participants knowledge and competencies ('epistemic' barrier), and those that arise between expressed or 'shared' knowledge and 'unshared' knowledge. In addition, the authors point to the discontinuities between different forms of participating and interacting as a group at a certain point and over time. Finally, this perspective argues that there are discontinuities that go beyond those related to knowledge and social structure but which involve gaps between the levels of motivation of different participants in a group or between the different levels of motivation of the same group at different points in time (p. 5) (see Table 3). The overall challenge of research under the interactions paradigm is presented to be, in this sense, that of understanding how participants overcome these three types of discontinuities as well as discovering other relevant gaps that participants orient to.

Table 3. Three Basic Discontinuities in Computer-Mediated Knowledge Communication. Adapted from (Bromme *et al.*, 2005)

Meaning Discontinuities	Social Structure Discontinuities	Motivational Discontinuities
<p>The individual and mutual construction of meaning and the exchange of information in groups:</p> <ul style="list-style-type: none"> • Common ground barrier • The epistemic barrier • Unshared knowledge barrier 	<p>The establishment and maintenance of structure (social order) in social interactions.</p>	<p>The establishment and maintenance of motivation to cooperate and communicate.</p>

Research under the interactions paradigm has also been associated often with studies of "microgenetic" features of the interaction (Dillenbourg *et al.*, 1996). From a conceptual point of view, the term "microgenetic" is derived from Vygotsky's detailed socio-cultural investigation of the formation of "intrasubjective" (individual) psychological process as the result a long process of "intersubjective" (social) interaction (Vygotsky, 1930/1978). This central tenant of socio-cultural psychology emerged from the empirical evidence of Vygotsky's dual stimulation experiments in which he aimed at tracing a "complex" psychological response as a "living process, not as an object" (p. 69). More recently, the label "microgenetic" has been associated with the methodological commitment to "dense sampling over an

extended period of time coupled with an intensive trial-by-trial analysis” (Siegler, 1996). As Wertsch puts it (1985) microgenetic studies are, in a sense “a very short-term longitudinal study” in which the ultimate objective is to document interactional processes, living dynamic processes, associated with the formation and development of new forms of interpsychological and intrapsychological functioning. Examples of such studies to date concentrate mostly around how individuals discover strategies for action, develop novel concepts, or create new forms of acting in the world (Rogoff, 1995; Siegler & Chen, 2002; Wertsch, 1998).

Whether microgenetic in their orientation or not, a great number of CSCL studies within the interactions paradigm have taken up as a core goal the investigation of Vygotsky’s ‘genetic law of cultural development’ (Vygotsky, 1930/1978) in online settings and settings where computational artifacts play a significant role. While Vygotsky’s law states that higher psychological functions in humans originate at the social level (between people), and only later, through a “long series of developmental events”, these functions are internalized by the individual, CSCL research in the interactions paradigm attempts to investigate the actual social dynamics that participate in this process and the roles of designed artifacts. As a result, CSCL research under this orientation has produced a number of candidate interactional mechanisms related to collaborative knowledge building which include *argumentation* derived from cognitive conflict (Andriessen, Baker, & Suthers, 2003; Baker, 1991), intersubjective *negotiation* or *negotiation of perspectives* (Stahl, 2003, 2006b; Stahl & Herrmann, 1999), *peer explaining* (Chi, 2000; Dansereau, 1988; Webb, 1985, 1991, 1992), *co-construction* (elaborative or evaluative) of knowledge (Herrenkohl *et al.*, 1999; Rafal, 1996), and *building common ground* (Clark & Brennan, 1991; Traum, 1998). In some cases, these mechanisms have been compared empirically as in Hausmann, Chi, and Roy’s (2003) experimental tests with dyads which documented that different mechanisms contribute differently to learning from collaborative problem solving. In their study, self-directed explaining produced the strongest learning gains followed by other-directed explaining and co-construction. Co-construction, although infrequently observed, was specially associated with high frequency of re-use of knowledge: 75% of the concepts derived by the dyads through co-construction were correctly used on a posttest. However, as we will see in the remainder parts of this section, the existing interactional mechanisms explored up to date in CSCL still leave gaps in our understanding of collaborative knowledge-building over time.

Peer explaining, negotiation, and argumentation are processes that are oriented toward specific discontinuities of the collaborative context. They document group responses to the gaps in competencies, perspectives and positions, respectively. For instance, Webb (1991) in her meta-analysis of empirical research studying the ways in which dyads engage in forms of *explanation* during collaboration discovered that elaborate explanations are usually linked positively to gains in knowledge by the explainer but not necessarily by the explainee, ruling out that simple “transfer of knowledge” is a compelling explanation for the effects of collaboration on knowledge. More importantly, her investigation regarding how explanations are actually delivered in interaction illuminates how both parties participate in the ongoing construction of the explanation and how other factors such as dyad composition seem to affect the dynamics of explanation practices employed in interaction. Similar results have been documented regarding the processes of *negotiation* in collaboration. For instance, Barbieri & Light (1992) found that the incorporation of negotiation as part of a computer-based problem-solving task was a better predictor of a dyad’s efficacy with jointly constructed solutions than gender or prior performance. Similarly, the study of *argumentation* (one of the most researched interactional processes in CSEL and CSCW) suggests that participants’ ways of engaging in discovering, developing, presenting and contrasting perspective on a topic can better explain outcomes of collaborative learning (Andriessen *et al.*, 2003). In addition participants seem to develop competencies and practices that involve not only topical knowledge (learning from arguing) but also learning to argue—learning the structures and language of argumentation and the methods of new knowledge construction. The particular role of computational tools in support for collaborative argumentation has also been a topic of particular study. For instance, Amelsvoort and colleagues tested the ways that dyadic collaborative construction of computer-based argumentative diagrams affected learning and discovered that the individuals who participated in dyadic interactions that concentrated more in contrasting nodes in the diagram (topics) as part of their collaboration showed better results in a post test (Amelsvoort, Andriessen, & Kanselaar, 2008). Suthers and colleagues have obtained similar results not only for argumentation but for more generic collaborative contexts that involved representational support (Suthers, 1999; Suthers & Hundhausen, 2003). Most of the studies that investigate argumentation, negotiation, and peer-explaining, however, concentrate in short-term, dyadic interactions and rarely explore extended periods of interaction with dynamic changes in participants.

Knowledge co-construction in small groups is perhaps the interactional mechanism that has received more recent attention and also the one that more directly studies the kind of episodic and participation discontinuities over time that we are interested in. Perhaps one of the best examples of research in this paradigm is Barron's study of "when smart groups fail" (2003). In this study, Barron investigated triads of 6th grade students engaged in collaborative mathematical problem solving face-to-face. Her analysis of the observed interactions proposed that when attempting to understand unsuccessful collaborations of triads comprised of participants with high levels of prior knowledge in contrast to the successful interactions of triads with low prior expertise, the answer could be found in tracing the social and cognitive dynamics of such interactions and investigating the ways in which both are interwoven in the establishment of a "joint problem-solving space" (Teasley & Roschelle, 1993). In fact, the concept of a joint problem space is another example of a study aimed at illuminating the interactional processes of collaboration. Teasley and Roschelle postulated the concept when exploring how dyads using a physics software simulation in order to learn about concepts such as velocity and acceleration constructed and maintained a shared set of goals, descriptions of the current problem state, and awareness of available problem solving actions and, as result, produced a "deep-featured situation" to which progressively higher standards of convergence was applied through interactive cycles of conversation. Barron's analysis, in turn, illuminated a set of specific practices that the participants in her study engaged in when attending to social and cognitive factors in the development and maintenance of a similar "between-person state of engagement" (p. 349). Interestingly, patterns of interaction related to a group's inability to attend to their common views of the problem or to coordinate their reciprocal participation were particularly salient in groups that failed to achieve and maintain "mutual engagement." As a result, such groups were unable to capitalize on the ideas and proposals of their members during their short-term collaboration (p. 311).

Another representative series of studies within this paradigm was conducted by Schwartz to explore the discontinuity between what a group could be expected to produce under the "most competent member" model of group performance and the actual products generated by dyads working with novel problems (Schwartz, 1995). These experiments showed that the dyads generated problem-solving representations that were of more abstract nature (e.g., directed graphs, matrices, etc.) in a rate that was above what the model predicted. In fact, Schwartz argues that these more abstract representations emerge from the 'demands' that collaboration

imposes on dyads to overcome the gaps or discontinuities between the representations constructed by individuals resulting in the creation of a common representation coordinating the different individual perspectives on the problem. According to Schwartz, it was precisely because the representation was built through interaction and oriented to overcoming discontinuities in the individual perspectives of the problem structure that it tended to be an abstraction as opposed to being the result of any individual's mental construction. More recently, Schwartz and his colleagues have explored the interactional aspects of knowledge transfer of over time and across situations or, more specifically, two types of knowledge discontinuities over time: the 'knowledge problem' (how prior knowledge can contribute to creating new knowledge) and the 'inertia problem' (how people fail to innovate even though they have the relevant prior knowledge) (Schwartz, Varma, & Martin, 2008). Although concentrated on individuals and not on groups per se, the results of these experiments seem to indicate that there are mechanisms that underlie knowledge transfer and innovation: '*similarity transfer*' (i.e. recognizing that well-formed prior ideas can be profitably used in a new way in a new situation) and '*dynamic transfer*' (i.e. coordinating component competencies through interaction with the environment to yield novel concepts or material structures).

Clark and Schaefer's "*contribution model of grounding*" (Clark & Brennan, 1991; Clark & Schaefer, 1989) is also one of the communication theories most commonly used in CSCL and CSCW studies to describe the processes of co-constructing shared understanding in small-group collaboration. This model concentrates on the ways that parties in a conversation (mostly dyads) manage the discontinuities in their individual knowledge and coordinate mutual knowledge, mutual beliefs and mutual assumptions. According to the model rational parties in a conversation not only produce and receive messages but also monitor their mutual understanding by seeking and providing feedback that the message has been understood or by "specifying some content and grounding it" (Ibid, p. 124). Grounding in this sense means a collective process by which the participants in a conversation try to reach the 'mutual belief' that the contributor of an utterance and his partners have understood what the contributor meant based on a criterion sufficient for their current purposes (the *grounding criterion*) (Ibid, p. 129). The mechanics of this process are described as the combination of a *presentation* phase followed by an *acceptance* phase operating on the underlying concept of "common ground." These concepts have been used to outline how conversational parties are seen to reach identical or closely aligned mental contents. As part of the interaction paradigm,

several studies have used grounding as a central theoretical concept to explain interactional aspects of how knowledge is established through conversation (Baker *et al.*, 1999; McCarthy, Miles, & Monk, 1991). The central premise of these studies is that the frequency and qualitative differences in which parties in conversation (mostly dyads) engage in grounding is closely related to the outcomes of the collaboration in terms, for instance, of increased individual knowledge or the ability to solve a problem together.

Recently, however, significant criticism has been expressed about the limitations and inadequacies of this model to truly capture the interactional aspect of collaborative meaning-making (Koschmann & LeBaron, 2003; Koschmann *et al.*, 2001; Stahl, 2006c). On the one hand, for these researches it does not appear to be clear how the systematics of the model scale up to interactions that span larger collectivities and time scales from the short dyadic exchanges studied by Clark and Brennan. In addition, the concept of *common ground* as a psycholinguistic object does not seem to be sufficient to explain how complex shared understandings, routines, and community norms, are created and maintained in sustained collaborative interactions. As Koschman and LeBarron argue (2003) the notion of common ground indexes “a place where things can be stored or recorded, but this is a profoundly misleading connotation...common ground is, after all, a place with no place. It is a cooperatively constructed mental abstraction, available to no one” (Koschmann *et al.*, 2001, August p. 520). In this sense, this concept, although initially derived from interest in the interactional process of “grounding” or monitoring the hearer’s understanding of the conversation, has often been used more as an object of individual mental representation or short-term memory. This situation exemplifies one of the central challenges for theories of collaboration and collaborative learning: specifying what is meant by “shared.” Some uses of common ground (in resonance with many information-processing approaches to collaboration) seem to equate shared with overlapping mental representations while other interactional approaches locate “shared” within the interaction itself and the methods used by participants to constitute and orient to the shared character of their experience (Garfinkel, 1967) or as Schegloff describes (1991a): “a procedural sense of common or shared, a set of practices by which actions and stances could be predicated on and displayed as oriented to knowledge held in common —knowledge that might thereby be reconfirmed, modified, and expanded” (p. 152).

Despite the progress made within the interactions paradigm, remaining challenges abound. For instance, most of the interactional mechanisms investigated so far within the field of Computer-supported Collaborative Learning concentrate on short-term collaborative situations of dyads or triads (e.g., peer-explaining, argumentation, negotiation) and fail to specify whether such interactional mechanisms would scale up to longer temporal engagements beyond single episodes of interaction or to larger collectivities (e.g., online communities or collections of small teams.) In the case of co-construction, for example, it has been presented in the literature as synchronous and local phenomena and theorized to work through episode-bound, moment-by-moment engagement in attending and monitoring shared issues of understanding (Chi, Siler, & Jeong, 2004), exploring and transforming the joint problem-space (Roschelle, 1996), and engaging with each other's proposals (Stahl, 2006d). Our choice of research problem challenges us to investigate how the apparent discontinuity of the interactions over time affect these processes when virtual teams collaborate over time as part of an online community, and what new processes of co-construction of knowledge might emerge in these contexts. The type of activity that we have identified as 'bridging' clearly goes beyond simple peer-explanations or recalling of findings, primarily, because of the active and multi-dimensional engagement that characterizes what team participants to orient to. In addition, the boundaries imposed by multiple interactional episodes over time and multiple changing collectivities seem to inflict significant constraints on how the traditional interactional mechanisms, discovered mostly from studying single-episode dyadic interactions, are enacted.

Progressive Problem Solving and the Theory of Knowledge Building

In general, even in CSCL only a handful of studies treat the small group as the unit of analysis while instead treating the collectivity as a context in which individuals interact. Our proposed focus on bridging and its relationship to collaborative learning over time, attempts to contribute to the emergent preoccupation for treating collectivities as holistic units and tracing their knowledge-related activity over time. One unique line of research in CSCL contrasts with the shortage of studies examining the continuous nature of knowledge-related mechanisms underlying longitudinal sequences of small-group interactions: the theory of knowledge building. In this theory developed by Carl Bereiter and Marlene Scardamalia (Scardamalia & Bereiter, 1996) (as well as in the computer supports designed to support it), it is argued that successful collective learning results from the

intentional engagement in a progressive process of idea refinement and communal discourse as part of a shared enterprise. Progressive problem solving is seen as the identifying characteristic of both individuals becoming experts and also experts working “at the edges of their competence” both strongly situated in a socio-cultural setting.

Bereiter and Scardamalia’s theory of knowledge building integrates cognitive theories of learning and intentionality as well as models of expertise development in an attempt to illuminate the ways that individuals within communities engage in defining and advancing challenges of understanding for themselves and for the whole community. Bereiter’s definition of knowledge building (Bereiter, 2002) builds on Popper’s (1979) distinction between three types of worlds or realities: the physical reality (World 1), the mental reality (World 2), and a third world pertaining to conceptual entities, such as theories, designs, plans, and ideas. In line with Popper, Bereiter emphasizes that humans actively participate in constructing and living in world three and that conceptual artifacts in world three are more central to human work today than physical things are (although often closely related). In contrast, much of education and traditional epistemology rely heavily on views that place world two, the world of mental ideas, at the core of what learning and knowledge are about. Knowledge building, on the other hand, argues for research to trace the deliberate and collective activities that people engage in when building knowledge together—collaborative efforts to create, develop, understand, and criticize various conceptual artifacts.

Research on collaborative knowledge building has experienced a considerable uptake in the last decade (Bereiter, 2002; Campos, 2004; Scardamalia & Bereiter, 1996, 2006). The main goal of this research has been the discovery of the processes through which communities produce *conceptual artifacts* and the tracing of these artifacts’ histories as they are shared, integrated and extended. This has resulted in the study of the essential conditions necessary for knowledge building communities to flourish which as Bielaczyc and Blake argue, involve “shifting epistemologies” in individual participants while Scardamalia and others note the need for “collective cognitive responsibility” as a defining factor for knowledge building (Bielaczyc & Blake, 2006; Gilbert & Driscoll, 2002; Scardamalia, 2002). In addition, studies such as those by Aalst and colleagues have illustrated how knowledge building takes place as a distributed activity in the collaborative context (Aalst, Kamimura, & Chan, 2005), and have also explored what could be indicators to signal

that knowledge building is actually taking place (Lipponen, 2000). However, much research is still needed regarding the actual dynamics of the processes that are characteristic of knowledge building and, specially, the way that such processes relate to the temporal unfolding of collaborative engagements.

Considerable research around this theory has also documented the viability of decentralized, open knowledge building and the development of collective knowledge as well as the necessary pedagogy and technological supports for it to flourish (Scardamalia & Bereiter, 2006). A series of principles have been advanced to characterize successful knowledge building including *idea diversity*, *collective responsibility*, *epistemic agency*, and *symmetric knowledge advancement* (Scardamalia, 2002). Many of these principles operate at the 'macro' or 'community' level while their interactional achievement at the small-group and individual levels is still a matter of open research. We see our proposed research as expanding this line of inquiry by illuminating the interactional aspects of how progressive knowledge building is actually achieved by small-groups situated in an online community and, specifically, how bridging of interactional episodes, collectivities, and conceptual artifacts over time contributes to the sustainability of knowledge building.

Research about virtual communities, a field closely related to CSCL, has also advocated a more encompassing approach to investigation of how knowledge is built over time in large online interaction spaces. Unfortunately, most of the online communities investigated are typically based on asynchronous mechanisms of participation (e.g., online forums and discussion boards) and offer views highly anchored by this factor. Despite this limitation, the foundation established by this research is highly relevant to our research interests. For example, Renninger and Shumar (Renninger & Shumar, 2002) in their introduction to the first collection of research on how learning and change can be fostered by online communities, argued that "the connection (that participants develop in) virtual communities is supported by affordances that invoke imagination about and identification with a site, such as autonomy, time, space, choice, opportunity, support, and depth of content. Furthermore, the learning that is undertaken as participants work with a site has an agency and opportunity for changed understanding of self" (Ibid, p. 7). It is our goal to examine through our analysis of virtual teams the similarities with these observations. The authors also state that "the availability of stored resources and information, coupled with the flexibility in the time and space of usage, may well account for the attributions of utopian possibilities for community via the Internet"

(ibid, p. 11). Our interest in the longitudinal interactions of virtual teams and in the ways that elements of their activity system can support them is aligned with this observation and will potentially expand its applicability to other forms of interaction. Other authors (Stahl, 2004b) also argue that small groups represent the central mediating force between individual learning and community learning, and that "community participation takes place primarily within small group activities. The proposed plan of research offers an opportunity to test this conjecture empirically.

Next, we review some of the supporting theoretical frameworks and areas of research relevant to the proposed research questions mostly as they relate to this third paradigm of research on the processes of building collaborative knowledge.

2.2. Situated and Group Cognition

As we mentioned before, a foundational research theory in the field of Computer-Supported Collaborative Learning and of Situated Cognition lies on the research program outlined by Vygotsky's socio-historical psychology (Vygotsky, 1930/1978, 1934/1986; Wertsch, 1985). Vygotsky's "genetic law of cultural development" suggests that higher psychological functions in humans originate at the social level (between people), and only later, through a "long series of developmental events", these functions are internalized by the individual. This perspective not only attempts to bring to human cognition an integrative approach which contrasts sharply with the emphasis given by traditional cognitive science to discrete disembodied acts (representation, pattern matching, decision making, memory, etc.) but also enhances the unit of analysis from such discrete mental processes to artifact-mediated and object-oriented action by individuals and collectivities.

The 'situative' alternative approach to the study of human cognition has led to developments in diverse fields. For example, in the 1980s social scientists became interested in investigating the social contexts of learning and cognition and understanding socially organized interaction as a form of cognition. Lucy Suchman, for instance, argues that the 'commitment' to situated action "orients us always to the question of just how, and for whom, culturally and historically recognizable formations take on their relevance to the moment at hand" which, in terms of the study of knowledge-building translates into the exploration of how knowledge is "recognized to be the accumulated history of locally co-constructed occasions of knowing-in-

action and whatever memories of those the participants can reconstruct to meet the demands of further situated events.” (Suchman, 2003). In her seminal research, Suchman (1987) shows that plans should be seen as “resources for situated action” instead of being mental objects which strongly determine the course of action (p. 52). Similarly, Jean Lave and her colleagues as well as other researchers studied everyday problem solving and learning and proposed that reasoning strategies and solutions were better understood as emerging from interactions between people and resources in particular settings, rather than as outcomes of mental operations applied to symbolic representations (Greeno & The Middle School Mathematics Through Applications Project Group, 1998; Lave, 1988, 1991; Lave, 1996; Resnick *et al.*, 1991; Rogoff, 1990; Stahl, 1993).

More recently, Hutchins’ theory of distributed cognition (Hutchins, 1995, 1999; Hutchins & Palen, 1998) has attempted to understand interactions among people and technologies in order to understand the organization of a ‘culturally constituted functional group’ as a cognitive system. Cognitive processes ‘in the wild’ are characterized by functional relationships among diverse elements such as individuals and artifacts which participate together in enacting the cognition of the system. The ‘distributed’ aspect of cognition encompasses three dimensions: the social (cognition distributed across members of a group), materiality (cognition distributed across internal and external resources) and historical dimensions (cognition distributed across events in time).

Greeno has argued that all of these perspectives share in common a “situative” approach to understanding ‘intact systems’ of activity (Greeno & The Middle School Mathematics Through Applications Project Group, 1998). An ‘intact’ activity system being that in which diverse participants, material resources, and their processes of interaction over time are preserved and accounted for within research instead of controlled for (Engestrom & Middleton, 1998; Maxwell, 2004; Suchman, 1987; Winograd & Flores, 1986). According to his view, in the situative approach, human practices are “always stretched across multiple participants, working together with complex designed artifacts” leading us to re-conceptualize learning as ‘appropriation of tools and practices’ of a community, rather than ‘internalization’ or ‘acquisition’ of a body of facts and cognitive procedures (Wertsch, 1998). Similarly, in their recent ‘primer’ on Situated Cognition Robbins and Aydede also argue that there are three central claims or aspects of these new approaches to human cognition: That mind is *embodied* (cognition depends not only on the brain but also

on the body), *embedded* (cognitive activity involves constructing and exploiting the structure in the natural and social environment), and *extended* (cognition goes beyond the boundaries of individual organisms) (Robbins & Aydede, 2009). The authors argue that assigning an important explanatory role to the interactions between brain and body (embodiment) and between agent and the environment (embeddedness) does not constitute a sharp break from 'classical' cognitive science, but arguing that the boundaries of cognitive systems can be 'extended' beyond individual organisms integrating material and social environments (Dourish, 2001) radically challenges the Cartesian internalist tradition and classical information-processing cognitive science.

**Table 4. Three central claims of Situated Cognition.
(Robbins & Aydede, 2009)**

The Embodied Mind	The Embedded Mind	The Extended Mind
Cognition depends not only on the brain but also on the body.	Cognitive activity involves constructing and exploiting the structure in the natural and social environment	Cognition extends beyond the boundaries of individual organisms

The challenge for the situative approach becomes then to describe to what extent and in what ways are practices such as those related to reasoning, representation, and knowledge building constituted in and through the social, cultural and material aspects of situations. For example, in the area of human problem solving, as Kirsh has eloquently argued in his review of empirical situative research, this perspective has succeeded in "calling attention to deficits of the classical approach" but it has yet to "offer substantive theories of problem solving" (Kirsh, 2009). In part, this deficit emerges, as we argued before, from the need to tailor and strengthen the analytical methods employed to pursue rich descriptions of naturalistic settings of joint activity. The challenge might be conceptual as well. As Adams and Aizawa argue, there is an important distinction between arguing that cognition involves systematic and 'causal' interaction with things outside the head as opposed to arguing that such things instantiate cognitive properties or undergo cognitive processes (Adams & Aizawa, 2007). Our proposed research takes this aspect of situated cognition as a central goal of our inquiry and aims at exploring within the context of VMT interactions the ways in which participants themselves orient to their collective organization of action and to the material resources they produce and

employ as part of moments of collective interaction which link multiple episodes within a team's trajectory of action over time.

As illustrated earlier, two recurring challenges which cut across different situative approaches to cognition are the challenge of extending our investigation of human practices to go beyond the individual as well as to study what Lave and Wenger described as "the relational interdependency of agent and world, activity, meaning, cognition, learning, and knowing" (Lave & Wenger, 1991 p. 50). The theory of Group Cognition takes these two central themes as its direct research interests (Stahl, 2006a). By investigating the moment-by-moment unfolding of the collaborative discourse and the ongoing development of meaning constructed through the interactions of small groups, research on Group Cognition attempts to illuminate the underlying interactional processes that make building collaborative knowledge possible. For example, in a micro-analysis of the interaction of a small group of five students working face-to-face with a computer simulation, Stahl traces the intricate web of discursive references (through talk, gesture, and direct manipulation of artifacts) and the ways that such practices allow the group to embed a previously confusing artifact with the local meaning that is required for their collaborative investigation (Stahl, 2004a). Tracing the moment-by-moment unfolding of this interaction allows this type of analysis to uncover the "indexical, elliptical, and projective" meaning situated through the participant's actions. In a similar investigation, Stahl traces the sequence of problem-solving proposals made by a virtual team of three students working on a mathematical problem and shows how the interactional construction of a "math proposal adjacency pair" influences the way the group conducts its problem solving and the ultimate outcome (Stahl, 2006d). This interactional pattern involves a pair of postings ("a bid and an acceptance" postings) and a follow-up, and usually ties together multiple conversational parties and often a number of conversational turns. The analysis put forward demonstrates that these interactions are not a simple "expression of pre-existing mental representations" but the careful co-construction of shared meaning constituted through the 'binding together' of postings from different people and the orientation to such bindings as meaningful units for the participants.

Although these different models of situated cognition have made significant contributions to an expansive and realist view of human cognition much work remains to be done. In our particular case, our research questions point to the need to better investigate how participants construct interactionally and historically

recognizable organizations of knowledge-building action within the Virtual Math Teams online context and how knowledge is recognized by the collectivity of teams to be the sustained history of those locally co-constructed episodes of knowing-in-action.

2.3. Time and Change Small Group Research and Team Cognition

The interdisciplinary field of Small Group Research has also contributed to the study of discontinuities in a great variety of types of groups and contexts. As Arrow and her colleagues have recently argued, theories of change in groups and group development, address three key concepts: *change*, *stability*, and *continuity* (Arrow et al., 2004). The goal of most research on group development is to learn why and how small groups change over time (e.g., Wheelan, 1994b). In other words, to understand discontinuities on group dynamics over time and examine patterns of change and continuity in characteristics of a group such as the quality of its output over time, the type and frequency of its activities, its cohesiveness, the existence of conflict, etc. A number of theoretical models have been developed to explain how different types of groups change over time (group development) although, in a similar turn as the one discussed previously for CSCL research, Small Group Research has often concentrated on understanding the intermediate processes which describe the ways that group interactions are related to the conditions in which groups act and their outcomes, instead of simply the effects of group activity or the performance comparisons between individuals and groups (Hare, 1976; Hare, 1992; Hare, 2003). In this section, we will explore some of the group development models that directly address episodic and participation discontinuities over time.

In general, some of the models of group development view group change as regular movement through a series of "stages," while others view them as "phases" which groups may or may not go through and which might occur at different points of a group's history. Attention to group development over time has been one of the differentiating factors between the study of ad hoc groups and the study of teams such as those commonly used in the workplace, the military, sports and many other contexts. An important observation made by McGrath and Tschan (2004a) regarding the different models of group development is that different models might explain different aspects of the history of a group. On the one hand, some models treat the group as an entity and describe its stages of development as a functioning unit or "intact system" (p. 101). In this case, the models should be independent of the

specific details of the task that the group is performing. On the other hand, some models might describe phases of the group's task performance and, because of this, tend to be very sensitive to the type of task that the group is engaged in (the "acting system", p. 101). In this section, we review those models that directly address the interactional processes which relate to how small groups orient to their own task-oriented development over time (See Smith, 2001 and Van de Ven & Poole, 1996 for a complete list of theories and models of group development).

Task and Social Concerns in Short-term Group Interactions

Studies pioneered by Bales since the early 50s (Bales, 1951, 1953; Bales & Strodtbeck, 1951) focused on discovering the sequences of activities through which groups reach solutions and pioneered the use of various systems of categorization to code and analyze groups interactions. By abstracting the rhetorical form of group members' talk from its content and recording percentages of statements made in categories like "agree" and "gives orientation," this type of research has constructed models of the structure of group discussion over time. Bales argued that there were two main categories of group behaviors: socio-emotional (i.e., showing solidarity/antagonism, showing tension/tension release, and showing agreement/disagreement) and task or problem-solving oriented (i.e., giving/asking for suggestions, giving/asking for opinions, and giving/asking for information). The classic model proposed by Bales and Strodtbeck (1951) described a unitary sequence of three phases in groups' movement toward goals: *orientation*, *evaluation*, and *control*. During *orientation*, leaderless laboratory groups began by placing major emphasis in activities such as asking for and providing orientation to the task. Such orientation serves to define the boundaries of the task (i.e., what is to be done) and the approach that is to be used in dealing with the task (i.e., how it is to be accomplished). The orientation phase is followed by a period in which major emphasis is placed on problems of *evaluation*, for example asking for members opinions or giving one's opinion about the task to be accomplished by the group. In the third and final phase the group is primarily concerned with problems of *control*, reflected in activities such as asking and providing suggestions for solutions to the task based on information gathered and evaluated in previous developmental periods. Although this categorization system and related model has been used extensively, its framework maintains a strong separation between social aspects of groups interactions and its task-oriented counterparts (Hare, 1992) without providing descriptions on the interactional ways in which the former relates to the latter. In

addition, this model does not explicitly address temporal-related processes through which groups constitute their episodes of interaction to be resources to shape their own development over time.

As Gersick (1988) has pointed out, some later models followed similar sequential patterns to those proposed by Bales and others. Examples include: define the situation, develop new skills, develop appropriate roles, carry out the work (Hare, 1976); orientation, dissatisfaction, resolution, production, termination (Lacoursiere, 1980); and generate plans, ideas, and goals; choose and agree on alternatives, goals, and policies; resolve conflicts and develop norms; perform action tasks and maintain cohesion (McGrath, 1984). In contrast, other models provided richer descriptions of the actual interactional concerns that groups experience over time. Fisher's model, for instance, outlines four phases through which task groups tend to proceed when engaged in decision making (Fisher, 1970). These phases were derived from observing the distribution of act-response pairs ('interacts') across different moments of a group's process and noting how the interaction changed as the group decision was formulated and solidified. During the *orientation* phase, group members get to know each other and they experience a primary tension: the awkward feeling people have before communication rules and expectations are established. Groups take time to learn about each other and feel comfortable communicating around new people. The *conflict* phase is marked by secondary tension, or tension surrounding the task at hand. Group members will disagree with each other and debate ideas. Here conflict is viewed as positive because it helps the group achieve positive results. In the *emergence* phase, the outcome of the group's task and its social structure become apparent. Group members soften their positions and undergo an attitudinal change that makes them less tenacious in defending their individual viewpoint. Next follows a stage of *reinforcement* in which group members bolster their final decision by using supportive verbal and nonverbal communication. Fisher, in analyzing the cyclical and sometimes erratic trajectories of groups, hypothesized that the interpersonal demands of discussion require "breaks" from task work and adaptations to their decision paths. For instance, in modifying proposals, groups tended to follow one of two patterns. If conflict was low, the group reintroduced proposals in less abstract, more specific language. When conflict is higher, the group might not attempt to make a proposal more specific but, instead, because disagreement lies on the basic idea, the group introduces substitute proposals of the same level of abstraction as the original (p. 64). This model offered richer descriptions of interactional group processes in comparison to Bales' approach

but still concentrated on contexts of where groups participated in single episodes of collaborative decision making and had no interaction with other groups.

Many other theorists of change and discontinuity in groups have orbited around the dichotomy of task and social activity expressed by Bales' and Fisher's models even when considering group interaction over longer periods of time than a single episode of collaboration. For example, recently, Poole has suggested that groups exhibit three activity tracks: task progress, relational, and topical focus. The *task track* concerns the process by which the group accomplishes its goals, such as dealing doing problem analysis, designing solutions, etc. The *relation track* deals with the interpersonal relationships between the group members. At times, the group may stop its work on the task and work instead on its relationships, share personal information or engage in joking. The *topic track* includes a series of issues or concerns the group have over time. Interspersed with these tracks are breakpoints, marking changes in the development of strands and links between them. Breakpoints occur when a group switches from one track to another. Shifts in the conversation, adjournment, or postponement are examples of breakpoints. Normal breakpoints pace the discussion with topic shifts and adjournments. Delays, another type of breakpoint, are holding patterns of recycling through information. Finally, disruptions break the discussion threads with conflict or task failure (Poole, 1983; Poole & Roth, 1989; Poole & Van de Ven, 2004a, 2004b).

Similarly, the TIP theory of groups (McGrath, 1991) emphasizes the notion that different teams might follow, over time, different paths to reach the same outcome but will always combine task and social concerns. The TIP theory suggests that teams engage in four modes of group activity: *inception*, *technical problem solving*, *conflict resolution*, and *execution*. According to this model, modes "are potential, not required, forms of activity" (p. 153) resulting in modes I and IV (*inception* and *execution*) always being at the onset and at the end of all team projects while modes II and III may or may not be needed depending on the task and the history of the group's activities. Sometimes the terms meaning, resources, integration, and goal attainment are also used for these four modes (Hare, 2003). TIP theory contends that for each identified function, groups can follow a variety of alternative "time-activity paths" in order to move from the initiation to the completion of a given function. Specifically, it states that there is a "default path" between two modes of activity which is "satisficing" or "least effort" path, and that such default path will "prevail unless conditions warrant some more complex path" (1991, p. 159).

This model also states that groups adopt these four modes with respect to each of three team functions: *production*, *well-being*, and *member support*. In this sense, groups are seen as "always acting in one of the four modes with respect to each of the three functions, but they are not necessarily engaged in the same mode for all functions, nor are they necessarily engaged in the same mode for a given function on different projects that may be concurrent" (p. 153). The following table illustrates the relationship between modes and functions.

Table 5. Modes and Functions in the Time, Interaction and Performance Model of Group Development. (Adapted from Figure 1 in McGrath, 1991, p. 154)

Functions			
	Production	Well-being	Member Support
Mode I: Inception	Production Demand/ Opportunity	Interaction Demand/ Opportunity	Inclusion Demand/ Opportunity
Mode II: Problem Solving	Technical Problem Solving	Role Network Definition	Position/ Status Attainment
Mode III: Conflict Resolution	Policy Conflict Resolution	Power/ Payoff Distribution	Contribution/ Payoff Relationships
Mode IV: Execution	Performance	Interaction	Participation

Group Dynamics Over Longer Sequences of Interaction

Gersick's study of naturally occurring groups departs from the traditionally linear models of group development. Her punctuated equilibrium model (Gersick, 1988a; Gersick, 1989, 1991) suggests that groups develop through the sudden formation, maintenance, and sudden revision of a "framework for performance". This model describes the processes through which such frameworks are formed and revised and predicts both the timing of progress and when and how in their development groups are likely, or unlikely, to be influenced by their environments. The specific issues and activities that dominate groups' work are left unspecified in the model, since groups' historical paths are expected to vary. Her proposed model works in the following way. In *Phase I* a framework of behavioral patterns and assumptions through which the group approaches its project emerges in its first meeting, and the group stays with that framework through the first half of its life. Teams may show little visible progress during this time because members may be unable to perceive a use for the information they are generating until they revise the

initial framework. At their calendar *midpoints*, groups experience transitions-paradigmatic shifts in their approaches to their work-enabling them to capitalize on the gradual learning they have done and make significant advances. The transition is a powerful opportunity for a group to alter the course of its life midstream. But the transition must be used well, for once it is past a team is unlikely to alter its basic plans again. A second period of inertial movement, takes its direction from plans crystallized during the transition. At completion, when a team makes a final effort to satisfy outside expectations, it experiences the positive and negative consequences of past choices.

This group development model has been scaled up to the level of the organization where the punctuated equilibrium paradigm has been used to explain how organizations, and even industries might develop over time and react to changes in their environments (Gersick, 1991). The basic idea is that major change occurs through “difficult, compact revolutions” which, as Weick and Quinn have argued (1999), only accounts for one type of organizational change and leaves out the more continuous ‘variations of practice’ that characterize organizations.

Similarly, Susan Wheelan proposed a “unified” or “integrated” model of group development (Wheelan, 1994b) which, although linear in a sense, takes the perspective that groups achieve maturity as they continue to work together rather than simply going through stages of activity. In this model “early” stages of group development are associated with specific issues and patterns of talk such as those related to dependency, counter-dependency, and trust which precede the actual work conducted during the “more mature” stages of a group's life. In the first stage of the model labeled ‘*dependency and Inclusion*’ there is significant member dependency on the designated leader, concerns about safety, and inclusion issues. In this stage, members rely on the leader and powerful group members to provide direction. Team members may engage in what has been called “pseudo-work,” such as exchanging stories about outside activities or other topics that are not relevant to group goals. In the second stage of *Counter-dependency* and *fight* members disagree among themselves about group goals and procedures. Conflict is an inevitable part of this process. The group's task in this second stage is to develop a unified set of goals, values, and operational procedures, and this task inevitably generates conflict. Conflict is also necessary for the establishment of trust and a climate in which members feel free to disagree with each other. If the group manages to work through the inevitable conflicts of stage 2, member trust, commitment to the group, and

willingness to cooperate increase. Communication becomes more open and task-oriented. This third stage of group development, referred to as the *trust and structure* stage, is characterized by more mature negotiations about roles, organization, and procedures. It is also a time in which members work to solidify positive working relationships with each other. Stage IV of *work and productivity*, as its name implies, is a time of intense team productivity and effectiveness. Having resolved many of the issues of the previous stages, the group can focus most of its energy on goal achievement and task accomplishment. Finally, groups that have a distinct ending point experience a fifth stage. Impending termination may cause disruption and conflict in some groups. In other groups, separation issues are addressed, and members' appreciation of each other and the group experience may be expressed.

It is important to point out, considering our interest in collaborative knowledge-building over time, that Wheelan's model does not assume an unproblematic flow of time in the process of a group reaching maturity. In particular she analyzes how external membership disruption can stifle development and even trigger the return to a previous stage. (Wheelan, 1994, p. 18). Similarly, early models of group development had recognized that there was a carryover effect of member continuity (Hill & Gruner, 1973) and their observations align with the more situated analysis of membership changes presented by Lave and Wenger (Lave, 1991; Wenger, 1998).

Based on this model, Wheelan has created and validated both a Group Development Observation System (GDOS) and a Group Development Questionnaire (GDQ). The GDOS allows researchers to determine the developmental stage of a group by categorizing and counting each complete thought exhibited during a group session into one of eight categories: Dependency, counter-dependency, fight, flight, pairing, counterpairing, work, or 'unscorable' (Wheelan, 1994a). The GDQ is used to survey group members and assess their individual perception of their group's developmental state (Wheelan & Hochberger, 1996). In her empirical validation of the model, Wheelan (2003) analyzed the relationship between the length of time that a group has been meeting and the verbal behavior patterns of its members as well as the member's perceptions of the state of development of the group. Her results seem to indicate that there is a significant relationship between the length of time that a group had been meeting and the verbal behavior patterns of its members. Also, members of older groups tended to perceive their groups as having more of the characteristics of Stage-3 and Stage-4 groups and to be more productive. Based on

these results, Wheelan's position supports the traditional linear models of group development and casts doubt on the cyclic models and Gersick's punctuated equilibrium model.

From Groups to Teams

Social psychology and the field of Small Group Research initially responded to research gap left by the fact that most of the behavioral research on problem solving and creativity has traditionally been conducted with individual subjects as the unit of analysis (Davidson & Sternberg, 2003; Sternberg, 1999). Recent interdisciplinary research has taken this transition one step further by acknowledging that key group processes such as those related to group formation, development, and adaptation have only been superficially understood by the laboratory experiments that had dominated the empirical studies conducted (Arrow *et al.*, 2000). In response, researchers have advocated studies that move away from laboratory experiments with ad hoc groups that have "no past and no anticipated future" (Arrow *et al.*, 2005) and investigate the temporal unfolding of "groups' traces, trajectories and timings." Some of this work which views of groups as complex systems has attracted particular attention in the field of CSCW (Fitzpatrick, 2003; McGrath & Arrow, 1995) and other areas of socio-technical research concerned with the dynamics of knowledge management and organizational learning. However, as we noted before, the development of new analytical frameworks able to model and describe the complexity of group interactions over time represents a major challenge to the success of this approach to small group research. Related to this topic are studies that take the "team" as the central unit of analysis an attempt to account for the dynamics of sustained interaction over time in contexts such as flight crews, sports, the military, business, surgery, finance, scientific research and others. We review this literature next.

Flight crews and other military teams have been used repeatedly to illustrate the difference between teams and other forms of collectivities as well as to investigate team dynamics. An empirical analysis of flight crews, for instance, found that such teams learn to develop relationships quickly and that their patterns of communication provide better discrimination their performance than the content of their communication (Cannon-Bowers, Salas, & Converse, 1993; Stout, Cannon-Bowers, & Salas, 1996). A second study reported that newly formed crews communicate less effectively and are more likely to have accidents than are crews

that have been intact for at least a short time (Foushee *et al.*, 1986). Despite these supportive findings, more recent inquiry suggests that keeping the same crew members together for the long-term may lead to overconfidence and potential errors (Leedom & Simon, 1993). In a study of the temporal coordination of 35 global, virtual, student project teams communicating asynchronously, Massey, Montoya and Hung reported that teams enacted the same four team processes (i.e., conveyance, convergence, social/relational, and process management) but in different patterns over time and such differences influenced coordination on interaction behaviors that directly affected performance (Massey, Montoya-Weiss, & Hung, 2003). This type of study and its results point to a growing interest in the study of time and temporal coordination in teams (Arrow *et al.*, 2004).

The study of teams in organizations has been instrumental in the shift in focus from the study of ad-hoc groups into the analysis on teams or groups with a common history and a projected future. For instance, the most recent Annual Review of Psychology chapter dedicated to work groups concentrates its attention entirely on teams in organizations (Ilgen *et al.*, 2005) and points to the fact that there has been transition from linear Input – Process - Output models of teams (I-P-O models) toward models that offer a more complex iterative flow between Inputs-Mediators-Outputs-Inputs (I-M-O-I models). Conceptually, the authors argue, team researchers have converged on a view of teams as ‘complex, adaptive, dynamic systems’ existing in particular contexts and performing across time. Team interactions over time affect the teams themselves, their team members individually, and their environments in ways “more complex than is captured by simple cause and effect perspectives.” To summarize the recent literature from this perspective the authors organize concepts around three major phases of team development: *Forming*, *Functioning* and *Finishing* which manifest themselves in three dimensions: *Affective*, *Behavioral* and *Cognitive* (See Table 6).

**Table 6. Team Development Phases, Processes and Dimensions.
(Adapted from Ilgen et al. 2005)**

	Team Development Phases		
<i>Dimension</i>	[1] Forming (Input-Mediator)	[2] Functioning (Mediator-Output)	[3] Finishing (Output-Input)
Affective	Trusting: Team potency (competence); Safety (interpersonal).	Bonding: Managing Diversity of Membership, Managing conflict among team members.	Planned ending, collapse, task failure, member loss of interest, etc. Finishing processes: end-stage adjourning, decay, or termination. Also completion, transition, and metamorphosis.
Behavioral	Planning: Gathering information, developing strategy	Adapting: Performance in routine versus novel conditions, Helping and workload sharing.	
Cognitive	Structuring: Shared mental models, Transactive memory (collective awareness of who knows what)	Learning: Learning from minority and dissenting team members, Learning from the team's best member.	

The overall conclusion from this review points to the fact that theories of team development have visibly stated the importance of 'dynamic conditions' experienced by teams over time but that empirical research is yet to show the related team processes in detail. The authors also praised temporally-based models such as that of Marks, Mathieu and Zaccaro in which team processes are differentiated as 'action' processes (e.g., monitoring progress, monitoring systems, team monitoring, and coordination), 'transition' processes (e.g., mission analysis formulation and planning, goal specification, and strategy formulation), and 'interpersonal' processes (conflict management, motivation and confidence building, and affect management) (Marks *et al.*, 2001).

The construct of 'team knowledge' joins most of team research and is highly relevant to our research goals. Team knowledge, according to research in 'team cognition' includes knowledge about the group itself, its culture, structure, and norms; knowledge of each team member (e.g., who has special abilities); and knowledge about the tasks and in general the work of the team (Levine & Moreland, 1990; Salas & Fiore, 2004). In many cases, team knowledge is presented as the combination of 'mental models' which individual members bring to the group and which get 'updated' or co-constructed by the team members within the group interactions (Cannon-Bowers *et al.*, 1993; Stout *et al.*, 1996). By orbiting around meanings of "shared" or "common" that equate it with "overlapping" of schema or schema similarity (Salas &

Fiore, 2004), team cognition research often falls short of accounting for the social distribution of cognition in the ways called for by situated cognition and explored in our previous section.

One construct used in team cognition research, however, departs slightly from this view on team knowledge and attends more to the interactive way in which a team develops knowledge through interaction. For this, team researchers have borrowed the construct of *transactive memory* developed by Wegner from the study of interpersonal relationships.

Transactive memory was originally conceived as a way to comprehend group behavior “through an understanding of the manner in which groups process and structure information” (Wegner, 1986). The theory argued that a collectivity composed of individuals develops a memory system (internal and external) by constantly updating a ‘directory’ of expertise (knowing who knows what), communicating to allocate information, and communicating to retrieve information (Wegner, 1995). These three processes that allow a group to develop a ‘complete transactive memory system’ (i.e. *directory updating, information allocation, and retrieval coordination*) are, however, expressed by Wegner in terms of classical information-processing activities: acquiring information about what others are likely to know about, communicating incoming information to individuals whose expertise is likely to facilitate its storage, and having a retrieval plan for any topic based on one’s own expertise and that of the others in the group. The success of these processes is highly dependent on the establishment of a shared conception of the topics that the individual members know which the theory of transactive memory predicts is achieved through the grounding processes of communication described by Clark and Brennan as discussed before. Transactive memory is the basis for explaining how a team becomes a “knowledge-acquiring, knowledge holding, and knowledge-using system” (Wegner, Giuliano, & Hertel, 1985). The interdependence developed in this way, is theorized to create a holistic system of people, knowledge, and tasks responsible for the performance benefits usually attributed to teams. In this sense, the value of teams is related to an enhanced memory system that supports unique distributed operations.

In team cognition, transactive memory has been theorized as a distributed memory system through which a collectivity stores and recalls information. Experimental tests of the effect of transactive memory have attempted to measure it

through the lens of shared mental models (Hollingshead, 1998a, 1998b) and, as such, found to increase and affect performance positively when, for instance, teams participate in collective training programs (Moreland, 1999; Moreland & Myaskovsky, 2000) These studies have also suggested that group performance decreases with the turnover in group membership but that giving newcomers access to information about the knowledge of other group members (and vice versa) has positive effects. Although the concept of *transactive memory* seems to bring team research closer to an analysis of collective interactional processes, unfortunately, its utilization has not resulted in richer descriptions of 'how' teams develop and advance their knowledge building over time. Transactive memory has been measured in teams as type of content stored by individuals (Hollingshead, 1998a; Moreland, 1999; Moreland, Argote, & Krishnan, 1996) instead of as a set of interactional processes through which the distributed system of knowledge and memory is achieved and used in interaction.

Several studies have also proposed multiple transactive memory systems in teams. For instance, in a study of teams performing a flight simulation task, Mathieu and colleagues found two distinct types of 'shared' mental models: one concerned with task work and the other related to team work. When assessing the degree of overlap among individual members' mental models ('sharedness') and its relationship with overall task performance, the researchers found that outcomes were mediated by team processes such as strategy formation and coordination, cooperation, and communication (Mathieu *et al.*, 2005). Similarly, Rentsch and Klimoski found that 'schema agreement' ('sharedness') was critical for task performance (Rentsch & Klimoski, 2001).

Another unique topic which has recently emerged in the study of teams and which is highly relevant to our research questions is the study of team learning. Every theory and model of team development (and to some extent group development as well) explicitly or implicitly acknowledges the fact that newly formed teams learn to work together and existing teams change or adapt.. Empirical studies of learning in teams has revolved around three main strands: learning curves in operational settings leading to outcome improvement, team member coordination of task knowledge and task mastery, and field research on learning processes in teams (Bunderson & Sutcliffe, 2003; Edmondson *et al.*, 2003; Edmondson & Singer, 2008). Given our particular interest in interactional team processes and the fact that we have already reviewed some of the main studies in the first two strands, we review

the last strand here. Research investigating learning processes in teams generally departs from the measurement of performance changes as metrics of learning to, instead, concentrate on describing actual learning processes. Although many of these studies have taken a qualitative and descriptive approach to the study of team learning process, many of these processes have been inferred from reported behaviors via survey research. Nonetheless, both results are informative. For instance, a qualitative case analysis of process-improvement teams within the same organization described qualitative differences within two major team learning processes: a first set operating within team interactions included posing problems, presenting and discussing new ideas or information, etc. while a second set concentrated on outside-in processes such as those related to gathering and sharing information from outside the organization and the teams themselves (Brooks, 1994). Similarly, a second study focused on team leaders in more than 50 product development teams within several technology organizations and found that leader behaviors such as involving members in decision making, clarifying team goals, and bridging to outside parties had an facilitating effect on team learning (Sarin & McDermott, 2003). A study of surgical teams described a four-step learning process that included *enrollment*, *preparation*, *trials*, and *reflection* which teams used to organize their collective discussion and learning of each surgical case (Edmondson, Bohmer, & Pisano, 2001) while Gibson and Vermeulen analysis of team learning describes it as a cycle of *experimentation*, *reflective communication*, and *knowledge codification* (Gibson & Vermeulen, 2003).

Examples of the more quantitative survey research conducted in the area of team learning, includes Wong's survey of more than 70 teams from different companies across several industries in an attempt to capture 'local learning' or learning from interacting within the team and 'distal learning' or learning through using external resources. The more cohesive a team seemed to be, the more local and distal learning behaviors seemed to be present and, in turn, positive effects on performance were documented. However, the study indicated that distal learning could have a negative effect on team efficiency and suppress local learning on a team (Wong, 2004). In addition, in two surveys of more than 40 business-unit management teams the authors found that a team's emphasis on proactive learning and skill development (i.e. the team's 'learning orientation') can be a strong predictor of team performance but with an inverted-U relationship with the downward slope of the curve coming earlier for previously high-performing teams relative to those that have struggled initially.

Since a lot of the process-oriented research on groups has been conducted within organizational science and follows the assumption that team learning leads to organizational learning, we will revisit this topic in our next section.

Finally, it is worth mentioning that some of the group development models that we have explored in previous sections have also been the subject of study within team research. In particular, the *Team Evolution and Maturation (TEAM) model* combines ideas from models such as those of Tuckman and Gersick to describe a series of nine developmental stages through which newly formed, task-oriented teams are hypothesized to evolve (Morgan, Salas, & Glickman, 1994). The periods of development are labeled 'stages' and are conceived to be relatively informal, indistinct, and overlapping, because "sharp demarcations are not often characteristic of the dynamic situations in which operational teams work and develop". According to this model, teams might begin a given period of development at different stages and spend different amounts of time in the various stages. Teams are not always expected to progress in a linear fashion through all of the stages. A team's beginning point and pattern of progression through the stages depend on factors such as the characteristics of the team and team members, their past histories and experience, the nature of their tasks, and the environmental demands and constraints .

The TEAM model identifies a total of nine stages, seven central ones supplemented by two additional ones. The seven central stages begin with the formation of the team during its first meeting (*forming*) and moves through the members' initial, and sometimes unstable, exploration of the situation (*storming*), initial efforts toward accommodation and the formation and acceptance of roles (*norming*), performance leading toward occasional inefficient patterns of performance (*performing-I*), reevaluation and transition (*reforming*), refocusing of efforts to produce effective performance (*performing-II*), and completion of team assignments (*conforming*). The development of a team might be recycled from any of the final stages to an earlier stage if necessitated by a failure to achieve satisfactory performance or if adjustments to environmental demands are required or if problematic team interactions develop.

The core stages of the model are preceded by a *pre-forming* stage that recognizes the forces from the environment (environmental demands and constraints) that call for, and contribute to, the establishment of the team; that is,

forces external to the team (before it comes into existence) that cause the team to be formed. The last stage indicates that after the team has served its purpose, it will eventually be disbanded or *de-formed*. Here individuals exit from the group (separately or simultaneously) and the team loses its identity and ceases to exist.

The TEAM model also postulates the existence of two distinguishable activity tracks present throughout all the stages. The first of these tracks involves activities that are tied to the specific task(s) being performed. These activities include interactions of the team members with tools and machines, the technical aspects of the job (e.g., procedures, policies, etc.), and other task-related activities. The other track of activities is devoted to enhancing the quality of the interactions, interdependencies, relationships, affects, cooperation, and coordination of teams.

The way the TEAM models portrays team dynamics resembles what Arrow has argued to be a recent turn in group development literature: away from single 'best paths' to, instead, investigate the 'adaptive patterns' through which groups respond to task and contextual demands for their own purposes (Ancona & Chong, 1996; Arrow *et al.*, 2004)

The empirical study of teams today cannot be divorced from the study of teams use of technologies or from the analysis of the organizational contexts in which many teams operate. To reflect this, our next section concentrates on research in the fields of Computer-Supported Cooperative Work and Organizational Science.

2.4. Discontinuities in Collaborative Work, Information Systems, and Organizations

Virtual teams are often portrayed as collectivities 'spread across' discontinuities of location, time, and functional area (Gillam & Oppenheim, 2006) among other possible dimensions of discontinuity. In a recent review of the research literature on virtual teams, Martins, Gilson and Maynard point out to the fact that empirical interdisciplinary research in the last decade has responded actively to the growing demand for applied knowledge derived from the almost ubiquity of virtual teams interacting through technology within organizations (Martins, Gilson, & Maynard, 2004). The review concludes, however, that empirical research on this critical new type of organizational unit is still in its infancy but shows significant

promise. In reviewing team processes, for instance, the review uses the temporally-based framework proposed by Marks, Mathieu and Zaccaro (2001) mentioned earlier. This framework classifies team processes as ‘*planning*,’ ‘*action*,’ and ‘*interpersonal*’ processes. It was concluded that the majority of studies of virtual teams have focused on differences in team communication and participation patterns which show significant differences on how these processes manifest themselves in virtual teams versus face-to-face teams. However, the review suggests that more research is needed around three moderators of virtual team performance: *task type*, *time*, and *social context*. Related to time, the authors argue that most research on virtual teams has concentrated on using single work sessions, “thus ignoring the roles of time on group processes and outcomes” (p. 819). Strong interactions are reported between how *time* is conceived and approached and the other two moderator factors: *task type* and *social context*. In addition, the authors point out to the fact that interpersonal processes in virtual teams constitute an area in which major gaps exist, specially, as such processes relate to “long-term group outcomes” (p. 821). Similar reviews from the perspective of Information Systems (Powell, Piccoli, & Ives, 2004) and Information Science (Gillam & Oppenheim, 2006; Watson-Manheim *et al.*, 2002) support this assessment.

Research in the field of Computer-Supported Cooperative Work (CSCW) has explored issues of continuity and discontinuity of collaborative action and the designed environments aimed at supporting it. For instance, in their call to “take CSCW seriously” Kjeld Schmidt and Liam J. Bannon (1992) proposed the use of one of Anselm Strauss’s concepts, that of ‘articulation work’ —the ‘meshing of tasks, actors, and efforts (Strauss, 1985)— to be the central concern of studies of joint work. The authors also argued that CSCW needed to go beyond socio-technical studies of work in order to implement design research better suited to support successfully such types of cooperative arrangements. Building on the view of several CSCW researchers, Watson-Manheim, Chudoba and Crowston have argued that the notion of *discontinuity* as any “gap or a lack of coherence” in any aspect of work and the ways in which different arrangements of work address them constitute the central concepts that tie together studies of virtual or In reviewing 75 published articles on virtual work environments, the authors identified six dimensions of work that can be discontinuous: *physical location*, *temporal location*, *work group membership*, *organizational affiliation*, *relationship with an organization* (e.g., permanent vs. self-employed), and *culture* (e.g., nationality). Interestingly, the review points to the fact that most of the studies analyzed described how stability is

achieved through continuities — factors that are in place or emerge to bridge the discontinuities, such as shared motivation, understanding of the task, mutual expectations, and others. Examples include the way that well-structured governance mechanism emerge in voluntary open source software development projects (Markus, Manville, & Agres, 2000) as well as the many aspects of the socio-technical system in Wikipedia which lend themselves to the collective creation of formalized process and policy (Viégas, Wattenberg, & Mckeon, 2007). Finally, the authors argue that research should investigate “the discontinuities that enable the group to function effectively” such as those related to common tasks, common beliefs and values, common media; and common work practices. Although this observation seems to support our work we also want to caution against taking continuities (as well as discontinuities) as abstract static concepts disassociated from the actual doings of participants in interaction through which what is common or not gets constituted.

A large concern within CSCW research has revolved around decision-support systems and electronic meeting environments (e.g., Nunamaker *et al.*, 1991). Within these environments, it became evident that supporting continuity of interactions was both an opportunity (given the digital recordings available) but also a significant challenge. Diverse approaches to meeting synthesis and summarization have emerged, some which attempted to build intermediate semantic representations of the structure and content of the artifacts available as guides for the creation of summaries. Few of these approaches have evolved into mature summarization systems given the complexity of such approach. However, it is interesting to note that these line of research has concluded that providing users with appropriate interfaces for them to manage their own issues of continuity might be a more effective strategy than attempting to create perfect summaries of interactions (Farrell, Fairweather, & Snyder, 2001; Waibel *et al.*, 2001). More recently, Greenberg and Roseman have argued that using designs based on the room metaphor is an effective way to overcome the numerous “gaps” identified in computer-based joint activity by almost 20 years of CSCW research (2003). In particular, the authors explore how room-based designs with persistent records can ameliorate four different types of gaps: the gap between individual and team work, the gap between synchronous and asynchronous interaction, the social awareness gap, and the gap that needs to be overcome in order to foster a sense of community among teams. Unfortunately, no experimental data has been provided to date validating these claims. This dissertation provides an empirical analysis of how some

of these boundaries or gaps are actually bridged and how the proposed designs are enacted in naturalistic interactions.

In orienting to discontinuities of multiple actors and their different activities, CSCW has explored extensively the problem of coordination of work (Malone & Crowston, 1990; Montoya-Weiss, Massey, & Song, 2001). Coordination can be seen as the interactional work necessary to overcome the “gaps” that characterize collective activity. In a recent study on the work practices of two oncology clinics, for instance the authors describe work practices as an almost endless combination and recombination of artifacts, formats, notations, and routines (Schmidt, Wagner, & Tolar, 2007). In some cases, such gaps and the challenges they impose in coordination can be magnified in computer-based environments (Ishii, Kobayashi, & Grudin, 1993). What is perhaps more relevant to our research, is the research that has been conducted specifically oriented to the intersection of episodic and participation discontinuities in group interactions. This area of work has represented a closer interaction between literature in CSCW and other fields such as Organization Science and Information Systems research. In these and several other fields, a recent ‘practice turn’ or a turn toward analyzing actual situated practices (Schatzki, 2001) has motivated researchers to explore the embodied, embedded, and extended aspects of human activity as framed by Situated Cognition (Button & Dourish, 1996; Hutchins, 1995; Lave, 1988, 1991; Suchman, 1987; Suchman, 2003; Suchman & Trigg, 1991). For instance, in their study of the scientific community that revolved around the development of the Common LISP programming language, Wanda Orlikowski and Joanne Yates point to the ways in which the participants, through their everyday action produced and reproduce “a variety of temporal structures” which eventually end up shaping the “temporal rhythm and form of their ongoing practices” and guide, orient, and coordinate ongoing collaborative activities (Orlikowski & Yates, 2002). The authors argue that such structuring of temporal patterns is highly sensitive to other features of the collaborative context such as those related to participation. For example, temporal structures with broader scope should be more persistent and more difficult to change than those with narrower scope. For instance, they argue that the number of participants in a community, how widespread a temporal structure is within a community (penetration), how geographically spread are the different members using a particular temporal pattern (dispersion), and other similar participation factors will affect the way in which a particular temporal structure might be amenable to change. Finally, the authors argue that this practice-based view on joint action and its temporal patterning

attempts to bridge the subjective-objective dichotomy that underlies much of the existing research on time in organizations. This perspective coincides with similar statements made within the field of Small Group Research in which recently researchers have argued for the need to transition from a view of time as either a resource (objective calendar or clock time) or as an individual construction (as a pre-existing belief or as a socially constructed and later internalized conception of time and time urgency) toward a view where the temporal patterns of group processes and the multi-level nature of time and change are directly investigated and accounted for (Arrow *et al.*, 2004).

In a study of six computer manufacturing firms, three of them with successful multiple-product development portfolios and three of them less successful, Brown and Eisenhardt showed how successful firms continuously enact '*semisttructures*' (e.g., responsibilities, priorities, time allocation, etc.) which supported flexible change over time without letting teams degrade into chaos and connect the present and the future "through rhythmic, time-paced transition processes" (Brown & Eisenhardt, 1997). Such "*links in time*" were observed through the explicit practices that addressed past, present, and future and the transitions between them. The view of organizational change as built from flexible *semisttructures* and *time links* contrasts with the punctuated equilibrium model (Gersick, 1991) by highlighting rhythmic, time-paced transition processes which teams and organizations managed in different ways in an ongoing way. Similarly, in an ethnographic study of six Swedish product and industrial designers, researchers documented a series of temporal perspectives that are strongly rooted in the nature of design itself (Hellström & Hellström, 2003). This research indicates that designers actively bring past experiences into present solutions, project goals into the future (e.g., by visualizing a possible world, transcending the restrictions of the present, and trying out a model of the future product) and 'emote' a vision of the future (e.g., by conveying an unrealized idea or conveying an understanding of the effect-loaded future product) (p. 269). This study, despite its local scope, highlights the consequential ways in which time and temporality are integrated into the situated act of designing.

Nardi's recent ethnographic analysis of the use of Instant Messenger (IM) in the work place also highlights an interesting intersection between temporal and participation patterning in CSCW (Nardi, 2005). Nardi challenges the prevalent information channel metaphor widely used in Computer-mediated Communication research (e.g., Media-richness Theory, Social Presence Theory, or Social Cueing

Theory) and argues that a different and critical aspect of communication is left unaccounted for by such research: the dynamic ways in which participants establish a relational connection among themselves. As we have seen, the duality of task and relational dimensions of groups and collaboration is a recurrent research theme. Nardi builds on Social Information Processing (SIP) theory in interpersonal communication theory which according to her analysis “goes beyond bandwidth in suggesting that the timing, rather than simply the information content of a message may be crucial to communication” (p. 98). In her analysis of communicative practices related to work groups, Nardi postulates that participants engage in the collaborative construction of a “field of connection” as a “labile” multidimensional space comprised of feelings of *affinity*, *commitment*, and *attention*. These dimensions of connection, Nardi argues, must be kept in a state of sufficient excitation or activation to promote effective communication in which participants can exchange information” (p. 92). More importantly, this research argues for a sequential organization between task work communication and relational communication: relational aspects of communication “ready people for further communication.” Finally, Nardi argues that fields of connection (relational) and common ground (task oriented) could be the two components of a more comprehensive theory of communication working together to explain “how interaction is sustained over time” (p. 98). Earlier research in Information Systems Design had also pointed out the essential nature of the sequential and temporal dimensions of this intrinsically collaborative work. For instance, in Robey and Newman’s seminal analysis of the process of developing and implementing a materials management system through a span of 15 years, the authors developed a process model to explain the sequential patterns of events involving interactions between IS analysts and IS users (Robey & Newman, 1996). Through their careful sequential analysis of the long developmental process which included numerous periods of equilibrium (‘episodes’) in the relationship between these two actors and equally numerous ‘encounters’ in which actors had opportunities to challenge established practices, the authors document how a joint-development organization of action had been co-constructed. Similarly, in her study of the dynamics of sensemaking, knowledge, and expertise based on a group of managers engaged in the design of business process change and IT systems supporting an engineering firm, Gasson found that collaborative, boundary-spanning design could be described through a series of four stages each one representing a different set of concepts, valued skills, metaphor and stories and dominant genres (Gasson, 2005b). Over time for instance, as the group moved from “*defining design objectives*” to “determining an appropriate design process” the group moved from

distinguishing what was happening in the organization at the moment in contrast to what needed to happen toward defining “the what not the how” of the design and from using many different types of representations to standardizing on a single mode of representation. These and other transitions across the rest of the stages that the group went through represent their developmental change in enacting processes for managing relevant knowledge: from managing shared knowledge to accessing and managing distributed knowledge.

The last ten years of research in CSCW has led to the development of the area of “social computing” or “social systems,” largely as a result of a commitment to better understand the realities of social interaction, one of the critical failures of initial CSCW research pointed out by Grudin (1990) and others. A crucial goal of this area of work lies in realization that mutual awareness of the histories and interrelationships among participant in a collectivity is critical to the collective outcome. To support this kind of activity, some researchers have proposed the use of “social proxies” (Erickson *et al.*, 1999) and other strategies aimed at creating “socially translucent” environments. In addition, the design and use of systems that support “persistent conversations” (Erickson & Kellogg, 2001; Smith, 2002) has also emerged as a need to understand these new forms of interaction and their role in organizations and general culture. Persistent records of interactions, an apparent solution to problems of continuity, do not come without consequences and, as several researchers have pointed out, system designs have to go beyond “recording and reporting” (Bodker & Christiansen, 2006) and avoid the naïve view that “everywhere and forever” is always the best alternative (Grudin, 2002). Even in contexts where knowledge work is sustained over time, it is in the analysis of the practices that participants engage in that CSCW has been able to make progress in the understanding of processes such as “*knowledge distillation*” (Ackerman *et al.*, 2003), “*organizational memory*” or the use of boundary objects (Ackerman & Halverson., 1999). In general, work in this area is the result of sustained design experimentation and analysis of users’ interactions and serves as the basis for the claim that CSCW, and human-computer interaction in general, need to dedicate more attention to understanding the “collaborative user experience.” Our proposed work to study bridging in the context of virtual problem solving teams extends this orientation by considering the close relationship between multi-team collaboration over time and knowledge work.

Before analyzing in more detail research literature in Organizational Science

we should mention another recent addition to CSCW research: the study of group-to-group interactions. Moving beyond research single-team collaboration to consider larger arrangements of collective activity such as those in multiple team configurations, the issue of group-to-group collaboration in distributed settings has started to emerge as an important area of research in CSCW. Some researchers, for instance, argue that a “new class of interaction problems” emerge when collective activity is analyzed in these contexts (Mark *et al.*, 2003p. 101). These new interaction problems, the authors argue, stem from the need to overcome different terminology, perspectives, and work procedures across individual, sub-teams, teams and larger collectivities very much as we have described in our problem formulation. At the moment, it is clear that support mechanisms provided at the *data level* (e.g., offering access to records of interactions) or at the *process level* (e.g., controlling workflow) might be insufficient or too rigid (Miao & Haake, 1998) unless we understand how bridging activity works. Interestingly, research on group-to-group collaboration has highlighted the importance of studying the “space between” collectivities and understanding the connections, interdependencies and gaps across groups and organizations (Weick & Sutcliffe, 2005), a goal shared with research in organizational science and knowledge management.

Organization Science and Information Systems research literature has recently increased its attention toward studying the development of expertise in organizational contexts and toward interdisciplinary teams, boundary objects, and boundary-spanning work (Gasson, 2005a; Star, 1989; Star & Griesemer, 1989). The unit of analysis that is suggested by the concept of “boundary objects” is of particular interest to our approach. The concept, proposed by Star based on historical case studies of scientific work involving both professional scientists and amateurs (Star, 1989), suggests that the participants: “(1) cooperate without having good models of each other’s work; (2) successfully work together while employing different units of analysis, methods of aggregating data, and different abstractions of data; and (3) cooperate while having different goals, time horizons, and audiences to satisfy.” (p. 46). Star suggested that in the activity observed, it was the boundary objects that made cooperation possible. Boundary objects are “objects that are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites while sitting “in the middle of a group of actors with divergent viewpoints.” Recent research has highlighted the intrinsically cross-functional nature of boundary objects (Carlile, 2002), and has pointed out three different types of discontinuities in knowledge

sharing and development across groups: discontinuities in '*syntax*,' '*semantics*,' and '*pragmatics*' (Carlile, 2004). *Syntax* discontinuities or 'information processing' discontinuities are theorized to emerge from gaps in the *transfer* of information and although a common syntax might help groups with this discontinuity it might not be sufficient for groups to overcome such gaps. *Semantic* discontinuities or 'interpretive' discontinuities emerge from the different interpretation and meanings that individuals or group might hold and where '*translation*' and learning process might be necessary so that the differences and dependencies generated by novelties in meaning can be dealt with. This process resembles Nonaka's description of the process of 'externalization' or the making of tacit knowledge explicit (Nonaka, 1994) but the model offers one more discontinuity-related process beyond Nonaka's model. Finally, *pragmatic* discontinuities or discontinuities in 'political boundaries' or discontinuities on interests, incentives, and their political nature which require *transformation* of knowledge and practices, jointly resolving (at least temporarily) the political differences that impede effectively managing knowledge across domains. Although our context of study is not necessarily shaped by functional differences, this type of analysis is valuable in answering the question that Star has recently posed about the concept of boundary objects: "How are boundary objects established and maintained? Does the concept scale up? What is the role of the technical infrastructure?" (Bowker & Star, 2002).

Recent research in expertise development states that continued improvements in achievement are not automatic consequences of more experience but that, instead, successful "aspiring" experts seek out particular kinds of experience. This special experiences are characterized as "deliberate" practice and characterized by the types of activities designed, typically by another expert or a mentor, for the sole purpose of effectively improving specific aspects of an individual's performance (Ericsson, Krampe, & Tesch-Roemer, 1993). Only these types of activity provide optimal opportunities for performance improvement through cycles of feedback and re-construction of knowledge and skills. The careful study of bridging as an interactional phenomenon may provide an entry into the nature of these cyclical processes at the small-group level. Interestingly, in a recent review of the literature on problem solving, Pertz, Napes and Stenberg (2003) urge researchers to devote more attention to the early phases of the problem solving cycle related to problem formulation. Although considerable empirical research has been conducted on the latter stages of problem solving, the authors point to the little that is known about "what makes a person more likely to engage him or herself in seeking

out ill-defined problems and experimenting with various ways of representing them” (p. 27). Interestingly, there is a clear opportunity in investigating these phenomena in group-interactions going beyond theories of individual problem solving and exploring new constructs such as group and team cognition (Salas & Fiore, 2004; Stahl, 2005a, 2006a). By studying open-ended tasks in collaborative contexts and attending to the moment-by-moment unfolding of the interaction we hope to inform precisely these areas of problem exploration, problem finding, and problem definition.

As we mentioned at the start of this chapter, the concept of bridging has appeared, albeit from a different perspective than the way we have presented it, in Karl Weick’s most recent formulation of his model of Sensemaking in Organizations (Weick, 1995). This model echoes much of the interest in Organizational Science for the study of the discontinuities that emerge from the multiplicity of actors, perspectives, activities, temporal states, and ideas in workgroups and organizations; between the control exerted by managers and their subordinates, or between the interdependent connections among functional entities within a single organization and across multiple organizations. Research in this area is certainly abundant and varied in its perspectives but Weick has been shown through bibliographic analysis to be one of the top thinkers in organizational behavior (Anderson, 2006). Weick states in the preface to his book on Sensemaking in Organizations that his book is written “as if Lave and Wenger’s (1991) concept of ‘legitimate peripheral participation’ was a valid portrait of learning as a cognitive apprenticeship.” From this ‘situative’ perspective Weick attempts to investigate the discontinuities that emerge in sensemaking within organizations. In particular, those among individual (subjective), social (inter-subjective) and organizational (generic-intersubjective) sensemaking activity: “placement of items into frameworks, comprehending, redressing surprise, constructing meaning, interacting in pursuit of mutual understanding, and patterning” (p. 6). Among Weick’s more widely adopted ideas include the concept of ‘enactment’ which builds on Garfinkel’s notion of that retrospective accounts present action as if it had followed rules whereas actions themselves bear only a ‘retrospectively accountable relation’ to the rules they are said to follow (Garfinkel, 2002). For Weick, action precedes goals and enactment becomes then the process by which individuals in organizations act and, in doing so, create the conditions that become the constraints and opportunities they face. In addition, Weick has argued that there is constant ambiguity across multiple and often times conflicting interpretations of the same information leading to ‘equivocality,’ but that individuals in organizations make sense of such social reality by following a process of *enactment*, *selection*, and

retention (Weick, 1969) as well as *sensing, arguing, expecting, committing, and manipulation*. For example, Weick defines organizations as “entities that move continuously between intersubjectivity and generic intersubjectivity” (Weick, 1995 p. 75) while managing the ‘tensions’ between intersubjective innovation and the necessary control of such innovation which builds generic subjectivity (p. 72). In attempting to support selection and retention, organizations create, preserve, and implement the innovations that arise from intimate contact, focusing and controlling “the energies of that intimacy.” (p72). Organizing (as opposed to simply organizations) are for Weick “a mixture of vivid, unique intersubjective understanding and understandings that can be picked up, perpetuated, and enlarged by people who did not participate in the original intersubjective construction” (p. 72). This aspect of Weick models is specially relevant and one which states clearly his situative perspective. Weick as Lave and Wenger pointed out before, bring attention to the fact that subjective internalization of knowledge and practices from the inter-subjective world of interaction is never ‘perfect;’ nor is externalization. For Lave and Wenger “changing membership in communities of practice, like participation, can be neither fully internalized nor fully externalized” (Lave & Wenger, 1991 p. 54). For Weick, “there is always some loss of understanding when the inter-subjective is translated into the generic (inter-subjective)” (Weick, 1995 p. 75) and it is precisely the function of the organizational forms to “manage this loss by keeping it small and allowing it to be negotiated” and this is achieved by managing the tensions between inter-subjective innovation and generic intersubjective control through ongoing reconciliation that involves “such things as interlocking routines and habituated action patterns both of which have their origin in dyadic interaction.” In a sense, Weick extends Vygotsky’s genetic law of cultural development one step further by arguing that organizing or generic inter-subjective practices emerge from inter-subjective interactions after being made sense, in an ongoing mode, at the intra-subjective level.

One final aspect of Weick’s model of organizational sensemaking deserves mention: his view on change and organizational discontinuities over time. In his original presentation of sensemaking in organizations Weick had presented seven properties that characterize sensemaking processes: *identity construction, retrospective, enactive of sensible environments, social, ongoing, focused on and by extracted cues, and driven by plausibility rather than accuracy* (Weick, 1995.) In his recent review of organizational change and development theories co-authored with Robert Quinn (1999), Weick argues that his view of continuous change emerging at

the inter-subjective level in organizations represents a contrasting perspective against the type of ‘*episodic change*’ that is usually portrayed in the organizational literature as *infrequent, discontinuous, and intentional* or planned . Weick’s model emphasizes long-run adaptability materialized through recurrent inter-subjective interactions, emergent patterns and shifting response repertoires, improvisation, translation and learning (Weick & Sutcliffe, 2005). Despite the fact that Weick’s model is strongly rooted in organizational life its applicability is far reaching. The empirical analysis of collectivities engaged in knowledge building and sensemaking over time can offer an opportunity for empirical observation of some of the processes outlined by Weick’s model, a type of empirical validation which Anderson’s citation analysis of Weick’s work has shown that the field of Organizational Science has only offered in very few instances (Anderson, 2006 p. 1687)

2.5. Methodological perspectives in the study of interaction

Given our set of research questions and our selected context of research, choosing an appropriate research method for the study of online collaborative knowledge-building interactions in the Virtual Math Teams online community requires an understanding of different methodological alternatives able to capture the interactional phenomena that we have set out to investigate. The multidisciplinary field of research in Human-Computer interaction as well as many other related fields such as Information Systems research, Computer-supported Collaborative Learning and Cooperative Work among others, certainly are not characterized by a shortage of research methods. In the recently published review of research methods for Human-Computer Interaction edited by Paul Cairns and Anna Cox, as an example, the authors present a wide array of data collection and data analysis methods including control experimentation, eyetracking, survey research, verbal and observation data, cognitive modeling, statistical analysis, and diverse qualitative research approaches (Cairns & Cox, 2008). In addition to reviewing the gaps in the relevant literature we investigate here the different research methods that have been employed to study the types of episodic and participation discontinuities we chose to explore. In this final section we will discuss a series of data collection and analysis methods and their strengths and weaknesses as they relate to our proposed scope of work. Our choice of data collection and data analysis methods are guided by the fit between our research goals and available methods.

Given our interest in online collaborative interactions, the methodological frameworks originated from the field of Computer-Mediated Discourse (CMD) studies are certainly ones that are closely related to our proposed research questions. CMD studies have evolved from research in computer-mediated communication in general and as such investigate a diverse array of interpersonal communications carried out on the Internet via e-mail, instant messaging systems, mailing lists, newsgroups, web discussion boards, and chat rooms (Herring, 2001). As Susan Herring has argued in her review of computer-mediated discourse analysis, CMD research often encompasses perspectives from the socio-linguistic and discourse-analytic perspectives which expect discourse to exhibit 'recurrent patterns' produced consciously or unconsciously by speakers, assumes that participating in discourse involves speaker cognitive and social choices some of which might be related to the technological features of computer-mediated communication systems (Herring, 2004). Its data collection methods usually revolved around observations about language and language use (e.g., the compilation of linguistic units such as individual messages in an e-mail exchange or threads of postings in an online bulletin board) while its approach to data analysis can be characterized as 'content analysis' often using 'coding' methods to derive theoretical patterns. Actual methods of analysis in CMD studies concentrate on showing how representative certain linguistic units are within a genre of communication or deriving patterns of communication that represent specific discourse practices (Herring, 2004). These methods can be of both quantitative and qualitative nature. As an example, Nardi's studies of Instant Messenger use in the workplace mentioned in an earlier section analyzed from a qualitative and ethnographic perspective the content and temporal patterns of IM exchanges to derive its observations regarding the construction of a field of connection oriented toward *affinity*, *commitment*, and *attention* (Nardi, 2005). In contrast, Massey, Montoya-Weiss, and Hung's study of global virtual teams coded each one of 812 'communication incidents' based on the four types of group processes (conveyance, convergence, social/relational, and process management) derived from the Time, Interaction and Performance theory of groups (McGrath, 1991) and proceeded to apply cluster analytical techniques to determine whether such distribution of codes could differentiate among the 35 teams studied (Massey *et al.*, 2003). Issues of segmentation, inter-coder reliability, and the statistical significance of such quantitative analysis become relevant in this type of approach. In addition to text analysis, Herring compares the following five discourse analysis paradigms with its different issues, phenomena and procedures:

Table 7. Five discourse analysis paradigms. Adapted from Herring (2004)

	Issues	Phenomena	Procedures
Text Analysis Example: (Chi, 1997)	Classification, description, “texture” of texts	Genres, schematic organization, reference, salience, cohesion, etc.	Identification of structural regularities within and across texts
Conversation Analysis Example: (Sacks, 1992)	Interaction as a jointly produced social order	Methods, turn-taking, sequences, topic development, etc.	Interactional analysis of the mechanics of interaction
Pragmatics Example: (Clark & Brennan, 1991)	Language as an activity—“doing things” with words	Speech acts, relevance, politeness, etc.	Interpretation of speakers’ intentions from discourse evidence
Interactional Sociolinguistics Example: (Duranti, 1998)	Role of culture in shaping and interpreting interaction	Verbal genres, discourse styles, (mis)communication, framing, etc.	Analysis of the socio-cultural meanings indexed through interaction
Critical Discourse Analysis Example: (Harré & Lagenhove, 1999)	Discourse as a site in which power and meaning are contested and negotiated	Transitivity, presupposition, intertextuality, conversational control, etc.	Interpretation of meaning and structure in relation to ideology, power dynamics

In some cases, CSCL studies have adopted a methodological orientation similar to that used in textual analysis within CMD studies. Different coding schemes have been developed and used in CSCL in order to quantify aspects of observed collaborative processes. For instance, in a study of students learning classical mechanics the authors analyzed the students’ dialogue by coding their interactions using the DISCOUNT coding scheme and conducting a sequential analysis that showed that groups moved from qualitative to quantitative representations over time (Ploetzner *et al.*, 1999). In these schemes, roles (e.g., information seeker, explainer, task performer and reflector), “moves” (e.g., statement, counter-proposal, elaboration, etc.), episodes (e.g., negotiation, explanation, etc.), and other theorized elements are labeled and their quantitative patterns analyzed as a way to understand, and sometimes assess, processes such as negotiation, argumentation, externalization of knowledge, elicitation, or consensus building. These approaches to data analysis follow also the methodology of *verbal analysis* within learning research which Chi has outlined as a process of “quantifying the subjective or qualitative coding of the contents of verbal utterances” (Chi, 1997). According to Chi’s description, the goal of verbal analysis within learning research is to “identify the knowledge that might underlie utterances and to do so in a way that is not subjective” (p. 275). To do this, Chi states that the researcher should be able to determine the

content of what is said by “listing it as a set of propositions, a set of concepts, a set of goals or a set of rules” (p. 275). The overall process of coding and analyzing verbal data, according to Chi, is guided by the following eight step process (p. 283):

1. Reducing or sampling the collections of verbal data
2. Segmenting the reduced or sampled protocols (optional)
3. Developing or choosing a coding scheme or formalism
4. Operationalizing evidence in the coded protocols that constitutes mapping to some chosen formalism
5. Depicting the mapped formalism
6. Seeking pattern(s) in the mapped formalism
7. Interpreting the pattern(s)
8. Repeating the whole process, perhaps coding at a different grain size (optional)

Although this process has been used extensively within the learning sciences (Chi, 2000; Chi *et al.*, 2004; Chi, Feltovich, & Glaser, 1981) and, give its similarities with accepted methods of qualitative research (Miles & Huberman, 1994), also in similar ways in other fields, there are certainly other alternatives. Most notably, more inductive and interpretive approaches such as those of grounded theory development (Glaser & Strauss, 1967) offer an alternative. For instance, Gasson in her analysis on the use of grounded theory research for the generation of theory from qualitative field studies shows a the process of analysis that is much more reflexively anchored on emergent theory and ‘open’ coding than the way Chi’s steps are driven by pre-existing theory and ‘closed’ coding (e.g., the formalisms of steps 3 and 4) (Gasson, 2003). Such emergent theory is closely rooted on the patterns found in the empirical data and evolves through constant comparison between its codes and constructs and new data.

Whether through pre-determined coding or grounded coding there is a risk of adopting a perspective in which linguistic artifacts represent a message or meaning of which actual speakers and hearers are unaware of and which needs to be uncovered by the analyst, a position which contrasts with the tenants of Ethnomethodology (EM) (Garfinkel, 1967) and Conversation Analysis (Pomerantz & Fehr, 1991; Schegloff, 1995). Ethnomethodology-oriented analysis of the same verbal exchanges would not orient to analysts uncovering or interpreting signs, or to treating enacted local practices as texts that symbolize “meanings” or events

(Schegloff, 1991b) but instead, would concentrate on the recurrent details of ordinary everyday practices as evidence of the methods that participants use to create social order (Garfinkel, 2002). This perspective is also seconded by the 'realist stance' in social science (Maxwell, 2004) and in the philosophy of science (Putnam, 1990) which in contrast with both positivism/empiricism and constructivism in its understanding of causality not as consisting of regularities but of observable mechanisms and processes which may or may not produce regularities. Within this perspective, as with Ethnomethodology and other qualitative approaches, causation in social processes is conceived as directly observable rather than only inferred from covariation of presumed causes and effects. Maxwell, in his analysis of the use of qualitative methods for causal explanation from a realist perspective, presents three sets of strategies for researchers to deal with threats to causal inference: strategies associated with *variance*, strategies related to *observation and analysis of processes*, and strategies for *developing and assessing alternative explanations*. The first set includes the use and accounting of interventions and the active use of comparisons at different levels of granularity, while the second includes intensive, long-term involvement, rich data, narrative and connecting analysis. Finally the most critical set of strategies dealing with causal validity includes searching for confirmatory clues of the 'modus operandi' proposed, searching for discrepant evidence and negative cases, triangulation, and member checks. Many of these strategies resemble the recommendations made by Miles and Huberman for drawing and verifying conclusions in qualitative research (1994: 245-287) although in such case, the authors recommend researchers to be cautious with causal explanations.

A different method of analysis widely use in studies of small groups and which may as well use as its data verbal or communicative exchanges is Interaction Process Analysis. This approach to the study of collective action, also differs significantly from what we have referred to as a an interactional approach. In the traditional method of interaction analysis a system of codes and categories (e.g., giving information, questioning, harmonizing, dominating, etc.) are also used to label and analyze quantitatively the different ways in which teams engage in joint activity (Bales, 1951; Jordan & Henderson, 1995). These categories are centered on what an observer (i.e. the analyst) perceives while a truly interactional approach strives to uncover the perspective of the participants and how they orient to the moment-by-moment interaction. In addition, classical interaction and other coding approaches take the linguistic turn (e.g., an utterance, a conversational turn) as their unit or analysis when assigning a code to a sentence or posting. In the case of

ethnomethodology-oriented studies, the unit of analysis is defined at the activity level (as defined by the participants themselves) and the corresponding networks of activities that can span from a few seconds to longer series of interactional episodes.

We will explore in more detail our choice of research method in Chapter 3 (See Section 3.6 on page 83). Next we elaborate on how some of the concepts explored in this section will be used to articulate our theoretical framework and present the details of our proposed research approach toward the three research questions outlined.

3. CONTEXT AND RESEARCH APPROACH

Having explored the relationship between our research questions and the current state of relevant knowledge, we outline now our research approach and the corresponding plan of inquiry to investigate episodic and participation discontinuities within the Virtual Math Teams context. We start by presenting specific aspects of the Virtual Math Teams context which make it a unique computer-supported collaborative learning setting, appropriate for our data collection. Considering that our central aim is to characterize the ways in which bridging contributes to the establishment of continuity in the knowledge-building experience of virtual teams in online learning communities, our means of inquiry are fundamentally descriptive and grounded on naturalistic data collected longitudinally. In the following subsections we describe the theoretical framework guiding this plan and the research method selected, including the data collection and data analysis strategies devised.

3.1. Virtual Math Teams at The Math Forum Online Community

The Virtual Math Teams (VMT) project is part of the Math Forum at Drexel University (www.mathforum.org), an online community which since 1992 promotes interactions among teachers of mathematics, students, mathematicians, hobbyists, staff members and other interested parties involved in learning, teaching, and doing mathematics. Sample forms of participation within the Math Forum online community include *The Problem of the Week*, a service through which learners from many parts of the US and the world receive a problem designed by the staff of the Math Forum,

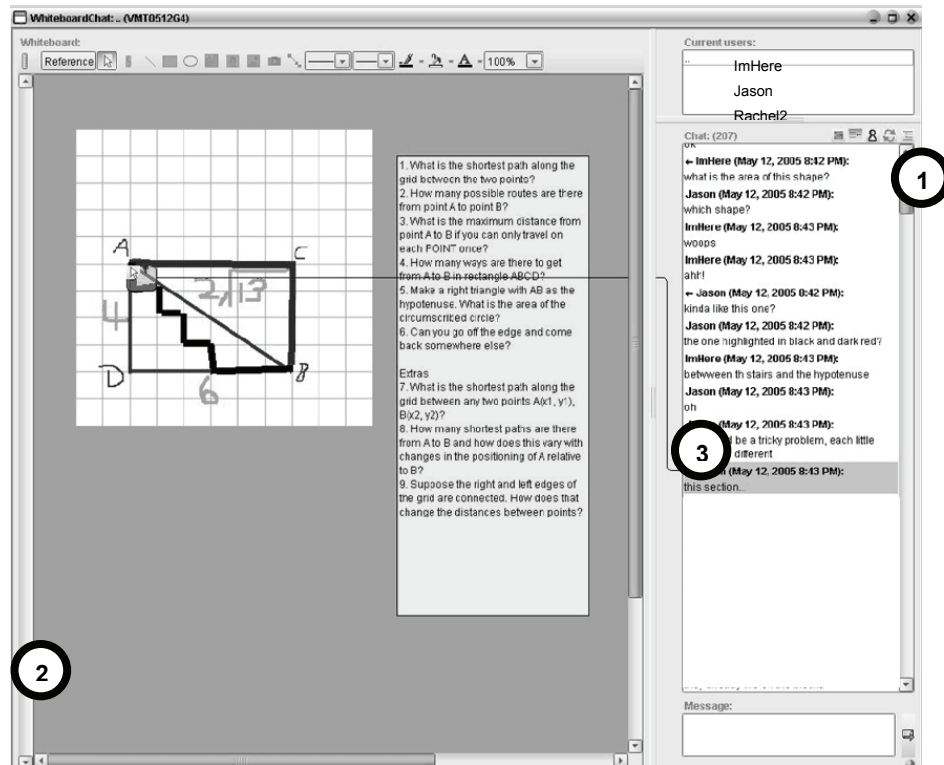
post their solutions online and, whenever possible, receive asynchronous feedback from mentors on problem-solving and communication skills. In the Ask Dr. Math. Service, students and others receive mathematics advice from professionals and expert volunteers. Other forms of participation include ways for K-12 teachers to share and discuss math tools (e.g., interactive manipulatives, online graphic calculators, etc) and other classrooms resources.

VMT is one of many initiatives aimed at exploring and supporting more engaging and productive online interactions at the Math Forum. In particular, VMT aims at enriching the mechanisms of community participation available at the Math Forum and offering a space for sustained mathematics collaboration. To achieve this, VMT investigates the innovative use of online collaborative environments to support effective secondary mathematics learning by offering online supports for a community of virtual teams to collaborate in solving open-ended mathematical problems and sustaining their interests and discoveries over time.

VMT represents as well a unique pedagogical perspective on mathematics learning. It attempts to promote and support a way of developing knowledge of mathematics and an identity as a learner that values collaborating with others to create, develop and solve mathematical problems, exploring relations among concepts, and sustaining the collaborative discourse over time. Learning to talk about math objects, to appreciate arguments about them and to adopt the practices of mathematical reasoning are considered central elements of this learning environment (Stahl, Forthcoming). This emphasis on active engagement in discovering and discussing math with others, on explaining one's own thinking, on making ideas visible and sustaining such engagement over time as central learning processes characterize the pedagogical beliefs behind VMT.

VMT also promotes and investigates particular online collaboration and interaction tools. The VMT collaboration environment studied in the course of this dissertation is based on ConcertChat (Mühlpfordt & Wessner, 2005; Wessner *et al.*, 2006), a research collaboration environment combining persistent chat with a shared whiteboard and a series of additional collaboration supports. The VMT collaboration environment is in itself subject to continuous modifications, but its central features involve text-based chat which, in contrast to many other chat environments, stores the entire conversation of a team as a persistent record that can be accessed by any user. In addition, the system offers a basic shared whiteboard which is also

persistent in the same way. Finally, a set of pointing functions are available so that participants can refer to specific chat messages or to specific objects on the whiteboard while posting their own chat messages in a conversation. These features of the VMT collaboration environment are shown in Figure 3.



(1) Chat conversations are persistent during and after each session. Latecomers can load all previous messages at will.

(2) The shared whiteboard allows chat participants to create drawings and share graphic information with each other. Every whiteboard action is recorded. Users can manipulate a slide bar to navigate through all changes made in the whiteboard since the creation of the chat room.

(3) When someone types a new chat message, they can select and point to an area in the whiteboard or to a previous message, displaying a connecting graphical line.

Figure 3. ConcertChat collaboration environment.

Studying the dynamic and complex group interactions that take place online in environment such as VMT poses significant challenges to researchers. To aid in the analysis of VMT interactions, access to a special research tool that re-plays group sessions is provided. All the collaboration sessions conducted in VMT are recorded through time-coded logs which allow researchers to “replay” the sessions using this special research tool. This “reenactment” of the session include time-synchronized transcripts of the chat discourse and all public activity performed on the whiteboard, as well as of other interactional events such as when participants entered or exited rooms. This “re-player” tool provided a naturalistic view of how the interaction was

performed from the participants' point of view, preserving, for example, the tempo and sequencing of actions. Figure 4 shows the re-player tool which integrates the same layout of the environment used by the teams (as shown before) enhanced with a series of controls and additional contextual information (e.g., timestamp and author of previous and last actions) displayed at the bottom part of the screen.

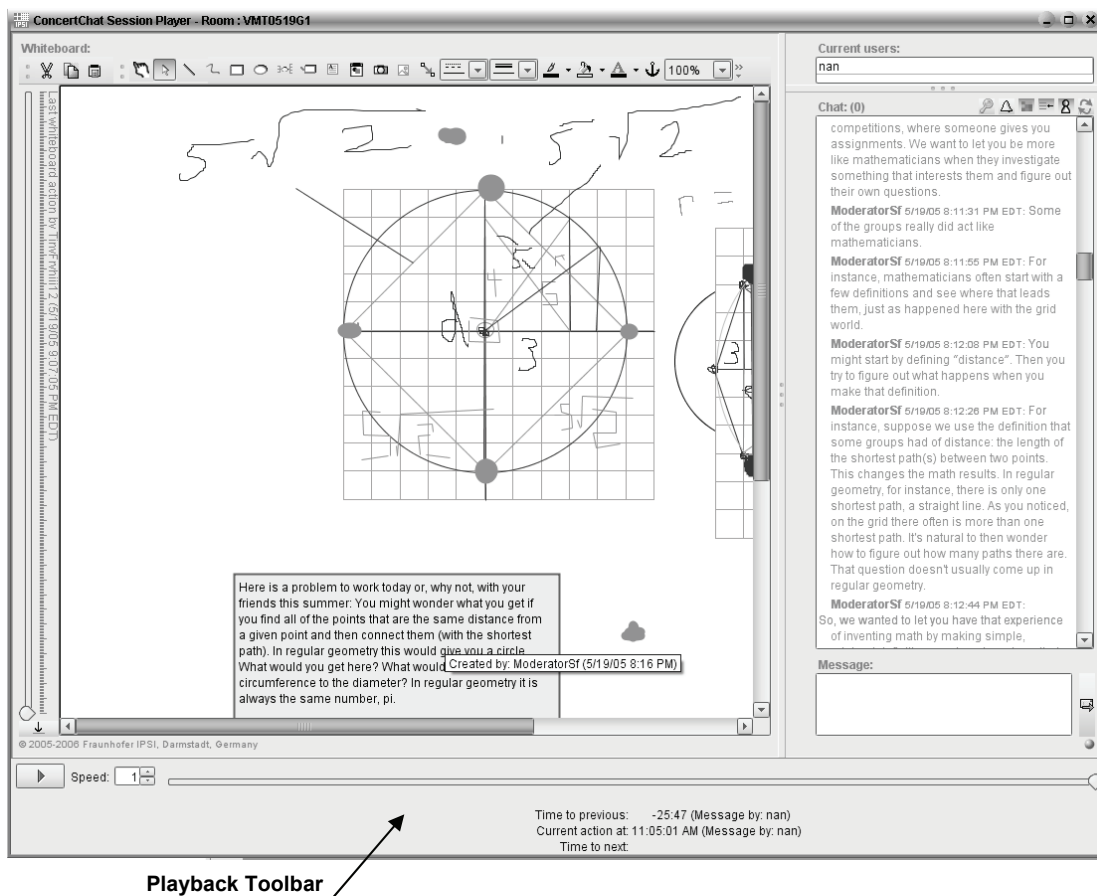


Figure 4. VMT re-player with playback toolbar.

In summary, VMT integrates both an agenda of research on computer-supported collaborative learning and also an attempt at developing a collaboration environment suitable for effective group interactions and for supporting research on group knowledge building. VMT iterates through cycles of *Design-based research* which allow for development of theory in synchrony with the evolution of the tools, processes and resources used during experimentation. Before presenting our general plan of data collection and inquiry we elaborate on the framework provided by Design-based research as a way to illustrate this aspect of the VMT context and, consequently, of our approach.

3.2. Research Framework: Design-based Research

As discussed in previous sections, The Virtual Math Teams online community in general and our research in particular are centrally situated in the field of Computer-supported Collaborative Learning (CSCL) and, more generally, within the emerging field of the Learning Sciences. Research in the learning sciences attempts to “better understand the cognitive and social processes that result in the most effective learning, and to use this knowledge to redesign classrooms and other learning environments so that people learn more deeply and more effectively” (Sawyer, 2006) . Our research goal is highly rooted in this orientation for we strive to understand bridging activity as interactional phenomena related to knowledge building in online collaborative learning teams and we expect this knowledge to contribute to the design of interaction supports for the Virtual Math Teams (VMT) and other similar online community. Consequently, we adopted the framework of “design-based research” proposed within the Learning Sciences as the guiding structure of our method of inquiry.

The concept of Design-based Research (DBR) was introduced in the early nineties, in writings by learning scientists Ann Brown (Brown, 1992) and Allan Collins (Collins, 1992) who proposed the use of “design experiments” as a strategy to cope with the complexities of investigating how designed artifacts (e.g., curricula, computational tools, etc.) contributed to learning in real-life settings . Design experiments were conceived as a way to extend laboratory experiments, ethnographies, and large-scale studies by providing a framework for formative research which combines incremental design and the progressive development of theory (Cobb *et al.*, 2003; diSessa, 1991). The typical design experiment is defined by Cobb *et al.* (2003) as “both *engineering* particular forms of learning and systematically studying those forms of learning within the context defined by the means of supporting them” (p.9). This iterative combination of applied design and systematic theoretical development is the central characterizing element of design experiments and the motivation behind its current widespread use (Barab & Kirshner, 2001; Design-based Research Collective, 2003; Edelson, 2001). It is precisely because of this iterative synergy between incremental design and systematic theory building that we adopted the framework of design-based research. In our case, we aimed at incrementally expanding our understanding of specific interactional aspects of learning in online teams and virtual communities while being sensitive to the particularities of the collaboration environment provided by VMT.

For our particular purposes, we employed two cycles of design case studies. These two cycles were conceived as a way to iteratively refine our understanding of bridging in the context of the VMT online community but also as a strategy to test the utility of this research framework. Each cycle was comprised of a Design Case in which a particular aspect of the theory in development was explored in close relation to a particular activity system and interaction environment. Initially, we used a design case aimed at characterizing the dynamics of bridging in virtual teams interacting with basic computational supports and providing an initial characterization of the processes of constituting individuals, groups and the collectivity of teams through interaction as well as the overall constituting of continuity in VMT. Following the results of the first design case, we confirmed and expanded such characterizations and consolidated the analysis of the role of bridging activity in collaborative knowledge building in VMT through an additional design case. These two design-research cycles or design cases, with their theory and design components, are presented in Figure 5.

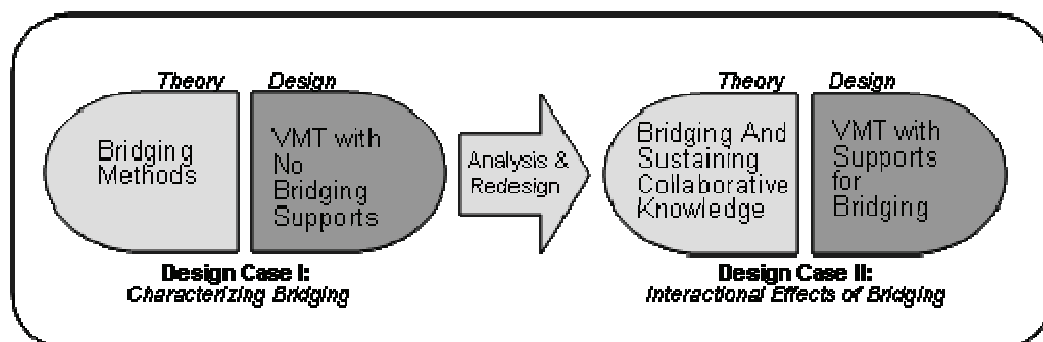


Figure 5. Two cycles of design experimentation employed.

We will address the analysis of data collected from each of these two design cases in section 3.6 after presenting each of these design cases in detail.

3.3. Data Collection: Design Case One

3.3.1. Goals

The central goal of this baseline design case was to reach an initial characterization of bridging phenomena as well as to produce an initial survey of interactional methods which participants engaged in, when overcoming the two type of discontinuity selected for study: *episodic discontinuity* and *participation discontinuity*. As defined through our research questions, we concentrated on bridging as the

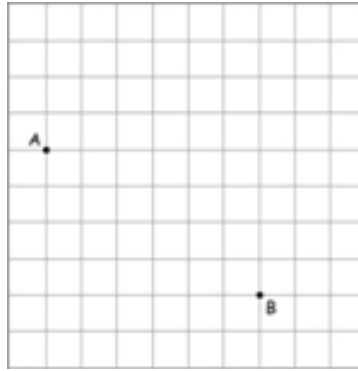
interactional work that virtual teams engage in when dealing with *two specific discontinuities* of their collective work: The discontinuity of their sequences of collaboration episodes (i.e., each online session they participate in) and the discontinuities emerging from changes in team participation (i.e., individual attendance to sessions and collective engagement in relevant problem-solving work). This design case attempted to expand this definition and provide a series of rich descriptions of bridging activities and their relationship to collaborative knowledge building over time.

The data for this study come from 18 collaborative sessions held in the spring of 2005 as part of the Virtual Math Teams “Spring Fest”—a unique online event offered through the Math Forum online community. Five teams of secondary students participated in this design case. Each team engaged in four online collaborative problem-solving sessions spread over a two-week period lasting for about one hour each. Two team sessions were not completed successfully and as such were excluded from the analysis. We expected that the sequential nature of the mathematical tasks that were teams worked with, in addition to the collaborative nature of the multi-team setup, would provide a propitious setting for bridging work to be investigated.

Our selected unit of analysis was the activity system comprised of the situated virtual team interacting on the task in the online environment. Three elements of the activity system in this study were of special interest: the sequential structure of the tasks addressed, the composition of the teams over time, and the online collaboration environment. Next, we describe each of these three elements in detail.

3.3.2. The task

Teams participating in this design case study worked on creating and answering questions about a non-traditional geometry environment—a grid-world where one could only move along the lines of a rectangular grid. As presented to the participating teams in their first session (see Figure 6), the task oriented the teams to both collaborative problem finding and problem solving.



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 6. Grid-world task.

In the first session, the teams were given a brief description of this mathematical situation and were asked to generate and pursue their own questions about it. In subsequent sessions, the teams were presented by the facilitators with brief remarks about their work and the work of other teams, for example, by presenting lists of questions about the grid-world compiled from the work of all teams. Below is a sample message that one of the facilitators provided:

[8:07:56 PM] Facilitator: We are ready to start. Today, you can finish the work that you have been doing as a team in the previous three sessions. There are five teams in this project and they have all explored very interesting questions about the "grid-world" that we started with.

In sessions two through four, all teams were encouraged to continue their prior work or decide on new grid-world problems that they were interested in pursuing. Although different teams may have pursued different problems, all their work was anchored in the situation presented by the grid world.

3.3.3. Team composition.

Each team was composed of three to four non-located, secondary school students. Participants were recruited through the Math Forum online community and selected by volunteer teachers at different secondary schools across the USA. Participants used anonymous handles throughout the four sessions and were encouraged to behave in a natural way. Every team was assigned a facilitator who,

in every session, 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.

Attendance to all sessions was encouraged but because of the voluntary nature of the study and the naturalistic environment that participation in The Math Forum entails, changes in team composition did occur. These changes were mostly motivated by attendance constraints or other personal issues of the participants themselves and, as such, provide propitious opportunities to study bridging. Patterns of participation are illustrated in Figure 7. Each team's trajectory of four problem-solving sessions is represented horizontally with clusters of colored circles representing teams and participants. Each circle represents a participant with a 2-letter code that identifies individuals across team sessions.

The minimum number of participants in a team was 2 and the maximum 5. Two of the participating 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. Despite this, after reviewing each one of the sessions it was found still appropriate to treat all teams, except for Team Three, as single entities which, despite their changes over time, still remained recognizable as such for the participants themselves.

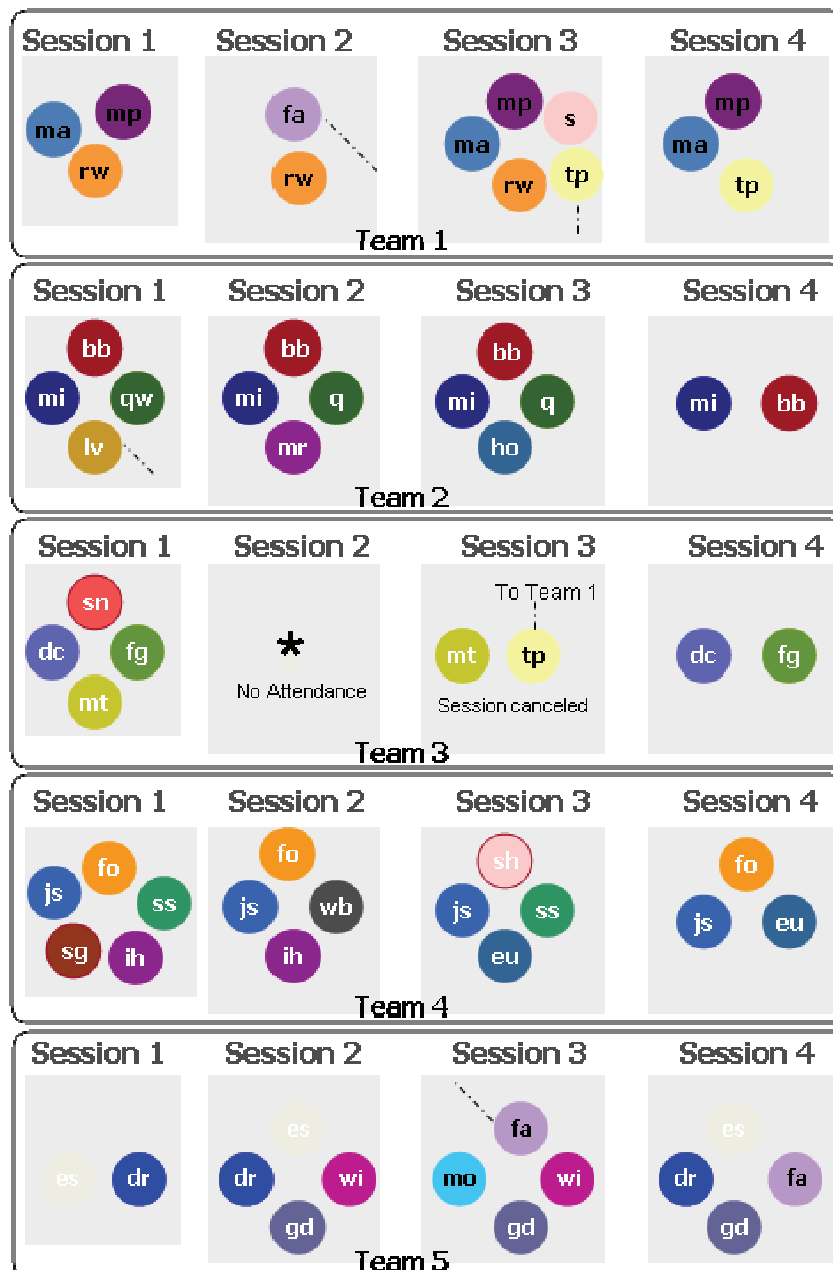


Figure 7. Patterns of Participation of Individuals and Teams in Case Study one.

3.3.4. Online Collaboration Environment

The participants were introduced to the online environment in their first team session and were also provided with technical assistance throughout all sessions when requested. Although materials are persistent in the VMT online environment, teams were given a blank new room for every collaborative session and were not provided with direct access to records of their prior conversations or drawings. No additional information was available directly in the system about the teams and their members, their meetings or results. We expected that the setup of the online environment can be considered one with no explicit computational supports for bridging.

3.4. Data Collection: Design Case Two

3.4.1. Goals

The goal of this second design case was to confirm and expand the initial characterization of bridging phenomena, and to explore the forms of continuity constituted by Virtual Math Teams through their building of collaborative knowledge over time. Participating teams in this design case study also face discontinuity of their multiple collaboration episodes and of the naturalistic changes in team participation over time. In addition, this design case study investigated interactional practices related to cross-team interactions and their relationship to collaborative knowledge building over time as the environment provided specific supports for this type of activity which were not present during Design Case One.

The data for this study come from 20 collaborative sessions held in the Spring of 2006 as part of the Virtual Math Teams "Spring Fest." Five teams of secondary students participated in this design case. Each team engaged in four online collaborative problem-solving sessions spread over a two-week period lasting for about one hour each. As with Design Case One, we expected that the sequential nature of the mathematical tasks that were addressed by the teams, in addition to the collaborative nature of the multi-team setup would provide with a setting appropriate for studying bridging as an interactional activity.


As in Design Case One, the sequential structure of the tasks addressed by the teams, the composition of the teams themselves, and the online collaboration environment were unique factors that defined the nature of the case study itself. Next, we describe each of these three elements in detail.


3.4.2. The task

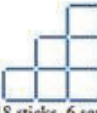
Teams participating in this design case study worked on creating and answering questions about a sequence of figures made using sticks to form connected squares, and about similar sequences created by the teams themselves. Figure 8 illustrates the way this task was presented to the participating teams in their first session.

VMT Spring Fest

Here are the first few examples of a particular pattern or sequence, which is made using sticks to form connected squares:

(1)  4 sticks, 1 square

(2)  10 sticks, 3 squares

(3)  18 sticks, 6 squares

N	Sticks	Squares
1	4	1
2	10	3
3	18	6
4	?	?
5	?	?
6	?	?
...
N	?	?

Session I

1. Draw the pattern for $N=4$, $N=5$, and $N=6$ in the whiteboard. Discuss as a group: How does the graphic pattern grow?
2. Fill in the cells of the table for sticks and squares in rows $N=4$, $N=5$, and $N=6$. Once you agree on these results, post them on the [VMT Wiki](#)
3. Can your group see a pattern of growth for the number of sticks and squares? When you are ready, post your ideas about the pattern of growth on the [VMT Wiki](#).

Figure 8. Sticks and Squares task.

In the first session, the teams were given this mathematical situation and were asked to complete the tasks outlined which included reporting their results to a Wiki page. In subsequent sessions, the teams found in their shared whiteboard a feedback note which outlined observations about their work on the previous session and suggestions for what to do next. Below is a sample feedback note that one of the facilitators provided:

Log 2. Sample Feedback Note. Design Case Two, Team C, Session 2

Dear 137, davidcyl, Jason, and ssjnish, It seemed to us that you had a very productive first session exploring the given pattern of sticks and squares. We were especially interested in the variety of strategies you used, such as constructing the next steps of the pattern on the whiteboard, separating the pattern in horizontal and vertical lines (other teams did that as well!) and deriving a formula for that sum.

As far as working as a math team, you built on each other's ideas and tried to work with them in interesting ways. We find it very important that

For the next step we will encourage you to think more about the different approaches and the problems that you can discover on your own which you find interesting to pursue.

--The VMT team.

In sessions two through four, all teams were encouraged to post their work to the Wiki. Although different teams may have pursued different problems, all their work revolved around patterns and sequences such as the original one with sticks and squares.

3.4.3. Team composition.

Each of the participating teams was composed of three to four non-collocated, secondary school students. Participants were recruited through the Math Forum online community and selected by volunteer teachers at different secondary schools across the USA and abroad. Participants used anonymous handles throughout the four sessions and were encouraged to behave in a natural way. Every team was assigned a facilitator who, in every session, 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.

As in Design Case One, changes in team composition did occur over time. However, these changes were less significant than in Design Case One producing a set of more stable teams. Patterns of participation are illustrated in Figure 9. Each team's trajectory of four problem-solving sessions is represented horizontally with clusters of colored circles representing teams and participants.

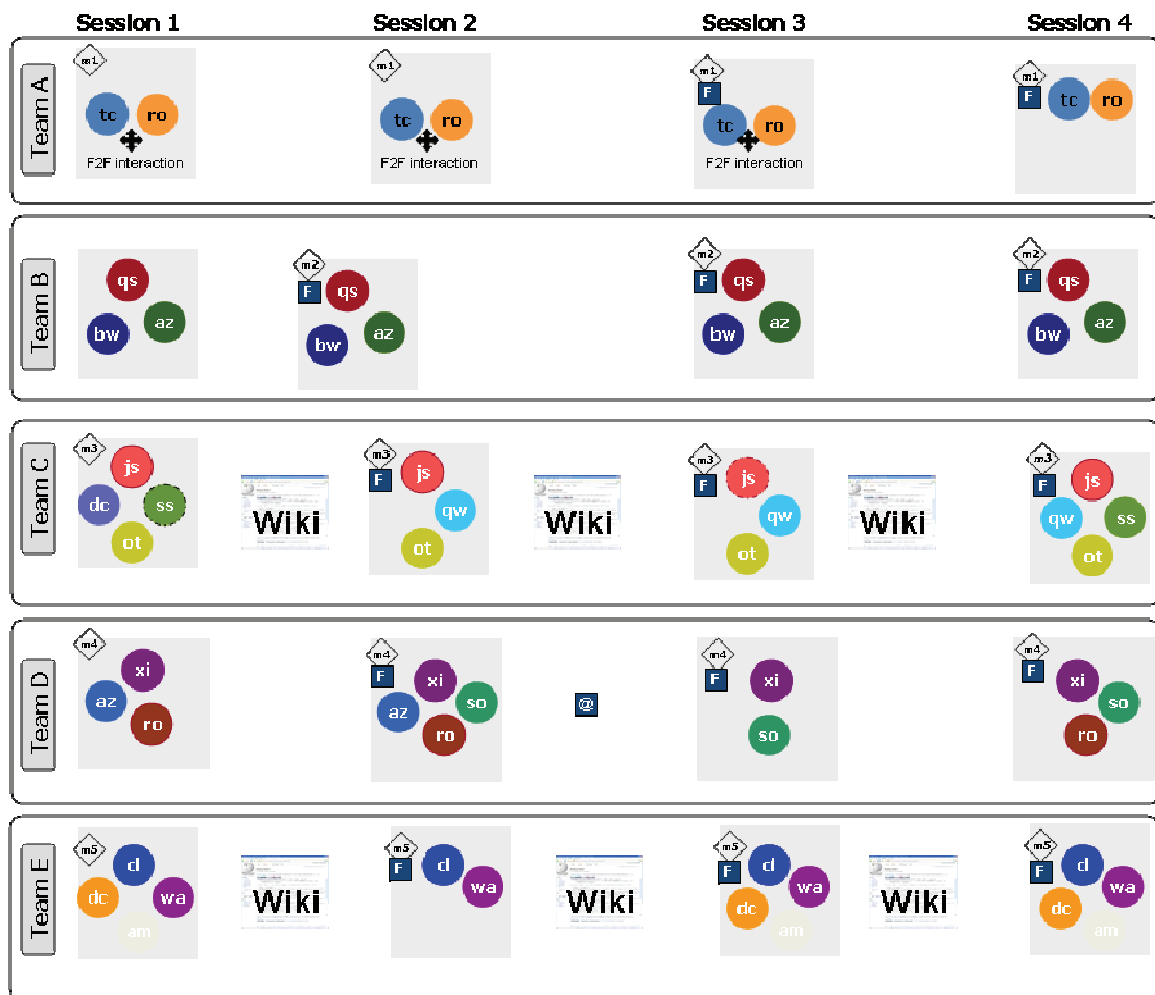


Figure 9. Patterns of Participation of Individuals and Teams in Case Study Two.

The minimum number of participants in a team was 2 and the maximum 4. All of the participating teams were highly stable (with 2 or more participants attending at least 3 of the 4 sessions).

3.4.4. Online Collaboration Environment

As in Design Case One, participants were introduced to the online environment in their first team session and were also provided with technical assistance throughout all sessions when requested. In contrast to Design Case One, teams were instructed to reuse the same VMT room for all of their collaborative session providing them with direct access to the persistent records of their prior conversations or drawings. In addition to the virtual rooms, a Wiki environment was provided in which teams could post results and observations of their work. The way the Wiki environment was configured, each team was to post their materials into the same page as every other team as a strategy to increase visibility across teams.

Figure 10 illustrates the Wiki environment. The setup of the online environment can be considered one with explicit computational supports for bridging.

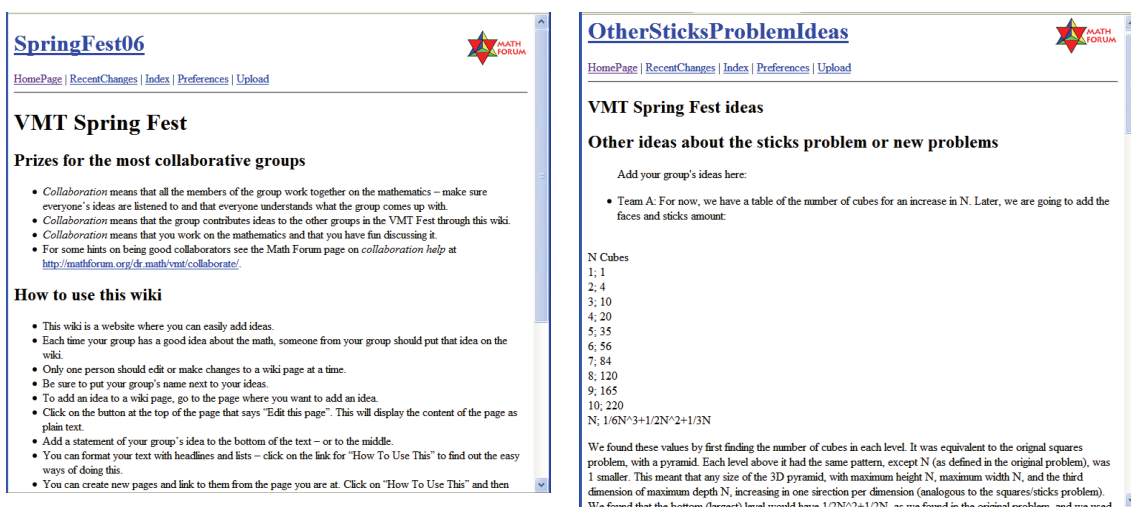


Figure 10. Two pages of the Wiki environment provided in Design Case Two. Left: Front Page. Right: Collaborative Team Page.

The two design cases described in the previous sections generated a total of 38 session transcripts (combined chat and whiteboard transcripts) which represent the main source of data collected. In these transcripts every action has a time stamp and is labeled with the participant self-chosen system name. These transcripts were used to recreate each one of the 38 sessions in real time as described in Section 3.1

Table 8 synthesizes the characteristics of each of the design cases as well as the goals pursued in the analysis of the data collected.

Table 8. Design Cases, Elements and Goals

Design Case One	Design Case Two
<p style="text-align: center;"><i>Elements:</i></p> <ul style="list-style-type: none"> • 5 Teams, 18 Team Sessions • Task: Grid World Task. Problem Solving, Problem Finding • Persistence in Online Environment: Teams used a different virtual room for each session • Team Composition: Possible changes in membership due to voluntary participation • Awareness of Other Teams' Work: No direct access to other team's work 	<p style="text-align: center;"><i>Elements:</i></p> <ul style="list-style-type: none"> • 5 Teams, 20 Team Sessions • Task: Sticks and Squares Task. Problem Solving, Problem Finding • Persistence in Online Environment: Teams re-used the same virtual room for all its four sessions • Team Composition: Possible changes in membership due to voluntary participation <ul style="list-style-type: none"> • Awareness of Other Teams' Work: Mediated access to other team's work via VMT Wiki
<p style="text-align: center;"><i>Goals:</i></p> <ul style="list-style-type: none"> • Initial characterizations of bridging and bridging practices • Initial characterizations of practices oriented toward constituting individual, group, and the collectivity of teams within bridging • Initial characterizations of continuity in VMT 	<p style="text-align: center;"><i>Goals:</i></p> <ul style="list-style-type: none"> • Confirm and expand characterizations of bridging and bridging practices • Confirm and expand characterizations of practices oriented toward constituting individual, group, and the collectivity of teams within bridging • Confirm and expand characterizations of continuity in VMT

3.5. Case Selection

The process of selecting episodes of interaction that involved bridging activity and which, as such, constituted the focus of our analysis phase followed an iterative procedure spanning both design case studies. As we have described in the previous section, Design Case One involved 18 team sessions which were captured via electronic logs (i.e. transcripts of chat conversation and whiteboard actions) that could be reproduced in real time from the perspective of the participants using a special VMT replayer tool. Each one of the 18 initial team sessions was reviewed with the intent of identifying all the passages or episodes where the teams were either orienting to another of their sessions of collaboration (episodic discontinuity) or to the changes in participation associated with those (participation discontinuities). This review produced a collection of 31 passages of interaction. Passages ranged from small ones involving 5-10 chat postings and covering 10-20 seconds of interaction to larger passages with 40 or more chat postings and whiteboard activities

across 10 or more minutes of interaction. After this initial collection of episodes was established, further analysis revealed that some of these episodes involved no significant interactional uptake by the team. After careful review, these cases were then removed from the initial collection. We explain this process in detail next.

An initial analysis of all the 18 team sessions in the first design case study revealed that the two sources of discontinuity that were the focus of our analysis (multiple episodes and changes in participation) undoubtedly registered as relevant aspects of the participant's interactions. For example, numerous times the participants referred to prior sessions, prior participants, and prior problem-solving resources. In order to identify and select instances of bridging activity, we gradually defined three features of the interaction which indicated the orientation of the teams to episodic and participation discontinuities. First, the presence of "boundary" markers that identified discontinuities (e.g., those generated by the suspension and recommencement of activity, by interactions across multiple collectivities, etc.); second, visible changes in the participants' orientation toward each other (e.g., changes in how participants oriented to each other and to the activities available to them); and finally, changes in epistemological orientation (i.e. the display of what can be claimed as known or as suitable to be known by an individual or a collectivity). For instance, in some cases participants used discourse markers such as those in the following postings: *"hi Mathman and Mathpudding where were u last time"* (Team One, Session 3, Design Case One), *"hey Templar come back here on thursday your welcome anytime"* (Team One, Session 3, Design Case One), or *"the other 2 aren't here yet though"* (Team 2, Session 4, Design Case One). These references appeared to be used by the teams as linguistic resources to achieve some specific activities such as welcoming back participants, extending an invitation, posing an objection, etc. In addition, other instances showed participants contrasting some features of their current problem-solving situation with features of a prior situation. For instance, several of the teams in Design Case One remarked in their second session that the points A and B in the original grid given in session one were no longer available (e.g., *"where is a and b"* -Team 4) or reminded the group that such points had a specific set of properties (e.g., *"wasn't it 4 and 6 yesterday?"* -Team 2; *"slope was 4, 6."* -Team 4).

From the interactional markers and moves that signal to us that teams were orienting to episodic and participation discontinuities, we followed the unfolding of the interaction with its different actors and their participation as a holistic unit. We also

traced some of such episodes back to prior interactions as a way to investigate how they were being reconstituted in the present. At times, we used additional contextual information such as the number of chat sessions that some team members had attended in the past in order to guide our analysis. In addition to the chat transcript we used snapshots from the shared whiteboard to trace the origin and uptake of certain graphical artifacts used by the team as knowledge resources. These resources and interactions are material evidence of the methods, strategies and routines that the participants used to accomplish the tasks that they were orienting to—of the situated activity system. These features which allowed us to identify bridging interactions emerged from the analysis of all 18 team sessions in Design Case One and were later refined within the selection of cases from Design Case Two. Initially, a dataset of 31 passages of were identified from Design Case One. However, despite the fact that these interactional episodes showed that the participants oriented to the discontinuities of interest as relevant aspects of their interactions, in several of these episodes we were not able to identify a clear or significant uptake in the subsequent activity of the team or, as we have characterized it, a significant interactional effect in the sense of the team shifting its activity in a new direction or engaging with such resources in a significantly different way. As an example, consider the following excerpt from Team 4, Session 3 in Design Case One.

Log 3. Design Case One, Team 4, Session 3

8:18:37 IH:	so last week, we found out that if moving only right and down, it will always be 10 moves from a to b
8:18:59 SH:	yea i got that
8:19:08 SH:	so wa do we do now???
8:19:22 IH:	ask questions
8:19:44 IH:	hey, vmtguy, do we still need a team name?

In what follows after this excerpt of interaction, the team engages in a series of activities that do not exhibit any visible connection with the report of prior activity made by IH (“*so last week, we found out that...*”). This lack of uptake parallels many instances in which the facilitators asked the teams to think about what they had done in a prior session but in which the accounts produced were not taken up as resources or triggers of new activity. The following excerpt from T4/S4 illustrates this situation:

Log 4. Design Case One, Team 4, Session 4

Facilitator:	Have you been thinking about the Math you have been doing during the last three sessions?
JS:	yes
Facilitator:	How so?

JS: well we were basically just discussing more questions about the points A and B on the cartesian coordinate
 ES: joins the room
 ES: Sorry im late, track finals
 FO: how did you do? (points to JS's message)
 ...

In contrast, in the rest of the episodes identified teams visibly oriented to and engaged with the relevancies displayed in the bridging attempts made by the participants, integrating the use of references to prior activity in a distinct trajectory of problem-solving activity. Recognizable uptake and a visible interactional engagement as far as the problem-solving activity of the team were then used as a criteria of inclusion for which episodes or 'instances' of bridging activity were selected for further analysis. Through this process, the initial dataset of bridging cases or 'instances' was reduced from 31 to 16 instances. As we have mentioned, each instance could range from a couple dozen actions spanning a few minutes of interaction to larger episodes of team activity. A year later, when data was collected through Design Case Two, this process was repeated. From the 20 team sessions 76 passages or episodes were identified where the teams were orienting to episodic and participation discontinuities and a total of 50 episodes resulted of the application of the same inclusion criteria used for Design Case One. Table 9 summarizes this process showing the total number of instances or cases identified and the final number of selected cases across the two design studies conducted. Despite the fact that our research questions did not predict quantitative patterns within and across design cases we will reflect on these apparent quantitative differences after presenting our results.

Table 9. Total and Selected Cases from each Design Case Study

	Design Case One	Design Case Two	Total
Initial set of all Instances	31	76	107
Selected Instances	16	50	66
Length of Selected Instances*	10-50 chat postings 4 mins. - 12 mins.	10-200 chat postings 3 mins. - 28 mins	10-200 postings 3 mins. – 28 mins.

(* Although the length in terms of time and number of chat postings is given for reference purposes, interactions were also interpreted with reference to interactions preceding or following the specific episodes that form the basis for these findings.

Once the instances were selected, analysis and constant comparison through different instances of bridging activity were used. Next we describe the method and process of analysis.

3.6. Data Analysis Method: Chat Interaction Analysis

The framework of design-based research (DBR) is strongly rooted in the theoretical positions of situated cognition outlined before; especially as it relates to the perspective that learning, cognition, knowing, tools, media and context are irreducibly co-constituted and cannot be treated as isolated entities or processes (Greeno, 2006; Stahl, 2006a). For this reason, we attempted to analyze the performance and transformations over time of VMT as an *activity system* consisting of situated arrangements of co-participants interacting with a variety of technological artifacts. Rather than concentrating on the individuals, their characteristics, abilities and thoughts, we looked at situated teams, their resources, interactions (within the team and between teams) and continuities. We focused on an activity system as the *unit of analysis*.

Although the activity system was chosen as the central unit of analysis, we did not approach the analysis of VMT interactions in a deductive way rooted in Cultural-Historical Activity Theory (CHAT). Rather than defining bridging as an analytical concept, we adopted a grounded approach to its characterization in the demonstrable instances recorded in the data collected and aimed at inductively investigating how participants approached the types of activities that we iteratively characterized under the concept of bridging work. Based on the instances of bridging selected for analysis, we adopted a research strategy that iteratively refined a descriptive theory of bridging in online collaborative learning contexts using a method of chat interaction analysis informed by Ethnomethodology (Garfinkel, 1967; Heritage, 1984; Livingston, 1986). In fact, Activity Theory does not prescribe any particular data analysis approach and does not reject the usefulness of other conceptual schemes such as situated cognition —as Kaptelinin has argued, no conceptual tool, no matter how powerful it is, can serve all needs and help solve all problems’ (Kaptelinin, 1996). Next we present our data analysis method and the ways in which we sought to approach the analysis of the VMT activity system from the perspective of ethnomethodology which, as we will outline later, provided a more

concrete set of guidelines for how to explore the interactional aspects of specific activity systems in action.

The activity system was chosen as a flexible unit of analysis allowing us to focus our attention simultaneously in different directions and apply different lenses when pursuing our questions of interest. The particular method that was used to analyze the data collected is derived from interaction and conversation analysis and strongly rooted in the Ethnomethodology tradition (Garfinkel, 1967; Heritage, 1984; Livingston, 1986). 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, Schegloff, & Jefferson, 1974), 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 p. 37). As a result, Ethnomethodology encourages the study of phenomena within its natural setting, insisting that “the research interaction should take place with the entity-in-context for fullest understanding” (Lincoln & Guba, 1985). It also promotes an inductive approach to data analysis as a way to iteratively build characterizations of interactions and explicate the realities and experiences of the participants.

In Ethnomethodology, particular attention is given to the ways that the participants demonstrably orient to the interaction moment-by-moment. One could say that the fundamental assumption of Ethnomethodology-informed studies is that participant in social situations have some shared methods which they use to mutually construct the “meaningful orderliness” such situation (Garfinkel, 2002). The goal of any analysis becomes then the description of the methods employed in the production of orderly character in social interactions. As a result, at each moment of the interaction our approach was to attempt to answer the question “*why this now,*” approaching it not as analysts but as competent members of the culture of the participants being observed. We inquired about how the textual postings and other actions in the online environment demonstrated to the participants the methods used to accomplish the tasks being carried out. Members’ methods are seen as the ways that people produce social order and make sense of their shared world. For instance, conversation analysis, a particular branch of Ethnomethodology, has shown that there are well-defined procedures that people use to take turns at talk (Sacks *et al.*,

1974), to conduct telephone conversations (Schegloff, 1979) and to recommence meetings (Atkinson, Cuff, & Lee, 1978). Applying the approach of Ethnomethodology to the analysis of our team interactions meant that we needed to define procedures to analyze the textual messages and other actions observable in the online environment when teams are engaged bridging work and explore the relationship of such activities with their overall collaborative knowledge building work. Using this approach, we attempted to identify through the data the relevancy of the types of phenomena that we have labeled as “bridging work,” validated the theorized structural elements related to bridging activity, and investigate the members’ methods utilized to deal with instances of bridging work as well as their interactional effects.

The actual process of analysis consisted in traversing each of the datasets assembled for the two design case studies employing, iteratively, the following procedure:

- a) Interaction Analysis of the first session of a particular team in one of the design cases, noticing the team’s patterns of participation and problem-solving developments.
- b) Followed that team to the second session identifying changes in participation and possible “bridging-related” activity linked to work conducted on the previous session
- c) Completed that team’s trajectory through sessions three and four analyzing episodes of bridging activity
- d) Repeated the cycle of steps (a) through (c) for a different team
- e) Compared the instances of bridging activity of the two teams “horizontally” noticing their trajectories and dynamics of bridging activity
- f) Repeated cycle of steps (a) through (e) to complete all the teams.
- g) Compared instances of bridging “vertically” by session
- h) Compared all instances of bridging activity iteratively within and across design case studies

For each one of the team sessions, we wrote a set of descriptive vignettes synthesizing the major problem-solving work conducted in the session and some of the most salient activities. In doing this, ‘bridging descriptors’ (e.g., “comparing current problem to previous work”) were created and revised iteratively in a similar

fashion to the methods commonly used in grounded theory (Glaser & Strauss, 1967). These vignettes were written and maintained using an instance of MediaWiki and its correspondent tagging supports. In addition, the analysis of the first dataset of instances or cases of bridging activity from Design Case One provided a first set of theoretical characterizations which were confirmed and expanded through the analysis of the second dataset collected one year later. Each design case was designed in a way that all three research questions could be answered from it individually, while the availability of the two design cases offered a richer dataset to conduct constant comparison and to evaluate theoretical saturation (Gasson, 2003). However, since the second design case presented variations to the activity system in comparison to the first design case, such factors were carefully considered as part of the analysis and will be noted in our presentation of results whenever necessary.

To confirm and expand the validity of the iterative observations made through the data analysis process, we used *data sessions* (Jordan & Henderson, 1995) in a way that allowed us to iteratively refine our analysis of the interactional data collected. Data sessions assembled a number of researchers participating in the Virtual Math Teams project, who reviewed and discussed excerpts from the data available and collaboratively responded to analyses presented, as competent members of the culture. Researchers as a group tried to make sense of the data as participants, since they had access to the same resources as the participants had and were able to understand them in similar ways. By encouraging analysts to work collaboratively, data sessions can minimize the idiosyncratic analyses. These data sessions were conducted as part of the regular research activities of the Virtual Math Teams project at the Math Forum. Once instances of bridging work were identified and their structural characteristics analyzed, further comparative work was conducted as a way to expand the components of a theory of the role of bridging in online collaborative learning. This method of analysis complemented the iterative framework provided by design-based research by offering an analytical focus to the overall project of theory building and system design. As mentioned previously, although this dissertation is written using the first-person plural pronoun, the ideas and points of view expressed in it are not presented as the collective responsibility of those who participated in the data sessions here described but represent the author's intellectual responsibility unless otherwise explicitly acknowledged through citations.

Two final notes regarding our research framework and method of analysis are necessary. Although design-based research is a powerful tool for investigating learning in real-life settings, serious challenges arise from the intrinsic complexity of such settings. One commonly acknowledged weakness of the method is that large amounts of data emerging from the investigation pose a serious management and analytical demand on researchers (Barab, 2006). In our case, we have purposively tried to delimit the object of our investigation in a way that will allow the researcher to manage this risk. Although large amounts of data will emerge from the two design case studies, by selecting the recordings of the interactions as the primary data source and concentrating on the activity system as a unit, we expected to generate a manageable set of instances of bridging which will be sufficient to advance the corresponding theory.

Another challenge related to design-based research which applies to our study is related to the difficulties in establishing comparisons and generalizing across contexts. In our case, our data includes teams using similar sets of collaboration tools and performing similar activities within each individual design case, and, at the same time some variability when comparing the tools, and tasks across design cases. However, underlying every team session and both of the design cases, there is always the common structure of online, mathematical collaborative-learning interactions. We are confident that this overarching setting provided enough of a unifying structure for all cases to be comparable within reasonable measures. We will not claim to extend generalizations to other contexts, for instance virtual teams in organizations or general online communities of interest. This dissertation is not intended to produce replicable quantitative findings or statistical models, but to explore and refine concepts of bridging in settings like the VMT online community. It is a descriptive and analytic study.

4. RESEARCH RESULTS

4.1. Four interactional bridging methods

At the onset of our research, we focused our attention on collective interactional activity through which teams participating in Virtual Math Teams attempted to overcome discontinuities emerging from their multiple episodes of collaboration over time and from the dynamic changes in participation. We expected this type of collective activity to be achieved through a set of practices used by the

teams to deal with such discontinuities in the ways that they found relevant for their collective engagement. Our first research question focused on identifying and describing such methods: *What interactional practices are used by participants in the Virtual Math Teams online community to overcome two types of interactional discontinuity: episodic discontinuity—multiple episodes of collaborative knowledge building, and participation discontinuity—changes in group participation over time?* (RQ1)

In the following sections we describe each one of the four bridging methods discovered through our interaction/chat analysis of VMT sessions in the two design cases studies conducted. We attempt also to synthesize the common underlying structure of the four methods as a way to advance a common characterization of all bridging activity. Central to the task of characterizing the interactional methods used by teams was our inquiry into the observable and demonstrable effects that engaging in such practices brought to the team and, especially, to its attempts to build collaborative knowledge. For each one of the methods outlined in this chapter, our process concentrated specifically on identifying interactional effects visible especially through shifts in the organization of particular activities within VMT such as problem discovery, formulation and exploration.

4.1.1. Method I: Reporting prior activity to frame current problem solving

The single most recurrent bridging activity that VMT teams engaged in both design case studies, involved the referencing and re-presentation of prior doings and prior resources (of specific actors) as past ones in relation to a current interaction. The dynamics of the interactional episodes that oriented to this kind of activity resembled the collective production of a report or a narrative of past doings to which specified individuals or collectivities were associated. However, such reports were not simple re-transmissions of stored information but closely situated and responsive to the joint knowledge-building activity of a team. These interactionally-produced reports reintroduced specific problem resources and constituted them as relevant to the initiation or continuation of a current activity, usually through a series of jointly coordinated interactional moves by the team (e.g., chat postings or whiteboard actions). In doing so, teams expanded the field of resources and possible actions relevant to their building of collaborative knowledge and enacted specific forms of participation (e.g., reporter-interactive audience, narrator-challengers, etc.) which made reporting not only possible but also highly consequential to the teams overall trajectory of knowledge work. A total of 40 instances of this type of interactional

method were identified in the overall dataset of selected instances from both design cases. Below, we present the analysis of the most salient interactional characteristics of this collaborative practice.

You always have to move a certain amount to the left/right...

In the first collaborative session of Team Five in Design Case One, two participants, Drago and Estrickm worked on exploring the grid-world task and attempted to create a formula for the shortest distance between two points A and B in the grid world. In the team's second session, the two original participants were joined by two new team members: Gdo, who had worked on this problem with another team in a previous session, and Mathwiz who was new to both the task and the team. The following excerpt corresponds to the beginnings of this second session:

Log 5. Design Case One, Team 5, Session 2

302	gdo:	now lets work on our prob (<i>Points to Whiteboard</i>)
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		<i>gdo leaves the room</i>
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 (<i>Points to line 314</i>)
316		<i>gdo joins the room</i>
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 (<i>Points to line 317</i>)
322	gdo:	ok (<i>Points to line 314</i>)

This excerpt exemplifies an interaction in which the participants are engaged in constituting a task for themselves. Such task is being constructed through reporting activity which indexes resources that Drago and Estrick had 'came up' with 'last time.' Early on this second session, the team had decided to work on one of the questions presented by the facilitator on the whiteboard: "*What is the shortest path along the grid between any two points $A(x_1, y_1)$, $B(x_2, y_2)$?*" The initiation of this reporting activity comes in line 303 right after Gdo had attempted to transition from what they were doing before to 'now' working on 'their problem.' The relevance of Drago's initiation of the reporting activity is then constituted through this sequential ordering.

Drago's telling of what he and Estrick discovered in their prior session is linked to the problem previously selected by the team by virtue of this sequentiality, despite the lack of an explicit reference in Drago's posting. It becomes a potential interactional need for the team to fully work out this relevance. Drago's telling, on the other hand, does involve an explicit reference to who is to be seen as associated with what is being reported ("me and estric"), an indexical that marks a particular point time ("last time"), and a *reportable* with the structure of a rule-like presentation: "*you always have to move a certain amount...*" The intelligibility of this reportable and its relevance is something that, as we can see by following the unfolding of the interaction, has to be worked out as a present concern (i.e. bounded within the current interaction). In fact, as can be seen in the unfolding of this passage *reportables* are not simply displays of memories but highly situated 'bridging objects' that respond to and link together the particularities of the present situation and the reported past. A systematic analysis of the ways in which the team oriented to their current situation and to the situation which Drago is reporting about, can illuminate specifically how teams situate or constitute objects both retrospectively (in relation to the reported past) and prospectively (in relation to the current and ongoing opportunities for action).

One aspect of the way in which the reportable introduced by Drago is highly situated both retrospectively and prospectively, emerges from a contrast between the way that the Drago and Estrick had structured the points on the grid world in the first session and the way that the team had done up to this point in their second session. Figure 11 presents snapshots of the team's whiteboard for each of the two sessions capturing the location of points chosen to be explored each time.

Log 6. Design Case One, Team 5, Session 1

Log 6 was taken from the teams' first session and contains the discovery that Drago is referencing in their second session and should help us illustrate the relevance of the differences in their situated problem space.

Log 6. Design Case One, Team 5, Session 1

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 always have to go down and to the right the same amount of times
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)

In line 173 we can see Estrick stating—in response to a question by Drago, that “*you will always have to go down and to the right the same amount of times.*” “Down” and “right” become meaningful here, at least in part, in relation to the arrangement of points that the dyad is orienting to (see Figure 11, left). As we have noted, Drago’s reporting on behalf of the dyad in session two contains a variation of Estrick’s original posting but replaces “down” and “to the right” by “left/right” and “up/down.” Whether Drago realized this generalization via further individual work in between team sessions or whether the current arrangement of points provided the need for the generalization to happen, is something that we cannot say conclusively. However, Drago’s posting, like any other, is situated in the ongoing flow of the team’s interaction and as such, the preceding postings and actions as well as the objects visible to the participants at the moment, play a significant role in the ways that they make sense of it. By indexing a prior event, Drago has attempted to expand the set of resources which might be effectively used by the team to make sense of the posting and has made it possible for the current material situation as well as the reported one to be used for sense making. This sense making is available to all participants but not in the same ways. The members of the team positioned as not having participated in the prior work, orient to the reportable as a resource whose relevance needs to be worked out interactionally in cooperation with the reporter and all of those who can speak on behalf of the prior activity being referenced.

The mere introduction of this “reportable” or “gist formulation” (Schegloff, 1979; Shaw & Kitzinger, 2007) doesn’t make it automatically intelligible to others nor does it complete the work of integrating it into the current problem solving activity without any further work being required. Drago’s presentation of the rule-like discovery does not directly transfer any particular information in any definitive way nor is its

adaptation of terms immediately successful in integrating the past and current present situations. In the original excerpt from session two (Log 5), Mathwiz' question (line 314): "*would you want to keep as close to the hypotenuse as possible? or does it actually work against you in this case?*" illustrates the work necessary to collaboratively construct the intelligibility and relevance of a report, and advancing its current use. This kind of collective work seems oriented toward actively assessing, developing and displaying an understanding of the local meaning and relevance of what has been reported. Notice, that this question is not oriented to the past directly. This posting is constructed as a response to the "rule" that "you always have to go a certain amount" in both directions and, although interactionally it addresses Drago primarily, it also indexes the generic "you" that is part of the rule. An extended sequence of these interactional moves allows a team to fully engage with the reported past as present matter and to integrate it in their current problem-solving activity to the extent necessary.

Notice that Drago's response in line 321 returns to the original formulation of the rule without the adaptations we have referred to ("*you always have to go the same amount right, and the same amount down*"). It is possible that this move is a form of repair which takes Mathwiz' question as indication of potential intelligibility problems and, consequentially, potential interactional trouble. At some point, thanks to this collaborative sequence, a current task is co-constructed and the participants orient to it as their present matter with the reported past no longer being their central, visible, concern. For instance, the excerpt presented before reaches a point where Drago eventually formulates a task: "*we need to find a relationship between the numbers / like x_1, y_1, x_2, y_2 / but the relationship needs to work with whatever points,*" with which the team proceeds to work. In this way, Drago constitutes a task that has relevancies to prior doings but which, at the same time, is constituted for the current team to engage with. The "frame" of past activity seems to be less explicit at this point allowing us to state that the team has successfully bridged a prior episode of their interaction and constituted a collective task for themselves. However, the enhanced "temporal frame" that engaging in this bridging activity has constituted the current interaction, can resurface at any point in time where the participants might find it relevant. In fact, tracing the rest of this session, we see the team engaged with this problem for considerable time, testing a couple of potential formulae together until a point where a formula that Drago had offered in session one resurfaces and is explicitly marked as such by him: "*...I get it now ... I think ... it **was** absolute value x_1-x_2 , absolute value y_1-y_2 ... because / length is always positive...*" In doing so,

Drago again attempts to link the problem-solving activity they had been engaged in for the last few minutes, at least in some sense, as re-constructing a past resource. This resource had not been reported directly initially, but it is now being reported for the purpose of both validating the proposed formula and also linking it to prior activity; almost as a memory. We will come back to this type of interactional activity in a later section.

The kind of interactional reporting activity which we have traced through several passages in the first two sessions of Team Five in Design Case One, represents an exemplar of both the dynamism and relevance of bridging activity within a team's attempt at building collaborative knowledge over time. A few more detailed cases allows us to complete our characterization of this type of activity.

We already did that yesterday

Next we explore the second session of Team Two in Design Case One. In its first two sessions, the membership of this team has not changed much. In this second session, only one of the four original participants was absent and replaced by a different one. As noted before, in session two the facilitators presented on the whiteboard a list of nine questions collected from the work of all the teams that participated in the first session, plus some additional questions created by VMT staff based on their analysis of all the teams' work. This passage illustrates how Team Two oriented toward constructing a problem-solving task based on the list provided and their prior work.

Log 7. Design Case One, Team 2, Session 2

144 mathfun: **letz start working on number 8**
 145 bob: **we already did that yesterday**
 146 qwer: **we did?**
 147 mathfun: **but we did it so that there was only right and down**
 148 bob: i mean tuesday
 149 mathfun: **i guess we will do it with left and up?**
 150 qwer: It would be almost the same.
 151 bob: **it's $(|x^2-x^1|+|y^2-y^1|-2)$ choose $(|x^2-x^1|-1)$**
 152 bob: **try it if you like**
 153 mathfun: **nah**
 154 mathfun: **if you are so sure...**
 155 bob: **i'm not**
 156 bob: **actually**
 157 bob: take out the -2 and the -1
 158 mathfun: then letz check it
 159 bob: after taking out the -1 and -2, you get $5c^2$ or $5c^3$,
 doesn't matter, which is 10
 160 mathfun: **k so there are two ways right?**
 161 bob: yeah
 162 bob: $2c^1=2$
 163 Marisol: yes, I agree there are only two ways
 164 mathfun: then there is a one by two
 ...

In line 144 Mathfun makes a proposal for the team to initiate together the activity of working on problem number eight: *How many shortest paths are there from A to B and how does this vary with changes in the positioning of A relative to B?* Inserted at this point, this contribution calls for an assessment supporting or resisting the new activity being proposed. Bob follows with a type of reporting post that stands in response to Mathfun's proposal. This sequence of moves, a proposal for the initiation of a particular activity followed by a reporting move, matches the pattern presented in our first case. However, the work that this reporting activity seems to be doing in this case appears different. Here, the function of Bob's reportable and its relevance is very clear. Bob is presenting a reportable to object to the team working on problem number eight. That being said, the interactional relevance of Bob's reporting, i.e., the validity of the objection that they had already worked on that problem in their last session, is again for the group to establish. Qwer's response to Bob in line 146 asks for confirmation or elaboration on Bob's objection while Mathfun's response in line 147 acknowledges that the team had indeed worked on the problem last time but "only" for the case where "there was right and down;" suggesting that there is left over work to be completed: "do it with left and up." Qwer then disagrees (although in a mitigated way) with Mathfun's proposal siding with Bob by arguing that it would be 'almost' the same to do it "with left and up." Implicit in this exchange is the interactional commitment of the participants to not repeat prior work or engage in redundant work. Tracing the rest of the interaction we can see how the team engaged in first co-constructing an agreement about whether they should work on that task and, later on, actually conducting the problem-solving work they find necessary.

Bob's furnishing of a formula in line 151 (presented and oriented to as a reported object) and his subsequent "challenge" for others (perhaps Mathfun in particular) to try that formula "if you like" is followed by Mathfun's conditionally declining to do that, if Bob is "so sure." When Bob states that he is not so sure about the formula (not necessarily presented as his) Mathfun inserts a proposal for a new activity that responds to the current needs which have emerged from the original proposal of working on problem number eight and from the uncertainty of whether the team actually has a solution formula for it. It is important to note that the three members of the team that we see interacting here were part of the previous session. In fact, an excerpt from the previous session from this team illuminates some of the aspects of how the rest of this passage will unfold.

In Log 8 below we can see how in their first team session Mathfun introduces the question that in session two will reappear through the facilitator's posting on the whiteboard: "*How many ways are there to get from A to B?*" (line 226)

Log 8. Design Case One, Team 2, Session 1

226 mathfun: **How many ways are there to get from A to B?**
 ...
 236 mathfun: does everyone see the ACBD rectangle?
 ...
 239 mathfun: letz find the amount of way in that small rectangle
 ...
 241 bob: **56**
 242 bob: **8 choose 5**
 243 mathfun: not the shortest
 244 bob: **(4-1+6-1) choose (6-1) or (4-1)**
 245 bob: is 56
 246 bob: **that's the answer**
 247 bob: **assuming you can only go right and down**
 248 qwer: what does that mean?
 249 bob: the number of ways to choose 5 things from 8 things
 250 bob: it's a formula
 252 bob: the formula to find the number of ways in an n by m rectangle like this is
 $(n+m-2) \text{ choose } (m-1)$
 251 qwer: ok

After Mathfun introduces the question in this first session we can see that it is Bob who offers a series of postings which cycle from an factual answer (line 241) to more explanatory postings (lines 242 and 244) followed by a restatement of the answer (line 245) and an assumption (line 247) which seems to condition, at least partially, the validity of his answer: "*assuming you can only go right and down.*" Interestingly, it is Mathfun who brings up this assumption which was never explicitly addressed in session one back in session two (line 147, previous transcript). As we had said, this indicates his orientation to work left to be done by the team. Notice as well, that in this session there was no general formula offered (for all combination of points A and B on the grid) since the team was oriented to the particular ABCD rectangle that they had constructed on the whiteboard (referenced in line 236 by mathfun). In session two, not having access to their prior drawings, they attempt to re-create the arrangement of points on the grid which they had used in session although they end up with a slightly different rectangle (bob123: wasn't it 4 and 6 yesterday?). This change in the way the participants structured their problem solving space might again be the force behind Bob's variation to a more general form when presenting his prior formula: *it's $(|x_2-x_1|+|y_2-y_1|-2) \text{ choose } (|x_2-x_1|-1)$* . More importantly, when the team collectively orients to the work of "checking" the formula, they organize a series of different cases (ABCD rectangles) to which the formula is

applied, a practice reused from their first session. This process, however, is approached as a present matter responding to their current concerns and nowhere else throughout this interactional passage does the prior work conducted in session one become explicitly referenced. Presumably, after the reportable has been integrated into the current interaction, co-participants might find the references to what we have called the “extended temporal frame” less compelling or necessary. A final case of reporting activity from Design Case Two allows us to expand our characterization of reporting.

What was your pattern of growth, Quicksilver?

In contrast to the interactional arrangements in Design Case One, teams participating in Design Case Two reused the same virtual room for all of their collaborative sessions. Through the room’s persistent artifacts, teams had access to the entire transcript of their chat as well as all the graphical objects they had created on the whiteboard. As we had described previously, between sessions, facilitators analyzed the team’s collaboration and left a feedback note for the team using the textbox tool on the whiteboard. The feedback note for Team B in session two contained the text displayed below:

Log 9. Design Case Two, Team B, Session 2

VMT Feedback

We were very interested in the approach that divided the figure into the horizontal lines and the vertical lines and the quickness with which formulas fell out of that approach. It seemed as though you also were paying attention to each other's work and quickly reached agreement. You handled the technology of the chat environment and the Wiki easily.

We also noticed two places in the chat where some kinds of conversation did not happen. There was a point where 44 was posted as the number of sticks and 40 was offered as a correction. There was no discussion of how 44 was calculated. At another moment, **Quicksilver posted an explanation of the pattern of growth that was not discussed.**

There was a sense in which you indicated that your work was done when you had at least one answer for the questions in the problem. For the next step we will encourage you to think more about the different approaches and the problems that you can discover on your own and that are interesting to pursue.

This note is written in plural form as if a group had observed the first session and is reporting about things that seemed interesting, well done, or in need of improvement, as well as about suggestions on what the team might do in its second session. The interactional relevancy of this feedback note, however, as with any object embedded in an interaction, can be traced based on the uptake that the participants give it. When Team B initiates its second session, they first orient to reading their “topic” (through a special area of the room environment labeled “View Topic” and reserved for presenting problem descriptions) and then to reading the feedback note left on the whiteboard. After a few minutes, Team B’s uptake of the feedback note indicates that they take it as a relevant activity to either justify the observations made in the feedback or to project from it “rules” about what they might do differently in the future. In contrast to other instances of reporting activity, in this case, the feedback note reports not “on behalf” of the team or some of its members but about the collectivity and its work (Lerner, 1993). Quicksilver first takes personal responsibility for the “conversation not happening” but also blames it on technical problems outside of the team’s control (*Well,, the part about converstaion not happening is because of me / my computer was lagging.../ but that's out of our hands*). Later on, he adds that last time he “gave a wrong answer” but that his explanations “didn't come up on the computer because of the lag.” By doing this, Quicksilver has constituted the feedback as an assessment that requires verification and explanation; something he has done for himself and on behalf of the group by offering two reasons why the conversation about his pattern of growth did not happened: technical problems and the fact that the explanation he provided was wrong. One way to read the feedback paragraph posted above, however, indicates that VMT expects certain conversations to happen, including, perhaps, conversations about wrong answers. Perhaps responding to this concern, Bwang asks Quicksilver to describe now in session one what his pattern of growth “was”. Naturally, this kind of request for a report is a common trigger of bridging activity as can be seen in the following excerpt.

Log 10. Design Case Two, Team B, Session 2

- 320 Quicksilver: Now did you two read today's topic?
321 bwang: **what was your pattern of growth, quicksiler**
 322 Quicksilver: i think it was something about the amount of squares that increased with each row....and how one of the new squares had 3 new sticks while the other new ones had 2 new sticks
 323 bwang: oh, ok
(Quicksilver starts to draw squares with sticks to illustrate his talk to which he refers to in his next chat message)
 324 Quicksilver: i drew some sqaures
 325 Quicksilver: the left one had three new sticks

- 326 Quicksilver: the right one has a new stick on the bottom and on the right
 327 Quicksilver: the top one is from an old square
 328 VMTMod : **It was at 7:00:39 -- to get the old messages, click on the icon above here with the two circular arrows**
(This messages points to a message from the previous day's session)
(The feedback textbox is deleted from the whiteboard)
 329 Quicksilver: **yea it's at the very top. but i think there ae errors in that paragraph**
 330 Quicksilver: **yea that's wrong**
 331 Aznx: So let's brainstorm through some problems that we think are challenging.
 332 Quicksilver: **yes...new topic**
 ...

Bwang's request for a report in line 321 is addressed specifically to Quicksilver and as such responds directly to the bridging report embedded in the feedback note which states that "Quicksilver posted an explanation of the pattern of growth that was not discussed." In doing so, Bwang also acknowledges the collective responsibility of the team by putting forward a bid to respond to the assessment included in VMT Feedback about a sort of failure in session one. Before considering Quicksilver's response to Bwang's request, it is interesting to note that the team seems to have oriented to the second of the conversations which the feedback alleges "did not happen" in session one. The first one, the one about whether a figure had 44 or 40 sticks, was not presented as having a particular team member directly related to it, as opposed to the explicit mention of Quicksilver's pattern of growth. This might indicate that the way individual participants are positioned in relation to certain topics or activities matters interactionally in the way they orient to the moment-to-moment rights and duties of their conjoined participation.

Quicksilver responds to Bwang in line 322 with a second bridging report which varies slightly from other instances of reporting activity we have seen before. Quicksilver's response, prefaced with uncertainty ("I think it was...") seems to indicate that he might orient to his report more as a reconstruction of his prior finding than simply as building a reporting about it. As we have seen in other instances of bridging activity reports of past activity require significant work for a collectivity to constitute the situated meaning of reports (e.g., prior findings, reasoning procedures, or other key elements) in the present moment. This is true even for teams whose membership does not change from one episode to the next, as is the case with this team. However, the orientation to a reconstruction can add to the reporting challenge the need to achieve the embedding of prior experiences in a present moment without those experiences being fully defined. Quicksilver, however, orients to Bwang's request for a report and launches into a narrative of his prior work in the rest of line

322. We will come back to reconstructions in detail in a subsequent section. However, we want to note certain aspects of Quicksilver's reporting activity which will be helpful in introducing a the role of graphical and persistent objects as part of bridging activity

In the kind of reporting that Quicksilver is engaged in, he seems to attempt to construct and organize resources so that his co-participants can both have access to the prior episode he is reporting on and, possibly, assess his report. This challenging task is critical for the team to be able to make sense of the bridging activity, and usually involves iterations of construction and assessments in which different participants may participate in several ways. In this case, for example, Quicksilver's initial response indexes how he visualized the general growth of the squares in the pattern. He does this explicitly with the phrase in line 322 *"the amount of squares that increased with each row"* indicating, perhaps, that he sees the change from one stage of the pattern to the next as adding a new row of squares at the bottom of the previous figure. There are other ways in which the growth of the pattern can be visualized as Figure 12 depicts for the transition from $N=1$ to $N=2$ in the problem used in Design Case Two. Quicksilver's perspective corresponds to the "new row" view but other team members could have seen the pattern growing through new columns, new diagonals, or in other more idiosyncratic ways.

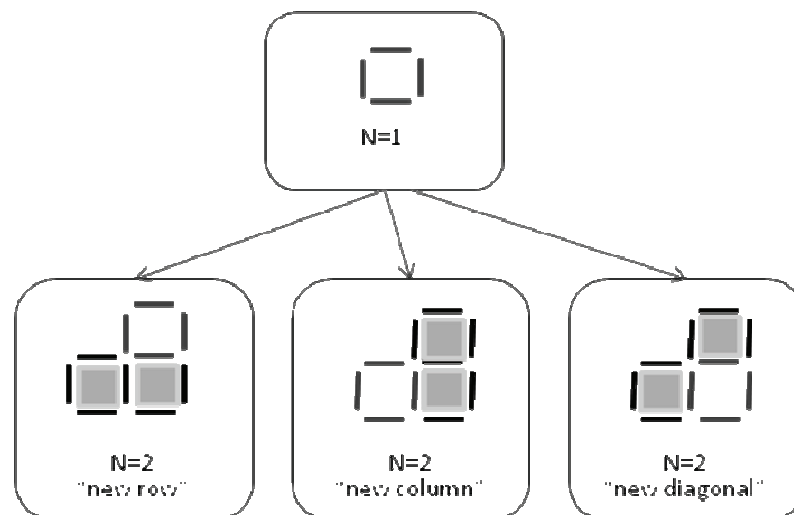


Figure 12. Three possible ways of seeing the problem's pattern grow.

These perspectives or ways of representing the problem might be considered 'isomorphic' in the information-processing theory of problem solving. However, from an interactional perspective they are clearly not. For the participants themselves,

ways of understanding their problem solving resources have to be made isomorphic in interaction; the different ways of “reading” and manipulating the elements of the pattern need to be directly addressed by the participants when and if they become relevant to their joint action. The way Quicksilver indexes his way of seeing the pattern grow as part of his report doesn’t explicitly address a potential divergence of perspectives but indicates that he does consider it relevant for others to know how he saw (and sees) the growth of the pattern. Interestingly, the general approach to the problem that Quicksilver is taking with his report diverges from the way the team oriented to the problem in session one. His approach is to concentrate on the way the pattern grows from one stage to the other and to build a recursive function that takes this into account. Quicksilver referenced this approach in his original message in session one by describing how to calculate the number of sticks for “*the entire figure*” by adding “*the amount to the previous amount.*” In contrast, the team concentrated on a “direct” formula which calculated the number of squares or sticks of a particular stage of the pattern based, solely, on the value of N for that stage.

In the messages that accompany Quicksilver’s drawings, he indexes discrete elements of the way he sees the sticks growing as the pattern evolves. Verbally, he divides the new squares into two categories, each one with unique properties, and reports how “*one of the new squares had 3 new sticks while the other new ones had 2 new sticks.*” As mentioned previously, ongoing reports are deployed interactionally with some details furnished up front by those in charge of the report while other participants are often in charge of assessing relevancies, requesting further details, and helping orient the report itself. Up to this point Quicksilver has initiated the interactional sequence making it possible for others to engage in this participation framework. Bwang’s response (“*oh, ok*”) can be treated as a continuation token as much as an opportunity for Quicksilver to consider his report completed. In this case, it seems to prompt, as we have seen in other instances of reporting work, for further action oriented to advancing the report being produced.

Quicksilver attempts to further his report initially by drawing two squares on the whiteboard. His drawing actions (to which he alerts others with his posting “*i drew some squares*”) and the structure of his subsequent postings indicate that he has produced an illustrative case of his earlier “general” description of the pattern of growth. Using line segments, he draws on the whiteboard two squares. “One of the new squares” he drew, “the left one” is referred to as having had “three new sticks”

while the other (“the other new ones” in the original description but in this case, just one, the “right one”) is said to have one new stick on the bottom and on the right (“2 new sticks” total as described before). The “top” stick of the right square, Quicksilver adds, “is from an old square.” A mix of past-tense and present-tense verbs and a correspondence of terms with his original description signal his transitioning from report to present activity. The next action in the sequence, however, is a message from the moderator which creates a graphical reference to a persistent chat posting from their previous session and also instructs the participants on how to recover “old” messages (i.e. messages from that previous session).

The beginnings of the moderator’s posting (“*It was at 7:00:39...*”) positions it both as a response to Bwang’s original request for a report (“*what was your pattern of growth, quicksilver*”) but also as possibly supporting or challenging what Quicksilver had been reporting in the previous turns. This posting is in fact a unique example of further reporting in which the reportable is presented as a link to Quicksilver’s original posting from session one: “*Well, anyway, you can see a pattern that the amount of squares increases by the n . For the sticks, The bottom row’s square on the right has 2 new sticks. All the squares in the new row to the left of it have 3 new sticks. So, If te row has 5 squares, 4 of the squares have 3 sticks, the last on only has two. For the enitre Figure, you would add the amount to the previous amount.*” Up to this point, Quicksilver was producing himself a situated account of his past ideas about the pattern of growth. Now, the “original” text of his ideas is being referenced, not just a contrasting report about them. Despite the fact that about a minute and a half passes between the moderator’s posting and the next interactional move, we cannot say with certainty that the participants followed the instructions provided in the message, loaded the chat messages from last session, and looked at Quicksilver’s original posting. However, we can say that, interactionally, their reading of the moderator’s message as a report is informed by the sequential ordering of actions up to this point (i.e. the unfolding of Quicksilver’s report) and that the relevancy of such posting with its graphical reference (albeit not necessarily the content of the message being referenced) will be constructed in relation to the unfolding trajectory of activity. Quicksilver’s response to the moderators posting, follows an agreement-disagreement pattern (“*yea*” and “*yeah that’s wrong*”) positions the moderator’s action as both supporting his current reporting in one sense but also confirming that the reportable in question is in fact a wrong piece of information. In pointing out that there are errors in that original message (line 329) Quicksilver also uses a graphical reference to link to his original chat message and follows up with an

escalation of his dismissal of the message by labeling the entire original message “wrong.” Interestingly, this sequence of actions opens up a slot for a transition to a new activity which the entire team capitalizes on (lines 331 and on).

This instance of interrelated reports and the use of a persistent resource as part of reporting illustrate a very unique aspect of the activity system in Design Case Two. By having access to records of prior episodes of interaction (both in the form of chat messages and whiteboard drawings) participants can take advantage of this interactional opportunity to deploy very particular variations on how reports are addressed. In this case, contrary to what the original feedback may have intended, the presentation of the text of a message from a prior episode results in the shutting down of a conversation about a “wrong” idea and, consequently, another place where conversation does not happen. By exploring this instance of reporting activity we do not mean to suggest that, in general, Team B was not successful in its attempts to enact bridging practices as part of its sustained collaboration nor to suggest that access to persistent records of prior actions is always counter-productive to engagement in bridging activity. As a matter of fact, Team B engaged in numerous instances of bridging activity throughout its four collaborative sessions (many of which fall into the reporting category). On the other hand, in several occasions this and other teams in Design Case Two used the persistent record provided by the VMT system — specially the persistent whiteboard which allowed the teams to easily access and re-use results and ideas achieved in prior sessions. This instance of reporting activity, however, highlights the situated nature of the unfolding of this type of interactional practice and the way that the different interactional resources available to the participants may shape how reporting gets done. Before exploring the second bridging method identified we would like to comment on the way that the Wiki, another unique interactional resource available in Design Case Two, opened up new possibilities for reporting work.

We eventually found 4 different strategies and applied them..

As part of the activity system enacted in Design Case Two, participants were provided with a Wiki site where, as the instructions provided stated, each time a team had a “good idea about the math”, someone from the team “should put that idea on the Wiki.” In reality, most of the teams used the last part of their collaborative sessions to coordinate what to report on the Wiki as well as who should do it. What is particularly interesting about the use of the Wiki, is the fact that it provided an

interactional expectation and a medium for teams to report on their work. Team B, for instance, after their work in the second session posted a detailed description of their work part of which is reproduced below.

Log 11. Design Case Two, Team B, Wiki posting for session 2

- Team B:

To investigate the number of sticks in a flat faced pyramid with n levels with 1 block increase in length and width per level. Also, to find as many approaches and put them to use. We eventually found 4 different strategies and applied them, such as divide the problem up, finding a basic pattern, and use recursion to solve problems. We also found a formula, its origins, and how to use it.

$$f(n)=4n(n+1)+(n+1)^2+f(n-1) \text{ and } f(0)=0.$$

We first determine the number of squares in each level of the pyramid, 1 cubes in first level, 4 cubes in second level, 9 cubes in third level, and so on. Then we divide each level into 3 parts, the top, the bottom and the middle. The top is the same as the bottom part...

As can be seen in this Wiki posting, the structure of the text provided by the team follows a reporting pattern. The text describes, using a collective pronoun, different activities and findings that the team engaged in during the session (e.g., “we eventually found 4 different strategies,” “we also found a formula,” etc.). The posting also accounts for the sequential unfolding of their actions by indexing activities that were performed first and others that follow. As with the tracing of trajectories that we have done in other cases, we can in fact link this Wiki posting to the empirical data that supports the team’s description. As a brief illustration of this, consider the very brief passage below which corresponds to the team’s activity during session two.

Log 12. Design Case Two, Team B, Session 2

243	bwang8:	ok, how do we figure that out
244	bwang8:	3*3 blocks
245	Quicksilver:	Break it down
246	Aznx:	I'd say look for a pattern.
247	Aznx:	and yes, break it down.

In line 243 Bwang asks the team for ideas on how to tackle a sub-problem (3*3 blocks) and both Quicksilver and Aznx respond in lines 246 and 247 with strategies that were explored before by the team. Both of these strategies, “look for a pattern” and “break it down,” were in fact strategies that the team started to develop since their first session. In addition, earlier on in the session, when the team was starting the address a new problem Aznx had asked the group “what can we use that

we already know?”, a question that signals the team’s interest in re-using their collaborative knowledge over time. Furthermore, when the team engages in writing a report on the Wiki, these team strategies also make it to the their narrative of their work (“*We eventually found 4 different strategies and applied them, such as divide the problem up, finding a basic pattern, and...*”). These inter-related reporting events demonstrate the team’s considerable engagement in sustaining their collaborative knowledge over the course of their different collaborative episodes and the central role of reporting activity in achieving this.

Summary

Table 10 presents a summary of observed characteristics across the 40 instances of reporting identified in both design cases (See Appendix A for the complete list of instances analyzed). It highlights central aspects of the discontinuities that each of these instances of interaction oriented and which we have illustrated in the preceding analysis and gives the reader a sense of the breadth of reporting activity identified in the datasets as well as the commonalities across instances. Our analysis of the collections of instances of reporting activity from both design cases (of which the four cases presented in this section are primary examples) shows that such practices were used by VMT teams as a way to frame a current problem-solving activity as explicitly linked to prior work conducted by at least some members of the current set of co-participants

Reporting involves the referencing and re-presentation of prior doings and prior resources as such and for the purpose of integrating such resources in the initiation or continuation of the present building of collaborative knowledge. This kind of activity appeared at the onset of new trajectories of problem-solving or, alternatively, toward the closing of certain problem-solving work. In initial stages, prior work was most often introduced as additional relevant resources (e.g., “last time me and estrick figured that...”), or as a way to object to a problem-solving proposal (e.g., “we already did that yesterday”). At the closing of problem-solving activity, interestingly, reporting appeared related to ways of reflecting on the work conducted in an episode.

Reportables, the knowledge artifacts that collectively get built and positioned through engagement in reporting activity, included rules, procedures, discoveries & results that become tasks themselves or resources for shaping current tasks. Although *reportables* played different roles within each problem-solving instance

investigated, they were involved in the similar “interactional effect” of a new trajectory of problem-solving work being constituted within an expanded “temporal frame” offered for the current interaction. These *reportables* were always highly situated within the teams’ current/relevant situation and were visibly co-constructed in interaction. They involved explicit labeling of prior doings (e.g., “the each square with 2 sides thing”) or adaptations of prior statements to the current situation. What is common about all instances of this kind of reporting activity, as far as the interactional effects on problem solving and knowledge building are concerned, seems to be that the set of resources relevant and available to conduct a current task is enhanced from what is currently available to include “reported” resources from prior activity. These new resources are constituted in interaction as parts of possible current team activities (and associated frameworks of participation) which include exploring new problem constraints not already attended to, testing of candidate solutions, reusing prior reasoning procedures, and validating potential problem-solving strategies or heuristics, among others.

Table 10. Summary of Reporting Cases

	Knowledge Building Trajectory	Knowledge Artifacts	Organization of Participation	Temporality
<p>Reporting (See Appendix A for a complete list of observed instances)</p>	<p>Integration of a defined report or narrative of past problem-solving doings;</p> <p>Framing a current problem-solving activity as explicitly linked to prior work conducted by at least some members of the current set of co-participants;</p> <p>Responsive to current problem-solving situation but anchored on past doings;</p> <p>Initiates, supports, or resists a team problem-solving course of collective action;</p> <p>Toward ending phases of a team session, Reporting framed as Learning.</p>	<p>Reportables constructed as:</p> <ul style="list-style-type: none"> • recovered resources • partial results relevant to ongoing activities • reusable or similar resources, objections against explicit or implicit repetition of work; <p>Prior rules, procedures, discoveries or problem results indexed (e.g., labeled) or explicitly represented;</p> <p>Reportables reference or present prior doings and prior resources (of specific actors) as past ones in relation to a current problem or proposal;</p> <p>Intelligibility and relevance constituted as a present concern if and when necessary;</p> <p>If persistence resources (e.g., diagrams and formulas are available to teams they can be constituted as reportables and re-situated for the present team.</p>	<p>Affiliating particular individuals and or sub-collectivities to past doings, prior problem-solving resources and possible current actions;</p> <p>Positioning individuals and differentiated or undifferentiated collectivities in participation frameworks that allocate specific rights and duties. Examples: reporter-narrator-audience or narrator-challengers;</p> <p>Changes in session attendance (instability of a team) open up opportunities for reporting although stability does not preclude Reporting.</p>	<p>Enhanced temporal framework that links current team session with a prior episode (undifferentiated) or a specific temporal segment within a prior episode (differentiated);</p> <p>Boundary between reported past and current activity can be contingently reopen</p> <p>Reporting makes and orders a team's situated time through the retrospective and prospective integration of past and current activity.</p> <p>Contributes to establishment of diachronic continuity by retrospectively threading past and present episodes of collaborative action and organizing participation around reported knowledge resources for current problem solving purposes.</p>

It is interesting to note that there seemed to be relationship between the instances of reporting activity and the participant's orientation to learning. In some cases such connection was made explicit (e.g., when participants made report of the form "we learned that...") but even in those cases where the connection was not explicitly made, we can argue that at the most basic level when we observe a team reporting on prior work and prior findings, the team is in fact organizing itself around what is to be considered to be known or learned, from an interactional perspective. Furthermore, in many of the instances of reporting activity analyzed, the reporting of observations, proposals, and solutions was initiated by a team member who was different than the one who had stated such observations in a previous session. This change in author or agency might indicate that in fact, the different team members orient to such resources as common and shared, although, not entirely symmetrical ways. For instance, reporter(s) and ratified past participants become accountable and can claim rights of knowledge while others who might be positioned as newcomers could not do so directly.

In most cases analyzed, the chat conversation was the primary medium through which reporting was conducted and organized although, in a few cases, whiteboard resources were used as well. The persistent records offered by the VMT environment (e.g., chat transcript and whiteboard objects) were only used in a few instances mostly as confirmatory resources (e.g., "remnants of our conversation last time are on the whiteboard"). In addition, in a few instances from Design Case Two, the Wiki environment was also used as a resource in reporting activity. In many cases, we lack empirical evidence for how the Wiki reports were subject of interactional uptake as part of the team's activities. However we can clearly recognize that this alternative form of interaction was also used as a space for reporting activity in similar ways as observed in the synchronous and ongoing interaction within the VMT virtual rooms. In our analysis of the fourth type of interactional bridging method (4.1.4 Method IV. Cross-team Bridging) we will explore other aspects of the Wiki and its integration in the teams' knowledge-building activity.

4.1.2. Method II: Collective re-membering

A second interactional method involving a team's orientation toward prior doings as resources for current problem solving involves the *reconstruction* of past activity, a practice that we have labeled "*collective re-membering*". In this activity, a

past resource is not simply *reported* by a prior participant in the context of an existing activity but, instead, previous participants and non-participants reconstruct together a prior arrangement of participation (e.g., a series of problem-solving steps) and related resources as relevant for present purposes. Engagement in the reconstruction project includes sequencing the current activities based on the structure of past doings, being accountable for retrospective assessments (e.g., responding to inquiries about what was done before), but also assessing the current relevance of the co-constructed memory and indicating repairs necessary for the proper understanding of the group. An example of this kind of activity is illustrated by the following excerpt from the last session of Team 5 in Design Case One.

Log 13. Design Case One, Team 5, Session 4

114 8:26:05 MFMod: Last Tuesday you worked on finding a formula for the number of shortest paths between any two points A and B on the grid. You explored multiple possibilities and figured out that $x+y$ and x^2+y^2 work (where x and y correspond to the # of units you need to travel along x and y axis to get from A to B) but only for some points, not all. You may want to continue exploring more cases and see if you can find a general formula.

115 8:26:31 Mod: or you can work on the problem i posted earlier

116 8:26:50 drago: ok

117 8:27:04 Mod: I can also post all the original questions if you would like to see them

118 8:27:17 gdo: post the original

119 8:27:42 drago: ok

120 8:30:11 gdo: where did u guys last leave off (To 119)

121 8:31:20 MFmod: I think that the above section I wrote is where the group last was (To 114)

122 8:31:36 MFmod: yes?

123 8:31:42 drago: well

124 8:31:48 gdo: i dont remember that

125 8:31:51 drago: actually, my internet connection broke on Tuesday

126 8:31:56 drago: so I wasn't here

127 8:32:12 MFmod: so maybe that is not the best place to pick up

128 8:32:14 estric: i wasn't able to be here on tuesday either

129 8:32:50 gdo: how bout u meets

130 8:33:01 meets: uh...

131 8:33:11 meets: where'd we meet off....

132* 8:33:16 meets: i remember

133 8:33:22 gdo: i was in ur group

134* 8:33:24 meets: that we were trying to look for a pattern

135 8:33:27 gdo: but i didn't quite understand it

136 8:33:34 gdo: can u explain it to us again meets

137* 8:33:38 meets: with the square, the 2by 2 square, and the 3by2 rectangle

138 8:33:42 meets: sure...

139 8:33:45 meets: so basically...

140 8:33:45 gdo: o yea

141 8:33:49 gdo: i sort of remember

142 8:33:55 meets: we want a formula for the distance between poitns A and B

143 8:34:02 drago: yes...

144 8:34:05 meets: ill amke the points
(meets draws 2 points on the existing grid on the whiteboard)

145 8:34:09 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
(meets labels the two points on the grid A and B)

146 8:34:55 meets: okay

147 8:34:59 meets: so there are those poitns A and B

148 8:35:08 meets: (that's a 3by2 rectangle
 149* 8:35:28 **meets:** **we first had a unit square**
 (meets draws the lines of a 3 by 2 rectangle with points A and B in its opposing corners)
 150* 8:35:44 **meets:** **and we know that there are only 2 possible**

Toward the beginning of the session the facilitator (MFMod) had posted a chat message which, similarly to other cases of feedback, is structured as a report outlining the work of the team in the previous session (line 114). Similarly to the characteristic elements of reporting practices, this posting involves the use of the temporal marker "last Tuesday" to index a prior event which is then described using declarative assertions using past-tense verbs (e.g., you worked on finding a formula, you explored multiple possibilities, you figured out that $x+y$ and x^2+y^2 work, etc.). These assertions, in addition to weaving together the collectivity of all the present participants (i.e. under the pronoun "you") index a set of artifacts that are closely related to the team's prior work: a formula for shortest paths, points A and B, the grid, etc. All of these resources, as presented, are positioned as part of the current developing interactional space. This report by the facilitator, however, receives no visible uptake from the participants. Perhaps responding to the interactional trouble that the lack of uptake suggests, the moderator suggests that the team can also work on a new problem (the "*circle problem*," he had introduced earlier in the session) or select one of the "*original questions*" compiled from the first session. Finally, after more than two minutes of silence, Gdo makes a request to the group for a report of where the group "last" left off (line 120). It is possible that Gdo was present in the prior session but left early and, as a result, wants to know about the last portion of the session that he missed. Perhaps he wasn't there at all but is still only interested in knowing what the group discovered at the end of the session to see if they could build on it now. In either case, Gdo is orienting the group back to "last Tuesday" although his participation in such episode of interaction is still left unspecified. In contrast, after the facilitator calls for an assessment in lines 121 and 122 of whether he had described where "the group last was" in message 114, Gdo states in line 124 that he does not remember "that." At this point Gdo has positioned himself in a different stance in relation to the object of reference "last Tuesday" and with the description produced by the facilitator in 114. Subsequently, Drago and Estric both decline responding to the assessment called for by the facilitator, also positioning themselves as not having participated in last Tuesday's session. Meets is the only participant whose position with regards to last Tuesday's session has not been addressed and Gdo calls for him to do so in line 129. In fact, in constructing his requests to Meets further, Gdog specifies in more detail that he remembers being in meet's group so

effectively, we had an asymmetrical position with regards to last Tuesday's session where Drago and Estric cannot claim direct knowledge of what was done but Drago and Meets can. Interestingly, after Meet has started his tentative recollection, Gdo attempts to reformulate Meets recollection as an explanation by requesting it to be presented to the group ("us") that way (136).

Meets initiates the reconstruction of prior work as a sequence of activities, and as can be seen in the transcript, there are a number of temporal and sequential markers used in the subsequent unfolding of this segment (e.g., *first, last, again, then*, etc.) deployed in conjunction with a regular shifts between past tense (e.g., "*we first had a unit square*"), present tense (e.g., "*we want a formula for the distance...*", "*we are trying to find a pattern here*", etc.), future tense ("*ill amke the points*", "*then we will probably derive a formula...*") and other temporal markers. Although it might appear as if it is Meets who individually carries on the remembering of what they were doing last time (e.g., lines 132, 134 and 137), this activity actually unfolds as a collective reconstruction in which different team members participate dynamically. Some of the current team members were not present in the previous session and yet, as we will see, later are instrumental in the reconstruction of that past and in shaping its current relevance.

A key element of how collective remembering unfolds is illustrated through this case by the fact that the team is oriented to attending to the structure of past doings by organizing current participation around the reconstruction of a sequence of previously-designed problem cases (the square, the 2by2 square, and the 3by2 rectangle). In doing this, Meets puts forward an organization of participation in which recently reconstructed knowledge artifacts are marked as "shared" (e.g., stating in line 150 that for the unit square "*we know that there are only 2 possible paths*") for the current purposes. This interaction proceeds organized through the sequence of cases recovered from the prior session up to a point where Meets claims that "*there are*", he thinks, 6 different shortest paths between the corners of a 2-by-2 grid but he is doubtful and reports that he can only "see" four at the moment. Drago, who did not participate in the original work leading to that finding, claims that he is able to see the six paths and proceeds to demonstrate a method of labeling each point of the grid with a letter so that he can name each path and help others see it (e.g., "*from B to D there is BAD, BCD ...*"). After this, Meets is able to see again that there are/were six paths in the two-by-two grid and together with Drago, they proceed to investigate, in

parallel, the cases of a 3-by-3 and a 4-by-4 grid using the method just created. Figure 13 illustrates some of the ways that the structuring of this sequence of activities is related to the creation and manipulation of graphical resources by the team. Part a shows a set of grid-cases with their paths drawn with colored lines as they stood at the end of Session 3. Parts b and c show the cases drawn in Session 4 with some of the intersections in the 2-by-2 grid labeled, while part d illustrates the parallel work of two participants labeling and counting paths in two different grid cases.

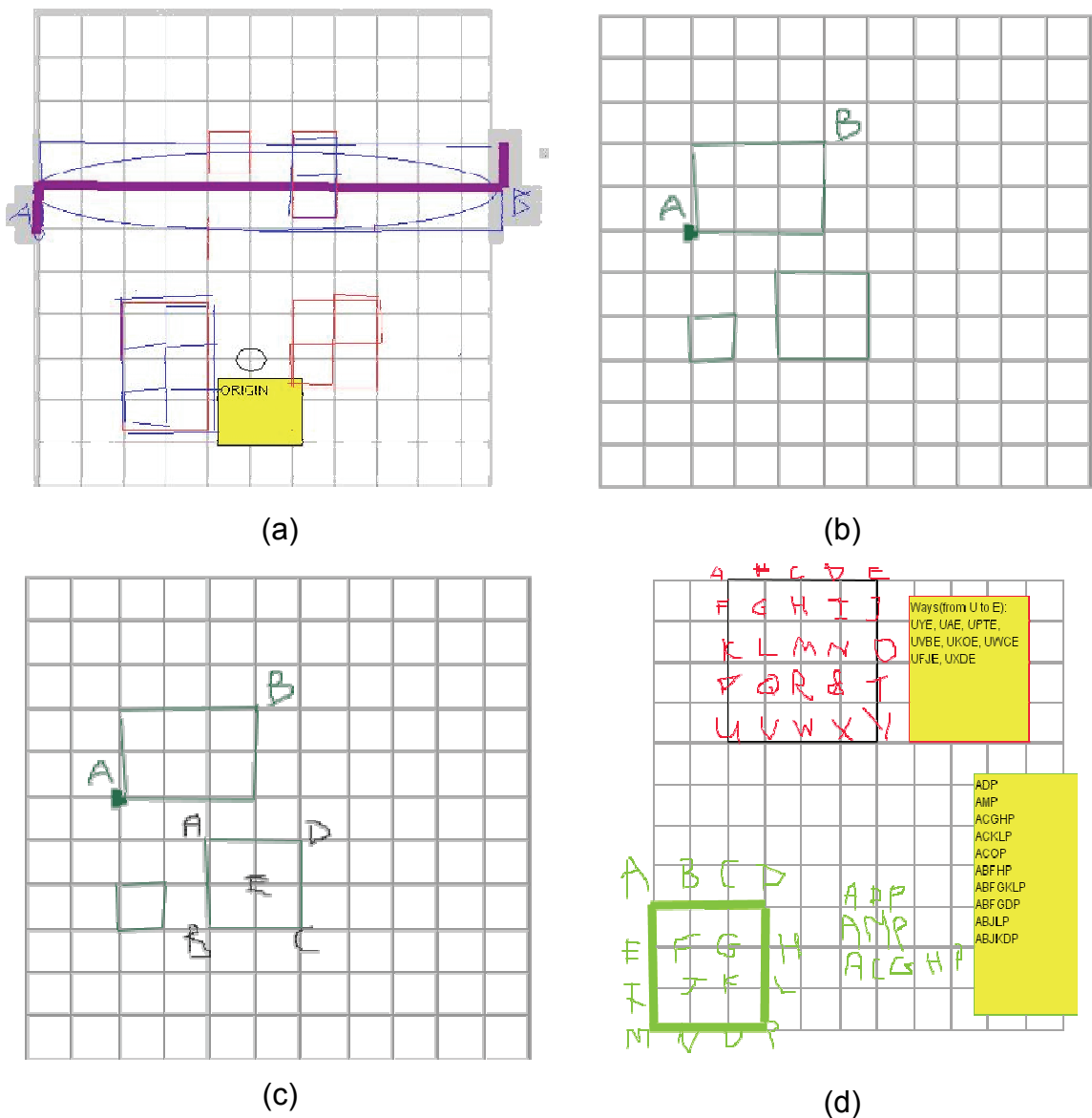


Figure 13. Whiteboard diagrams constructed by Team 5 when engaged in finding the number of shortest paths between two points on the grid world.

It is remarkable that the trajectory of this activity shows a collective engagement that goes from being unsure about how far the team had gone in their

previous session to developing an entire set of practices that allow the team to coordinate parallel work in such a sophisticated way.

We consider this activity as “*re-membering*” in the sense that whatever is being achieved in the present moment is organized with resources and a structural ordering (e.g., the sequence of cases) to which the current participants orient as being “reconstructed” from prior activity, not as being totally “recounted” nor produced in the present moment without a relevant provenance. Instead of the reporting of findings or discoveries as explored in the previous section, activities and their associated features are visibly reconstructed. Because of this, issues of fidelity or verifiability might become relevant as much as the issue of intelligibility and relevancy to present activity. This type of activity is also “*collective*” not only in the sense that is achieved by the concerted action of multiple parties but because, in its unfolding, it produces a trajectory of activity for a team that both differentiates current participants from past participants, but also ratifies current participants as actors of prior doings by virtue of their involvement with the reconstruction work. Finally, in this type of collaborative problem-solving interactions it appears as if *reconstructables* are commonly associated with reasoning procedures (e.g., counting paths, the use of a “birds-eye view”, etc.) and their related knowledge artifacts (e.g., a set of cases explored to derive a general formula) structured in ways that are used to organize present collective activity.

The role of the temporal markers and the sequential unfolding of interaction are specially striking in this type of bridging activity. Although there weren't many instances of collective-remembering across the entire dataset, in almost all of them co-participants actually used the temporal markers that index past and current episodes as resources not just to make the sequential organization of action known to others but to organize participation. By combining present markers such as “we want a formula...” and “that's a 3 by 2 rectangle” with past markers such as “we first had a unit square” as well as future markers such as “I'll make the points” the current organization of participation achieves the mixed sense of being a reconstruction of the past as well as a present engagement in which past non-participants have as much saying as past participants. It is in this sense that we find this type of activity to be a way in which past non-participants are made actual members of such prior doings (hence the use of the word re-membering) by virtue of how current participation is organized to stand as a reconstruction as much as a present

undertaking. A second case allows us to further expand the characterization of this bridging activity

What was a recursive formula again?

In the first session of Team C in Design Case Two, four team members were attempting to find a formula for the number of sticks in the pattern given by the problem. At that point the question of whether they should use a “recursive” or a “explicit” formula was posted by Jason, one of the team members. Davidc replied that he did not think that they needed recursion and that it was “*simpler to express it as $1+2+\dots+n$* ” (a summation approach) so the team proceeded to find the ‘explicit’ formula before moving into other problems. In the feedback provided by VMT about the work of Team C in their first session (received by the team at the beginning of session two) the facilitators made the following remark about the way the team handled the decision on using a recursive or explicit formula:

Log 14. Design Case Two, Team C, Feedback Note posted on Session 2

One question that was left unexplored was whether a recursive function shows better how the number of sticks and square grow. Someone offered that as a possibility but you opted for using a summation notation. We notice when ideas or questions are stated in a group but not discussed. What do you think about that situation and how groups deal with it?

As we noted before, often teams treated any external feedback as a list of things to be repaired from their previous session. In this case, although the note might suggest that the team talks, in general, about situations in which ideas are offered but not discussed, the team seemed to orient to actually having again (re-constructing) their conversation about the use of recursion. This can be seen in the following passage.

Log 15. Design Case Two, Team C, Session 2

091 Jason	so apparently there's something with a recursive sequence that we should discuss
092 U137	What was a recursive sequence again?
093 Qwertyuiop	recursive sequence?
...	
097 Jason	i think that an explicit formula is better, but a recursive one would show how the number of squares/sticks increases as N increases
098 Jason	it's something like this:
099 Jason	$a(n) = 5 + a(n-1)$
100 Jason	where the things in parentheses are supposed to be subscripts

101 Jason so a recursive formula relies on the value of a previous function

102 U137 Ah, I see.

103 Jason thus, you must specify something first, like $a(1) = 4$

104 qwertyuiop i get it

105 Jason great :-)

106 qwertyuiop for the number of squares, would that be $a(n)=n^2-1$

107 U137 so $a(1)=1$, $a(n)=n+a(n-1)$...

...

111 U137 $b(1)=4$, $b(n)=b(n-1)+4(n)-(n-1)-(n-1)$, b is the number of sticks...

112 U137 So $b(n)=b(n-1)+2n+2$?

107 Jason assuming only $(n-1)$ is a subscript?

...

108 Jason did u check that

109 Jason looks correct

110 Jason how did you get it?

In this passage we can see that Jason's reading of the feedback note conforms to the pattern in which the team selects and repairs certain aspect of their previous session—discussing “something” with a recursive sequence. The way U137 designs his question in line 92, by using past tense and the adverb “again,” opens up the opportunity for the team to orient to this activity as a reconstruction. By reconstruction we mean that U137's posting tentatively frames the discussion on recursion in the current moment as discussing it specifically in light of the work conducted in the prior session. In contrast, Qwertyuiop's question in line 93 seems to be designed more as an information question. This is congruent with the fact that Qwertyuiop is in fact new to the team and did not participate in the prior session. In the subsequent engagement of the team with this task, Jason starts by agreeing with Davidc's claim in the previous session that “*an explicit formula is better*”, but at the same time offers a counterclaim stating that the recursive formula would “*show how the number of squares/sticks increases as N increases.*” Davidc is absent in this session and yet his original claim is carried forward by Jason. Jason also offers a series of examples of what a recursive formula looks like, in general, to which U137 responds with an actual candidate recursive formula for the number of squares in the pattern that they were considering in the previous session. The group does some further work to understand how U137 got this formula and to test that it works and, after completing this work, they get to a point where U137 reiterates what Davidcil had stated in session one; that the ‘explicit’ formula from session one (“the original”) is simpler but Jason adds that the recursive one “*has a nice explanation.*” Jason makes a report which sums up the entire reconstruction process: “*so speaking of formulas, we got both explicit and recursive definitions for sticks/squares; explicit is easier while recursive shows how each step grows from the previous.*” Interestingly,

this new formula that the team created gets recorded witting the same textbox on the whiteboard used in their last session for the explicit formula:

Log 16. Design Case Two, Team C, Session 2

```

-----
| Formula for total # of squares: |
|                                 |
|   n(1+n)/2                     |
|   a(n)=n+a(n-1)                |
|                                 |
|-----

```

Notice here that the report that Jason produces covers both the activity the team has worked on in the two sessions—and in its two configurations with and without Davidc. The collective pronoun “we” sums up both collectivities and the reported events correspond to the work reconstructed from session one (explicit) and to the work advanced in session two (recursive). Although the group did not explicitly discuss in the conversation the contrast between the two types of formulae, the feedback note alluded to such contrast, so Jason’s report also integrates the feedback note into the reconstruction by summarizing the teams’ ideas of how the two formulae complement each other. This idea, interestingly, gets reported on the teams’ Wiki contribution as well:

Log 17. Design Case Two, Team C, Wiki from Session 2

We decided that while an explicit formula to calculate the number of squares or sides is clearer for calculating, a recursive formula is easier when one is trying to determine how a particular series or pattern grows.<p>

Summary

Table 11 presents a summary of the observed characteristics across the 12 instances of collective re-membling identified in both design cases. We do not believe that the relatively low number of instances of this type of activity indicate a lesser degree of engagement with continuity of building collaborative knowledge by the teams. Instead, this type of activity seems to lend itself to very particular interactional opportunities that the teams may or may not always encounter in the normal course of their joint activity.

Table 11. Summary of Collective Re-membering Cases

	Knowledge Building Trajectory	Knowledge Artifacts	Organization of Participation	Temporality
<p>Collective Re-membering (See Appendix B for a complete list of observed instances)</p>	<p>Collective reconstruction of past problem-solving doings constituted as not completely available to any one participant;</p> <p>Reconstruction embedded in re-enactment of a prior trajectory of work to organize and advance current problem-solving;</p> <p>Retrospective and prospective assessments guide unfolding of current problem solving.</p>	<p>Prior processes of collective problem-solving activity (e.g., a series of problem-solving steps) are used as scaffolds for guiding the reconstruction of past problem solving resources;</p> <p>Reconstructables oriented to as dually past and presently-produced</p> <p>Issues of fidelity or verifiability of reconstructed knowledge artifacts can become relevant as much as intelligibility and relevance</p>	<p>Previous participants and non-participants can orient to the reconstruction task symmetrically (“membering”) but can also opt out of participation;</p> <p>Prior participation frameworks can be activated in present action.</p> <p>Past participants can be become accountable for retrospective assessments while newcomers might concentrate on assessing current relevance</p>	<p>A mix of temporal markers that integrate the past being gradually reconstructed and the current unfolding of interaction;</p> <p>Reconstruction work makes and orders a team’s situated time. Sequential unfolding of previous problem-solving work used as temporal framework to organize current situation.</p> <p>Relevance of boundary between timeframes drops when activity is oriented to as completely currently situated, although contingent.</p>

Our analysis of the collection of this type of interaction shows that such practices were used by VMT teams within their problem-solving work as a way to recreate and re-enact a prior trajectory of work conducted by at least some of the members of a current collectivity. Typically, it appeared at the onset of a team's activity as a way to reconstruct prior discoveries or prior strategies which, usually, no individual team member could fully report on. In a few cases, this type of activity occurred within a single session as opposed as across different episodes of collaboration. For example, the participants in Team B in Design Case Two often found the task of reporting in the Wiki after each session troublesome in that , individually, they seemed hesitant to take on the job of narrating to others what the team had done in their rich explorations. As a result, they adopted the practice of "*explaining it together*" at the end of a session and reconstructing what they had done in a session "right there" so that later one it was easier for someone to actually write a report on the Wiki. Although this practice does not orient to crossing the boundary that multiple sessions of collaboration presents to the team, it still represents an orientation to reconstruction and, in an interesting way, prepares the ground for later reporting activity.

Interestingly, collective re-membering was associated, in a few cases, with a type of 'productive breakdown' in which the inability to recall certain aspect of prior work opened up the opportunity for a team (including those absent from the prior work in question) to participate in the reconstruction of such prior doings and in its integration in the current problem-solving. Teams engaged in collective re-membering by co-constructing 'reconstructables' —commonly associated with reasoning procedures or sequences of problem-solving steps. Reconstructables were often 'anchored' both in the present moment and in the past that the team was attempting to re-enact and this was visibly present through fleeting switches between the use of present and past tense. Those who participated in the original work being referenced work in conjunction with those who did not in the production of the "reconstructable" and in doing so work out their relative opportunities for action as it relates to engaging in retrospective or prospective assessments of work. Newcomers are often constituted as actual past team participants by virtue of the temporal and sequential organization of present activity based on the structure of prior activity.

The persistent records offered by the VMT environment (e.g., chat transcript and whiteboard objects) were only used in a few instances of collective-remembering, a fact that seems to confirm that participants in this activity are not

concern with the veracity of their reconstruction but with the organization of present activity based on the purported structure of some past activity. On the other hand, in many cases the teams did create substantial material resources as part of their collective remembering some of which were integrated with the persistent records accumulated through the VMT environment. A particular case of this practice involves the subsequent use of the Wiki through which reports of reconstruction activities were often produced as part of Design Case Two.

4.1.3. Method III. Projecting to future activity

A third interactional method in which activity within a particular team episode was linked to knowledge-building doings in a different episode and by other participants was that in which participants engaged in ‘*projecting*’ actions and resources for future problem solving. In this activity, the concern of the team was not only with what had been achieved at a certain time but also with ways of constituting a future activity. Although some of these ‘projections’ might not be actually attended to in future interactions (in fact, a good number of instances in the dataset were not) from an interactional perspective, our concern lies with the ways that participants oriented to the activity itself and the sorts of interactional purposes that such activity served in the building of collaborative knowledge. An example of activity in this category is illustrated by the following excerpt from the final portion of Team Five’s second session, in Design Case One:

Log 18. Design Case One, Team 5, Session 2

460 drago: notice how you can go two ways
 461 gdo: yea ok
 462 drago: actually there are a lot more than two...but here are the most simple ones I guess [Points to 460]
Drago completes a second path as shown in Fig.7(b)
 463 m344: yeah
 464 gdo: yep
 465 drago: so...
 466 drago: either way you go like 5 up and 6 over...
 467 m344: yeah
468* drago: but how would you determine whether you were going down or left? I don't know
 469 m344: and the x1-x2 thingy works
 470 gdo: yes
471* gdo: we could solve that next time
 472 drago: yea
 473 drago: I can't think straight right now anyways
 474 gdo: lol
 478 estric: no doubt no doubt peac out peace out
 479 estric: leaves the room
 480 m344: cya all next week

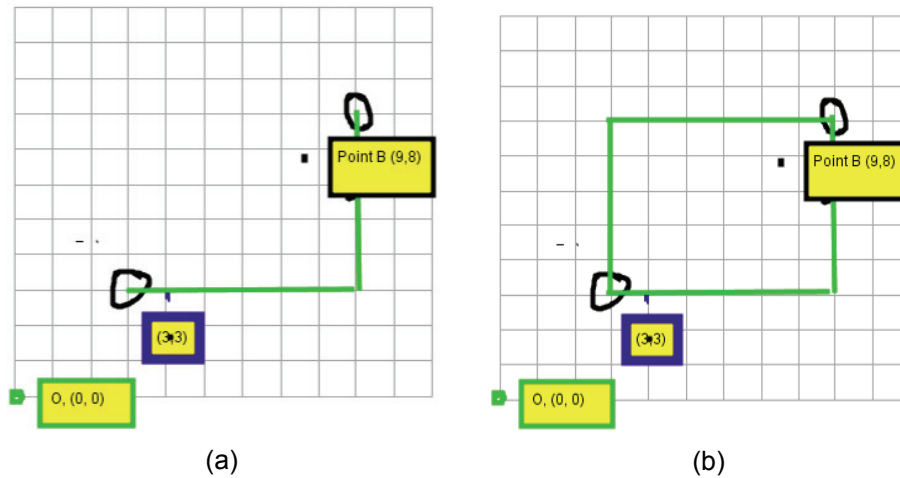


Figure 14. Two snapshots from the shared whiteboard in the Second Session of Team 5, Design Case One.

At the point where this interaction occurred, the team had been, for a while, trying to find a formula for the shortest distance between two points $A(x_1, x_2)$ and $B(y_1, y_2)$ on the grid. Diagram (a) in Figure 14 shows one “simple” path between the two points as drawn on the shared whiteboard of this team, while (b) adds a second way to complete the two “most simple ones” as indicated in turn 462 of Log 18. We traced the beginning of this passage when we analyzed how the team engaged in reporting activity at the onset of the second session. Such reporting gives room to the team’s present engagement with this task. As a result, the team explores several candidate formulae for the distance between points in different arrangements they had chosen and illustrated on the whiteboard. Initially, Drago had proposed that the answer could be “ $x_1 + x_2, y_1 + y_2$ ” (line 371) but the formula was found incorrect and, as a result, he makes a new proposal which indicates that he is still orienting to the work they were doing in the prior session: “*it was absolute value $x_1 - x_2$, absolute value $y_1 - y_2$.*” This new formula is tested and found to work, but Drago himself problematizes it starting in line 460. Specifically, Drago is concerned with the fact that there are sometimes many shortest paths between two points and that a formula might need to account for the different paths that one can take. This problematization opens up the possibility for the team to continue this ‘unfinished work’ as their next activity. They could, of course, ignore these troubles or attempt to postpone their resolution, as Gdo seems to indicate with line 471 (“*we could solve that next time*”). Interactionally, this proposal brings the current activity to a potential

closing by virtue of its unfinished business being projected for a later episode. The supportive uptake by the rest of the participants makes this possible.

The analysis of this and other instances of projecting activity revealed several aspects of the knowledge building trajectory of the teams and the related knowledge artifacts directly associated with projecting activity. *'Projectables'* —the objects that teams put forward as possible future activities through this type of interactional activity, were associated with either unfinished problem-solving work or with proposals for new or additional team work. The first case analyzed in this section illustrates the first situation— Drago's troubles with understanding "*how would you determine whether you were going down or left?*" are projected by Gdo as something they could "*solve next time.*" In addition, projectables included missing explanations for work constituted by the team to be completed. In these cases, the team reopened completed work in pursue of the additional work needed for all the team members to understand a result and be able to talk about it on behalf of the team. For example in the second session of Team 2 in Design Case One, Mathf responds to the facilitator's questions about how they got one of their answers and why it seemed to work, by stating that the solution "*was something that bob found out*" and that, since bob had left the room early, they "*should ask him next time.*" In doing so, Mathf effectively constituted such explanatory work as potential collective future work for their next team session and overcame the potential interactional trouble with the closing of the session brought about by the facilitator's questions. In other cases, *projectables* included new more complex problems derived from recently finished problem-solving work or completely new potential tasks. The analysis of a second instance of reporting activity allows us to explore these dynamics in more detail.

As a response to the work conducted by team B in the first session in Design Case Two, the facilitators posted a feedback note on the whiteboard of the team's virtual room, including certain projections about "next steps" for the team. This was in fact common across all feedback messages presented in both design case studies. However, since our interest revolved in the way that the teams themselves oriented to such projections and organized their uptake we concentrate here on such aspects. Part of the facilitators feedback note is presented below.

Log 19. Design Case Two, Team B, Feedback Note posted on Session 2

There was a sense in which you indicated that your work was done when you had at least one answer for the questions in the problem. For the next step we will encourage you to think more about the different approaches and the problems that you can discover on your own and that are interesting to pursue.

There is no explicit discussion by the team about this particular next-step recommendation made by the facilitators at the beginning of the session (as usually done by many teams) or during the course of their collaborative work. However, toward the end of the session, when the team is coordinating their reporting for the Wiki, the following exchange takes place:

Log 20. Design Case Two, Team B, Session 2

451 Aznx: I think bwang should put it in, since he's more familiar with the recursion method and how to use it than we are,
 452 Aznx: Agreed?
 453 Quicksilver: Today's topic siad go to the Wiki and share the most intersting math problems that your group chose to work on
 454 Quicksilver: agreed
 454 Quicksilver: but we do understand it now
 455 Quicksilver: that's important
 456 Aznx: Well, we should just say we wanted to explore yesterday's problem more.
457 Quicksilver: maybe we can apply it next time...who knows?
 458 Aznx: Yes, we do.
 459 bwang8: ok
460 bwang8: we can use the strategy we used to solve this problem to solve future problems
 461 bwang8: the method is important
 462 bwang8: not the answer
 463 Aznx: Yup.
 464 Quicksilver: definitely
465 Aznx: Always learned that wherever I learned math. =P
 ...
472 bwang8: we learn that divide the problem up can make it simpler and easier to solve
 473 Quicksilver: so bwang...are you updating the Wiki?
 474 Quicksilver: yea
475 Aznx: we also learned finding a pattern is a good step
 476 Quicksilver: yes and we could have also started with a simpler problem
 477 Quicksilver: in fact...we did
 478 Aznx: and recursion can be usually used when solving for a pattern, after finding the designated pattern of course
 479 Quicksilver: yesterday's problem was simpler
 480 Azn: yes, we did!
481 Aznx: so we actually used 4 strategies =D
 482 Quicksilver: yes
 483 Aznx: We also tried to look at the problem from different views, although it's not really a strategy.

At the point where the team is discussing what and who should “*put*” their work “*in*” the Wiki the team orients to their doings in this session first as producing “*technically*” the “*same result as*” in the previous session (Aznx, line 403) and, also, to the session as a whole as “*really a discussion*” (Aznx, line 409). As we have seen

in our analysis of reporting work, repeating the same work is something to which many teams oriented to as a dispreferred aspect of their joint action, so it isn't surprising that this team appears to be engaged in overcoming that potentially troublesome situation by interactionally reframing what they have done. Later on, they orient to "today's topic" (the actual task instructions, line 453) in order to clarify what should be reported on the Wiki which leads, interestingly, to the team making a projection for what they could do next time (line 457) and also to explicitly calling for the potential future reusability of something they have "learned" through their experience: the fact that, as *bwang8* states it "*the method is important, not the answer*" (lines 461, 462). They also list the concrete strategies they deployed to solve the problem (lines 472-483) and framed them as learned. Interestingly, when the team's report gets posted on the Wiki such discovered and "learned" objects are mentioned and offered for other members of the VMT online community to consider:

Log 21. Design Case Two, Team B, Wiki posting after Session 2

To investigate the number of sticks in a flat faced pyramid with n levels with 1 block increase in length and width per level.

Also, to find as many approaches and put them to use. **We eventually found 4 different strategies and applied them, such as divide the problem up, finding a basic pattern, and use recursion to solve problems. We also found a formula, its origins, and how to use it.**

$f(n)=4n(n+1)+(n+1)^2+f(n-1)$ and $f(0)=0$.

We first determine the number of squares...

Although this pattern in which projection work was linked to exploration and reports on team learning was only observed in one other instance also in Design Case Two, it seems important to consider the potential interactional dependencies between this type of bridging activity and this key aspect of collaborative knowledge building. This instance of projecting work, although visibly triggered by the approaching expiration of the one-hour time limit, appeared qualitatively different from other cases in that the projectable being put forward concerned the team not with an unfinished activity but with a potential application of aspects of their completed work. In this way, the team opens up opportunities for their past and successful knowledge building to be expanded in the future and, perhaps more importantly, for the articulation of multiple experiences together under the learning trajectory of the team.

Table 11 presents a summary of the observed characteristics across the 10 instances of projecting activity identified in both design cases..

Table 12. Summary of Projecting Cases

	Knowledge Building Trajectory	Knowledge Artifacts	Organization of Participation	Temporality
<p>Projecting (See Appendix C for a complete list of observed</p>	<p>Current unresolved problems or partial puzzles extended to future episodes of problem solving; Additional or possible trajectories of work framed as future courses of collective action;</p>	<p>Projectables constituted as:</p> <ul style="list-style-type: none"> • unfinished or unresolved problem-solving work • proposals for new or additional team work. • potential applications of aspects of a team's completed work 	<p>Those involved in projecting activity as well as the ratified participants of the current activity are constituted as potential actors of future tasks and partially accountable for them;</p> <p>Addressed individual participants and/or differentiated sub-collectivities positioned as responsible for projected actions</p>	<p>Enhanced temporal framework that links current team session with a potential specified future episode of collaborative action</p> <p>Constituting a possible future for the team orders a team's situated time in the present moment</p> <p>Contributes to establishment of diachronic continuity by retrospectively threading current and potential future episodes of collaborative action.</p>

Finally, it seems worth mentioning that the facilitators, in several cases, attempted to recover past projected matters (e.g., through their feedback or orientation messages posted at the beginning of a session) but rarely succeeded in having the teams recognize such matters as their own and organizing their uptake as such. Potential “projectables” recovered by facilitators’ messages were often attended to as work that the teams “must” or “should” do from a normative perspective but not as directly perceived by the team as their own trajectory of work. In general, although the actual uptake of projectables by any team was only seen in one single case, and in that case oriented to as reporting activity, it is clear that the interactional value of this type of activity offers the team a central mechanism to organize and manage their collaborative experience over time and, in some cases, integrate multiple experiences into reflection or learning work.

In summary, through their engagement with reporting activity teams constituted *projectables* as ‘unfinished’ or ‘open’ work (e.g., missing explanations, more complex problems, etc.) or as new potential tasks that the undifferentiated team could address in a future episode of collaboration. Those involved in projecting activity as well as the ratified participants of the current activity, in a sense, become potential actors of future tasks and partially accountable for them. In doing so, a possible team trajectory is constituted through the linkage of potential episodes of future interaction but the interactional reality of such a trajectory is only realized when, in present time, such past doings are re-constituted.

The three interactional bridging methods presented so far, *reporting*, *collective re-remembering*, and *projecting*, were exhibited by teams in both design cases with the same range of interactional dynamics. However a fourth method, which will be presented in the next section, characterized the activity system of Design Case Two and completes the range of interactional methods identified in both datasets.

4.1.4. Method IV. Cross-team Bridging

Finally, a fourth type of bridging activity emerged specifically within our analysis of Design Case Two. In this type of activity, prior work of one team was linked to the ongoing work of a different team through a series of interactional episodes put forward, collectively by the teams and the overall VMT activity system.

In doing so, the participants deployed specific interactional moves to expand the trajectory of participation and knowledge building of a single team and integrate the ongoing engagement and history of several collectivities together.

These practices mobilized many of the interactional resources that characterized the VMT activity system in Design Case Two. Central in this web of resources, however was the use of the Wiki which made it possible for teams to have direct access to the reports made of other teams' work on the same or related tasks. In contrast, the absence of the Wiki in the activity system of Design Case One might be the possible reason why cross-team bridging was not observed in the interactions of the participating teams (despite the moderators frequent references to the work of other teams).

In the rest of this section we present our condensed analysis of one instance of cross-team bridging which builds on the concepts outlined in previous sections.

During the second session of Design Case Two, Team C starts by following a suggestion from the facilitators' feedback for them to explore the recursive form of the formulae they had created in session one. After they give such work for completed, they turn to the actual topic provided for the day which suggests that they "think about other mathematical problems related to the problem with the sticks. For instance, consider other arrangements of squares in addition to the triangle arrangement (diamond, cross, etc.). What if instead of squares you use other polygons like triangles, hexagons, etc.?" The group decides that they will try "diamonds first" and eventually, after several trials, they create and test a formula for the number of squares in this pattern. A formula for the number of sticks or "sides" is introduced by one of the participants but never discussed by the team explicitly. Toward the end of the session the team compiles on the whiteboard all the formulae that they had created in this session as part of their preparation to report their work on the Wiki. This collaborative activity seems related in structure to the kind of reporting and reconstructing activities we have described before but differs in at least one fundamental way. In this case, the textbox that the team constructs (Log 22) serves as an object of reference for a report about their just-completed work which the participants are to produce on the Wiki where, in turn, it is to be oriented by others within their own interactional situations... inaccessible to the producing team. This forces the reporting activity to construct an artifact that can afford others certain

placement in their own interactional sequences (as opposed to the ongoing co-production of that sequence via the reporting activity itself).

Log 22. Design Case Two, Team C, Session 2 – Whiteboard textbox

```

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

```

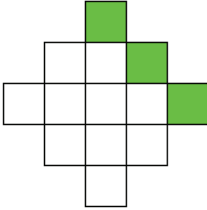
The actual reporting artifact put forward by Team C on the Wiki, builds on this initial reportable textbox and will allow the team to present their work, in a mediated or ‘displaced’ way, to other teams. Without the benefit of the synchronous co-construction of its meaning the team compensates in visible ways through the design of its posting. As can be seen in Figure 15, Team C’s posting is organized in three sections; two of them corresponding to the two different problems they worked on: the “original problem” and a “diamond-like arrangement of the squares,” and a third one constituting a response to the facilitators request to consider the value of having a recursive form of their previous formulae. The two initial sections reporting on their problem work share a similar structure. They present first solution artifacts (formulae for the sides and the squares) and then an explanation indexical. The first of these indexicals reports that explanations of the formulae for the first problem can be found elsewhere. The second indexical, placed after the formulae for the second problem is a diagram of the diamond arrangement of squares. These juxtapositions of artifacts are designed to both be recognized as solution-explanation pairs and to be used by others as resources to “build understandings.” How is the diagram in this posting to stand out as an “explanation device”?

• Team C:

For the original problem:
sides:
 $N(N+3)$
squares:
 $n(n-1)/2$

Explanations for the above formulas can be found in the wiki for our previous session.

We also found formulas for a diamond-like arrangement of the squares:
sides:
 $(n^2+(n-1)^2)*2+n*3-2$
squares:
 $n^2+(n-1)^2$



By "sides" we mean the three squares a side of the diamond is comprised of.

We decided that while an explicit formula to calculate the number of squares or sides is clearer for calculating, a recursive formula is easier when one is trying to determine how a particular series or pattern grows. <p>

Figure 15. Snapshot of the Wiki posting after the second session of Team C, Design Case Two.

It is interesting to note that except for the use of a few past-tense sentences, this Wiki posting departs from the detailed narrative retelling of activities that other teams chose for their postings as ways to make their artifacts recognizable as explanation and actionable as such by others. The diagram provided by Team C and the sentence “By ‘sides’ we mean the three squares a side of the diamond is comprised of”, placed at the explanation “slot” defined within their own posting, reproduces or transports the artifact used by the team on their private whiteboard in their exploration of the problem and, in fact, presents an explanation which, not being co-constructed in synchronous interaction, will have to be reconstructed by the readers. An interesting feature of this explanatory objects is the highlighted “side length” which, possibly, is to be read in conjunction with the additional clarifying sentence as an element that is to do the work of explaining the formulae. In “translating” this object that was embedded in their situated interaction to the Wiki, Team C opened up through the structural features of their posting the interactional possibility that other teams will recognize it as an explanation and attempt its uptake within their own interaction and for their own situated purposes. These objects will indeed play a key role when a different team attempts to attempt a second translation which we will explore next.

Feedback notes provided by VMT in between sessions, where also propitious resources for teams to orient to the work of each other. In their feedback message to team C regarding their work on session two, the VMT facilitators praised their work on the diamond pattern and the team's posting to the Wiki: "Your exploration of the diamond shape was also very interesting to us, and your posting to the Wiki should be helpful to other teams thinking about similar cases." On the other hand, in the feedback message that the facilitators provided at the onset of the third session to a different team, Team B, they asked them, among other possible tasks, to see if they could understand "how Team C got its formula for the diamond pattern." The excerpt below corresponds to the last part of this feedback note.

Log 23. Design Case Two, Team B, Feedback Note on Session 2

(...)

Can you explain your formula for the number of sticks so **that someone in a different group** can see how you got it by breaking each layer into its top surface, bottom and middle and then counting the horizontal and vertical sticks separately?

Do you understand how team C got its formulae for the diamond pattern of squares? What if they had a diamond pattern of diamonds (just rotate the squares 45 degrees)?

What shapes make mathematically interesting patterns in 2-D or in 3-D?

The first of the two questions posted in the second paragraph of this excerpt (Do you understand how team C got its formulae for the diamond pattern of squares?) opens up a few alternative interactional options to Team B. How is the team supposed to understand how a different individual or group, in an interaction that they did not participate in, "got" something like a solution to Team C's diamond problem? Team B can recognize this as a "challenge of understanding" and, ultimately, organize their participation to either "claim" understanding (e.g., simply answer yes or no to the question and be accountable for it) or to "display" their understanding in some recognizable way. However, before getting to such work, Team B, as we have noted that other teams did, organized the uptake of the feedback messages as an occasion to orient to some reporting activity of their own which will have some bearing on how they approach this challenge. Initially the team oriented to some discussion on things that they could have done and should do better (Quicksilver 7:10:51: so we have to explain our formula more) in a way that

projects past doings as exemplars for subsequent action. For instance, when they take on another of the tasks suggested earlier in the feedback (i.e., calculating the number of sticks and squares in a “corner pyramid”) they initially suggest that the same solution that they had created in their previous session still applies to this problem (Bwang8 7:14:29 PM: The equation would still be the same, right? / Quicksilver 7:14:46 PM: I think so / Bwang8 7:14:47 PM: because there are the same number of cube each level) but, impelled by their own uptake of the evaluative aspects of the feedback note, Quicksilver prompts the team to actually explain why the formula works in this new case (Quicksilver 7:14:50 PM: but lets explain that / bcuz that was in the feedback too). Interestingly, the feedback note referentially introduces the relevance of other teams when suggesting that they explain things “so that someone in a different group can see how (they) got it.” The team however faced significant troubles in carrying over this explanation work, understanding each other’s views of what this corner pyramid looks like and how it grows from one stage to the next. So much so, that after considerable discussion, Aznx projects this trajectory of activity to a future session bidding to “postpone” this work and take on a different task (Aznx 7:24:08 PM : Should we just go onto a different problem for now? / (...) / WE can come back to this on Thursday / And perhaps expands on it even more). The team agrees and, as a result, the need to find a new task becomes their next relevant move. In orienting to this, Quicksilver appropriates a question presented in the feedback and presents it to the team: *How did team C get its formula for the diamonds?* What follows this proposal is Team B’s attempt to resolve the challenge of “accessing” (like Quicksilver calls it: *How do we access that?*) the work of a different team (or at least its accessible translation) and organize their collective activity around it in a way that complies with the expected activity suggested by the feedback note.

Since the teams had been posting their collective results all on the same Wiki page: “Other Sticks Problem Ideas” (instead of having private Wiki pages for each team) Team B does not have much trouble locating the report posted by Team C presenting their work on the diamond pattern during session two (Figure 15). Because reading the Wiki is not an activity that they can do inside the virtual room environment the first thing the team does is to transport some of the resources posted by Team C into their room in their attempt to unpack them. Initially, Aznx reproduces the diamond pattern on the whiteboard (without the original color highlighting) and initiates a discussion on how the pattern might grow as a

tessellation. Soon after, the Team C's equations are transported into the chat and to a textbox on the whiteboard as the following interaction takes place:

Log 24. Design Case Two, Team B, Session 2

730 bwang: lets think about the equatin
 731 bwang: equation
 732 Quicksilver: yes
 733 bwang8: how did they derive it
 734 Aznx: There's the formula
 735 bwang8: $(n^2+(n-1)^2)*2+n*3-2$
 736 bwang8: $n^2+(n-1)^2$
 738 Aznx: The 3n has to do with the growing outer layer of the pattern I think.
 739 Quicksilver: the sides and squares
 740 Aznx: Right.
 741 Aznx: There.
 742 Aznx: I have an interesting way to look at this problem.
 743 Quicksilver: Tell us
 744 Aznx: Can you see how it fits inside a quare?
 745 bwang8: yes
 746 Quicksilver: Yes
 747 bwang8: oh
 748 bwang8: yes
 749 Quicksilver: You are sayingthe extra spaces...
 750 Aznx: Also, do you see if you add up the missing areas
 751 Quicksilver: Yes...
 752 Quicksilver: they look similar to the original figures
 753 Quicksilver: figure
 754 Aznx: It is equivalent in size to the small circle in the pattern
 755 Quicksilver: Small circle?

Not having a chance to interact directly with Team C, “understanding” how they got their formulae is a challenge for which the team needs to find a method given the resources offered on Team C’s Wiki posting. Interestingly, we can see in line 738 that perhaps Aznx has picked up on Team C’s “colored highlighting” in their diagram as a resource to make sense of certain portions of the formulae; in this case “the 3n.” However, soon after this, Aznx states that he has “an interesting way to look at this problem” (line 742) and, as we have seen in other instances of bridging activity, prior work gets embedded in the current work of the team. This “interesting way” of orienting to the problem which the team takes on is their own way of seeing and manipulating the diamond pattern (finding a whole square from which the diamond can be made by subtracting the four corner) which, as another feature of this complex web of bridging moves that this case encapsulates, integrates their own work from session one (because as Quicksilver remarks, each individual corner that gets subtracted “look similar to the original figures”). However, the exploration that the team embarks on does not lead them to a solution and as a result Bwang brings back the team’s attention to Team C’s formula by asking “what is n in their equation.” Notice, as we have remarked in other instances of bridging activity how the use of the present tense projects a unique blended temporality where prior work is indexed

in their current interaction. This time they decide to try to ask Team C directly and in a very proactive move, Quicksilver uses the VMT lobby (a separate virtual room with a chat panel and a listing of rooms) to contact the facilitator who is at the moment in Team C's virtual room and asks her to relate his question to the team: "Hey anyone from team c, our team needs to know what n was in your equations last week." The moderator relates Team B's question to Team C's and later reports back the responses (e.g., 137 The length of a side, qwertyuiop: was n side length?). While Quicksilver is pursuing this, the facilitator in Team B's room answers the question as well on behalf of VMT and indirectly on behalf of Team C (I assume N is the stage in the pattern / Just like in the original problem on the Topic / Stage N=1 is one square / Stage N= 2 is a cross of 5 squares / Stage N=3 is the bigger figure with 13 squares). What follows, however, is the team's framing of to their own idea of using a "big square" from which the diamond gets formed by removing four corners as the presumed method employed by Team C originally (Aznx: How about the sides? / How did they do that? / Bwang: i think they first calculate how many sides there are in the big square / and minus the extra ones). In doing so, Team B's "interesting idea" which is situated in their ongoing interaction gets transposed as a reconstruction of Team C's prior work and as a way to respond to the VMT feedback prompting them to "understand how Team C got its formulae." In a retrospective account at the end of the session, however, Aznxs presents a different translation of how the two objects relate to each other but we see this move as yet another reconstruction of their work in this session: "We derived one (formula) ourselves, and just used their(s) to double-check." Moments later when they realize that the part of the formula of the number of squares in the diamond which they have constructed (Aznx: $(2n-1)^2 = \text{the \# of squares in the big square}$) is not in Team C's original equation (Quicksilver: *But that is not in theri equation*) they exhibit some confusion and despite pointing to the record of the chat conversation in which at least one of the members (who had left moments ago) had explained the reasoning behind their method, the two remaining members of the team can't explain it themselves and project this incomplete activity for the next session: "let's pick it up next time when bwang can explain it."

Figure 16 summarizes the trajectory of bridging activity that we have traced so far. The work that team C reported on the Wiki after its second session has been the subject of uptake by team B in its third session. Team B's work in session three is also presented in the Wiki.

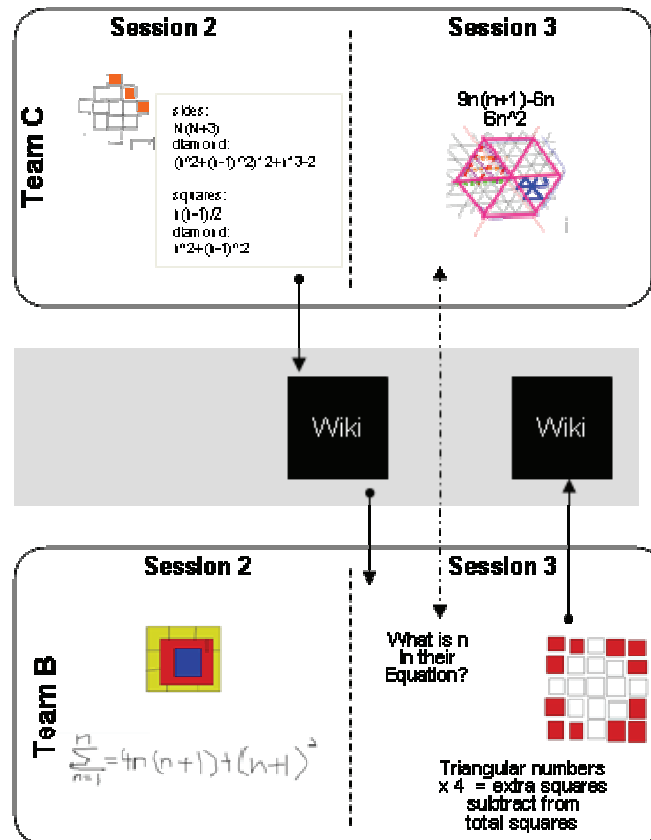


Figure 16. Bridging activity linking the work of teams B and C in sessions 2 and 3 of Design Case Two.

The sequence of interactional moves that follows this cross-team bridging trajectory is equally rich. First, bwang comes by himself into the virtual room in between the third and fourth sessions and announces through a chat message that he has posted additional materials to the Wiki. Then, at the onset of the fourth session, the VMT facilitators provide feedback for this final session which indicates that the team could revisit a problem they were working on before, “*in order to state more clearly for other groups in the Wiki: (a) a definition of your problem, (b) a solution and (c) how you solved the problem.*” All three participants attend this final session and “as usual” start by looking at the feedback and deciding what to address first. The team decides on continuing their work on Team C’s formula and bwang leads a similar problem solving path as the one explored in the previous session (big square minus corners). Interestingly this work starts with the statement “*we know how to Calculate the Big square at each Level*” which seems to attempt to orient the group to this as actual shared knowledge. This time they notice that they can use their formula from session 1 for the corners (*bwang : we can use the equation from session 1 | $n(n+1)/2 | 4*n(n+1)/2=$ the four corners*). Later on, they work on finding

Team C's formula for the number of the sticks and in doing so, the team realizes that Team C's formula is wrong. This significantly changes the qualitative nature of the team's engagement and motivates Quicksilver to state that they "*must put that on the Wiki*" and should next find the "*real answer*." To find the real answer they again re-use a reasoning procedure from session one through which they break the diamond up into horizontal and vertical lines. Their final two postings on the Wiki are reproduced below.

Log 25. Design Case Two, Team B, Wiki after Session 4

So in session 3, our team tried to understand Team C's formula and how it was derived. We found out we could use triangular numbers because we took the diamonds one stage at a time. We put a big square around each stage. We figured out that if you subtract the stage from the square, you will get a triangular number.

In session 4, we continued our progress on the diamond problem. We found that if we filled up the diamond with more squares and get an easier square with $2n+1$ as the dimension. So the number of squares in the big square is $(2n+1)^2$. We then minus the squares that we added on which was at the 4 corners, which grow in the same pattern as the triangle number in the first session. We used the formula for # of squares from the first session and times it by 4 to calculate the 4 corners that we add on to make the big square. The final formula for the # of squares in the diamond is $(2n+1)^2 - n(n+1)/2 * 4$. We tested it several times to check if it works.

We then move on to understand Team C's formula for summing up the total # of sticks in n-level diamond. We first tried to used the big square and then minus the extra corners, but the corners turns out to be to hard to calculate. Then we tried to simplify Team C's equation to help as find a lead, but we found out that their stick equation is wrong. We then decide to find out a whole new equation and tried to divide the sticks up into vertical and horizontal groups like we did before with all the other problems. The groups can be further divided into 2 equal parts. We found a pattern.

1st level: 1
 2nd level: 1+3
 3rd level: 1+3+5
 4th level: 1+3+5+7
 5th level: 1+3+5+7+9
 nth level: $(2*n)*n/2$

This Wiki posting culminates the integration of both Team B and C's work into a narrative that spans a number of VMT sessions and which, interactionally, can serve as a resource for any other VMT team to continue the work reported by both Teams on the Wiki. Figure 17 illustrates this trajectory schematically by showing how Team B has carried the work of Team C across two additional sessions of collaboration (while team C has continued to work on its own on two different problems). Although there is no visible uptake of Team B's Wiki postings by Team C, the reading of such messages is informed by the ways that Team B has designed such messages to be a narrative of both team's work.

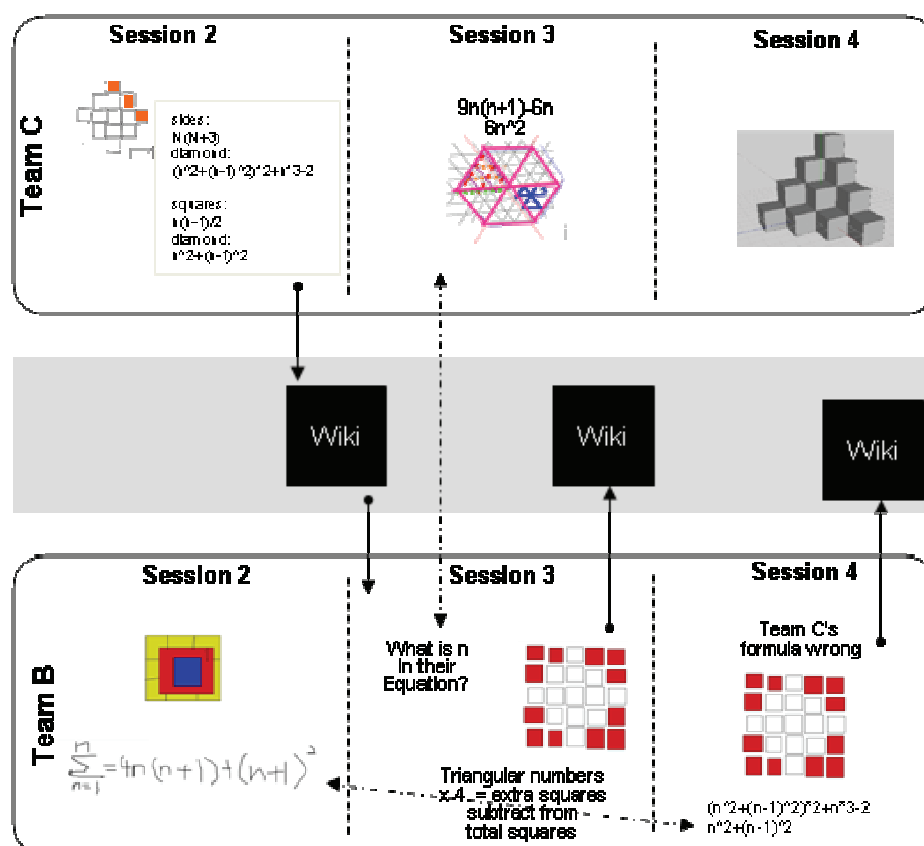


Figure 17. Bridging activity linking the work of teams B and C in sessions 2 through 4 of Design Case Two.

Although there were only three other cases in which these types of linkages across teams were established in Design Case Two, the instance analyzed in this section corresponded to the case where the interactional uptake, the nature of its dynamics and the reach of its interactional effects were the most significant. Table 13 presents a summary of the observed characteristics across these four instances of projecting activity.

Table 13. Summary of Cross-Team Bridging Cases in Design Case Two

	Knowledge Building Trajectory	Knowledge Artifacts	Organization of Participation	Temporality
<p>Cross-team Bridging</p> <p>(See Appendix D for a complete list of observed</p>	<p>Linking prior work of a team to the ongoing work of a different team or to the undifferentiated collectivity of all VMT teams across multiple collaborative sessions;</p> <p>Awareness and discovery of results and procedures, verification, Correction and referencing of problem-solving strategies and results.</p>	<p>A mix of reportable of self-created and other-created knowledge artifacts as well as other-created reconstructables.</p> <p>Validation of self activity as well as Challenge and Triggers for Expansion of self activity.</p> <p>Recipient Design: Artifacts from different teams presented on the Wiki next to each other are designed to be read as interrelated</p>	<p>Participants in bridging teams constitute other separate collectivities within interaction as well as through reports presented in Wiki</p> <p>Assessment of other teams' problem-solving results organized as a cooperative reconstruction of their problem solving activities</p>	<p>A mix of temporal markers that integrate prior episodes of multiple collectivities as relevant to current interactions;</p> <p>Bridging across team trajectories of work (self and other) makes and orders a collectivity of team's situated time;</p> <p>Expansive temporality that integrates the diachronic temporality of two or more teams</p>

As our analysis has shown these instances of bridging activity, this type of interactions attempted to link prior work of one team to the ongoing work of a different team through one or more interactional episodes. In doing so, the participants deployed a range of bridging moves to expand their trajectory of participation and knowledge building and to integrate their ongoing engagement and the history of several collectivities together. Although this is particular to cross-team bridging similar orientations to temporality were described in our analysis of reporting, collective re-remembering and projecting activities. We bring all of these observations together in the next section.

4.1.5. Bridging Activity as Temporal Organization

Although with some variation, all VMT teams, oriented to the discontinuity of their multiple episodes of collaboration over time, their multiple mathematical tasks, and the various participating collectivities. The range of bridging practices documented in the previous four sections represents the ways in which teams constituted such discontinuities as relevant to their interaction at particular moments in their trajectories of participation and for particular purposes. After completing the analysis of all the instances of bridging activity selected from Design Case One and classifying them as one of three interactional methods identified initially we attempted to describe the commonalities between all of these cases of bridging. This process generated an initial characterization of bridging that was then verified and extended through the analysis of the instances of bridging activity selected from Design Case Two. These instances were, in turn, classified into the same three bridging methods derived from Design Case One plus a new one emerging from this second design case. Table 14 below compiles the number of cases of bridging activity analyzed from both of the design case studies.

Table 14. Interactional Bridging Methods and Cases of Bridging Activity

	Design Case One	Design Case Two	Total Observed Cases
Reporting	8	32	40
Collective Re-remembering	5	7	12
Projecting	3	7	10
Cross-team Bridging	0	4	4
Total Observed Cases	16	50	66

Iterative cross-case analysis of instances of bridging in the dataset resulted in the characterization of bridging as collective, interactional activity that integrates, as resources for knowledge building action (a) the use of the temporal or sequential episodes, (b) bridging knowledge artifacts, and (c) the positioning of actors in participation frameworks. The four main types of interactional practices identified, Reporting, Collective Re-remembering, Projecting, and Cross-team Bridging, interweave together these three aspects of collaborative knowledge building interactions simultaneously. These elements are presented in Figure 18.

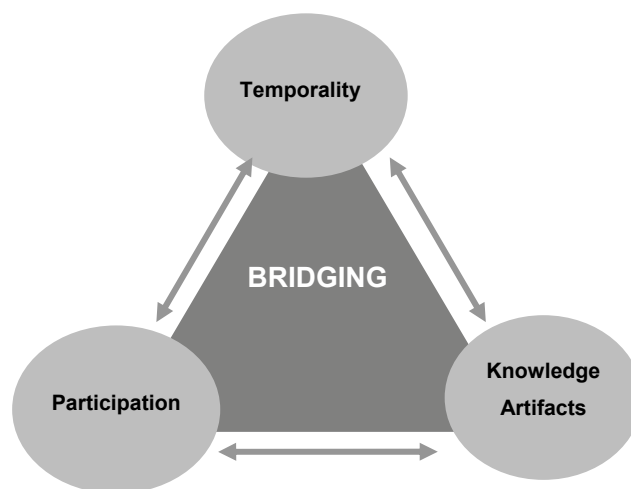


Figure 18. Three interrelated dimensions of bridging and continuity in knowledge building.

Throughout the preceding sections 4.1.1 through 4.1.4 we have shown how each instance of bridging activity manifest these three elements through the ways that participants attended to overcoming episodic and participation discontinuities. For instance, when we analyzed reporting interactions in Section 4.1.1 we discussed the ways that the referencing and re-presentation of prior doings and prior resources involved the use of specific knowledge artifacts or 'reportables' explicitly related to temporal markers (e.g., last time, yesterday, etc.), and described the ways that different participants oriented to such situated artifacts and to each other in the moment-by-moment unfolding of these interactions. Similarly, our analysis of projecting, collective-remembering, and cross-team bridging illustrated how team members actively organized their knowledge building activity in ways that were closely anchored by both temporal references and actual re-constructed sequences of past activities. For instance, in our analysis of Team Five's engagement in collectively remembering "where they had left of" in their previous session in Design Case One (Section 4.1.2) we highlighted the central role of the temporal markers used and the way that the sequential unfolding of their present interaction was structured through the reconstruction of the sequentiality of the cases explored in their previous sessions . These interactional resources used to index past and prior episodes as well as actual sequences of activities (e.g., "we want a formula...", "that's a 3 by 2 rectangle", "we first had a unit square", etc.) allowed newcomers and old timers to organize their own participation by aligning to particular activities and knowledge resources within a framework that combined the sense of it being a reconstruction of the past as well as a present engagement in which past non-participants have as much saying as past participants. It is in this sense, we argued, that the temporal and sequential organization of the team's activity was used to organize participation by, for instance, positioning past non-participants as members of prior doings as much as a participants in the present undertaking.

In analyzing these instances of bridging activity, we paid special attention to the ways that such type of activity related to the teams' knowledge building. The creation, referencing, manipulation, assessment and re-use of a set of knowledge artifacts represented in VMT the teams attempts at constituting the problem-at-hand, identifying which resources were relevant to it, creating tasks, constituting aspects of the problem situation and its resources as known or unknown, and deploying existing reasoning procedures. Interwoven with the development and use of knowledge

artifacts, teams engaged in the management of participation and actively oriented toward, for instance, who was and was not involved in certain problem-solving activity, who can or should speak about a particular matter and how, which activities (e.g., assessing and responding to assessments) are allocated to which participants, etc. In essence, the participants oriented to the development in interaction of specific participation frameworks (Goffman, 1981) which “positioned” team members in relation to each other, the resources at hand, and the activities they were engaged in. This positioning activity, for example, situates participants as problem-solving peers, narrator-and-audience, collaborative explainers, and within other arrangements of co-joint activity design by the participants to satisfy the emergent requirements of their interaction. We will explore specifically this aspect of bridging activity in the next section. However, what makes bridging unique is the way that knowledge artifacts and the organization of participation are closely interwoven with the teams interactional construction of sequential temporality. Through bridging teams created a temporal field that built on and expanded the sequentiality of synchronous interactions sustained over time: bounded episodes threaded as explicit sequences of interaction used to manage the teams dynamic participation and to constitute and expand specific knowledge artifacts.

Two of the three elements of bridging interactions which we have highlighted are common components of traditional theories of group collaboration: knowledge artifacts and the management of participation. For instance, ‘dual-space’ models of group collaboration usually integrate these two components sometimes characterized as a “content space” or “task dimension” (i.e. pertaining to the problem being solved) and a “relational space” or “socio-emotional dimension” which pertains to the ways that participants relate to each other (Bales, 1953; Barron, 2003). Depending on particular theoretical underpinnings, these dimensions are considered to be either mutually constitutive or actual separate topical components of interaction. For instance, some frameworks consider social/relational activity strictly non-task activity where as others allow for group interactions to serve both purposes and reinforce each other. Recent research on groups and collaboration has also highlighted the ways that group processes exhibit temporal and sequential patterns. However, time is an element often taken for granted as either a simple resource available to groups (e.g., time-to-task) or as a matter of group coordination (e.g., coordination of time perspectives). What the analysis of bridging reveals is that the teams orientation to time in these interactions is better characterized as their actual collaborative

construction of a sequential and temporal organization of their own activity over time in the ways that are relevant to their own purposes. Our analysis also suggests that this third aspect of interaction, sequentiality and temporality, is both an emergent result of the team's active engagement with bridging activity and a central resource used by teams to produce and manage knowledge artifacts over time and organized the relevant participation frameworks to sustain and expand such resources over time. In addition, we want to emphasize here that our analysis of instances of bridging interactions presented in the preceding four sections revealed that teams oriented to these three dimensions of their interactions not separately but in closely interrelated ways.

In a sense, what is revealing is not that these three dimensions of interaction (knowledge artifacts, participation, and temporality) appear to be relevant to participants but the ways in which each one of them is used as a resource to constitute the others within episodes of bridging activity. Temporality and the sequential unfolding of a teams' trajectory of participation was, for example, used as a resource to organize the participation of individuals and collectivities in relation to each other (e.g., as newcomers or past participants) as well as to specific knowledge artifacts and specific possibilities for action related to them (e.g., contributing to an account or providing assessments of its relevance.). We elaborate on these aspects of VMT interactions in our next two sections.

4.2. The Organization of Participation in Sustained Collaborative Knowledge Building

Often, research studies treat individuals within groups as taken-for-granted or unproblematic actors such as speakers and recipients and, similarly, treat one-time collectivities as conglomerates of individuals without a relevant history or a projected future. The sense that something is collective or shared across individual participants is often also taken as a simple derivation of the overlapping presence of multiple participants. Similarly, interactional activities such as posting a message, addressing or responding to a contribution are often treated as simple activities which are easily identifiable by analysts. However, when considering interaction of a naturalistic activity system over time such as VMT such approach falls particularly short in capturing the dynamics of the member's own organizing of their situation and their participation. As the study of participation as a construct has emphasized "*to make*

sense of what people do as members of a particular group means to understand not only what one person says to another, but how speaking and non speaking participants coordinate their actions, including verbal acts, to constitute themselves and each-other in particular spatio-temporally fluid but bounded units” (Duranti, 1998 p. 328) An approach that takes the social organization of participation as a primary concern should illuminate then the dynamic ways in which individuals, sub-groups and whole groups actively constitute themselves as interactional entities. In fact, given our interactional approach to the analysis of VMT sessions and our close interest in the ways that VMT participants overcame discontinuities emerging from their multiple sessions over time and from the dynamic changes in participation, it seemed necessary to explore in more detail exactly how is that individual and collective entities were constituted in the on-going unfolding of VMT interactions through bridging activity. Therefore, our second research question focused on describing the ways that individual participants, small groups, and the overall collectivity of VMT teams were constituted through bridging activity: *How are individual participants, small groups, and the overall collectivity of teams constituted in relation to episodic and participation discontinuities in the VMT online community? (RQ2)*

Throughout our analysis of the bridging practices observed in VMT and presented in the preceding sections, we have made a number of observations regarding how participation (individual and collective) is organized within episodes in which the teams oriented to overcoming specific discontinuities in their trajectory of interaction. For example, in describing the four methods of interactional bridging activity presented in Section 4.1, we highlighted the ways in which participants oriented to their multiple episodes of collaboration over time and to the related changes in participation through the use of reporting, projecting, collective remembering, and cross-team bridging activities which, in turn, allowed them to jointly coordinate their knowledge-building work over a temporal framework constructed by the teams and which established links to the participants and their activities retrospectively and prospectively. In our analysis of each of these four methods we reflected on the ways that the teams’ ongoing organization of participation involved asymmetrical access to coordinated possibilities for individual and collective action. Here we expand such observations and synthesize them in a common framework which describes the overall organization of participation in VMT.

Throughout our analysis of bridging interactions we found the concept of positioning in Positioning Theory, the study of positioning within human interaction (Harré & Moghaddam, 2003), to be fertile in approaching this aspect of VMT interactions. The concept of positioning, closely derived from Goffman's views on social encounters and his late notions of '*footing*' and '*participation frameworks*,' attempts to capture the ways in which participants in interaction find their relative alignment or their "stance." More importantly, Goffman showed that participants actively managed their footing and enacted specific participation frameworks (e.g., narrator and interactive audience) in ways that were directly related to the ways used to manage the production and reception of an utterance (Goffman, 1981, p.128). These insights have been advanced further by studies of talk-in-interaction (Sacks, 1992) which by attending closely to the unfolding of interaction illuminate the ways that participants constitute each other as individual speakers and hearers, and, in some specific situations, as collectivities (Lerner, 1993). This interactional work illustrates also the ways used by participants to demonstrate to each other their ongoing understanding of the relevant interactional entities (i.e. individual speaker, hearer, collectivities, etc.) and the events they are engaged in (Goodwin, 1981). Our goal in bringing this kind of analysis to our study of the ways that VMT teams overcame episodic and participation discontinuities is then to understand how individuals, small groups and the collectivity of multiple teams were constituted in VMT as part of the teams engagement in sustained knowledge building over time. Although, every single interactional move in VMT (e.g., posting a chat message, manipulating a drawing object on the shared whiteboard, etc.) has an effect on how participants are aligned relative to each other and to their ongoing flow of interaction, our interest lied on the patterned ways in which individuals, small groups, and the larger collectivity of groups were constituted over time and the ways that such patterns intersect with sustained knowledge building activities. As we will show in the following sub sections these dynamics can be considered representative of the overall organization of participation in the VMT activity system.

4.2.1. Positioning Dynamics in VMT

In both of the design cases analyzed, small groups of VMT participants came together to work on open-ended mathematical problems through a series of four one-hour sessions in which they used an online collaboration environment that mediated

their possibilities for interaction as well as their perception of other individual participants and groups. Three features of the VMT activity system were identified in our analysis as relevant to the ways that participants oriented to managing their participation within one episode of collaboration as well as over time. First, VMT was characterized as an activity system of freedom and relevance for identity construction. For instance, participants selected a login or screen name which identified (automatically) many of their actions in the environment (e.g., posting a message or creating a drawing). In addition, no particular roles were explicitly assigned to participants in VMT since a large part of their experience was expected to be shaped by their own collaborative decisions as peers and as members of a team. The VMT environment did not present any additional information about the participants (e.g., participant or team profiles) other than their self-chosen screen names. Some participants in Design Case One moved around teams or skipped sessions generating significant changes in team membership over time. Although participants in Design Case Two had the same freedom, such teams were much more stable. It is in this sense that we say that the VMT activity system was one in which it became relevant to constitute and manage one's identity and position relative to other and to the team-constructed ongoing purposes.

In addition, two other aspects of the VMT activity system were particularly relevant to the organization of participation. The fact that teams met for a sequence of sessions over several weeks made it possible for the history of individuals and collectivities to be relevant for the interactions themselves. The fact that someone was or was not a participant in prior sessions or that a team had met previously with similar or different members did become a relevant aspect of the VMT interactions observed. This aspect of VMT as an activity system was relevant within both design cases as we will see later in this section. Finally, the fact that in Design Case Two there was a community lobby and a Wiki space which offered participants a more explicit view of other participating individuals and teams, as opposed to the indirect references made by facilitators to 'other teams' in Design Case One, also characterized how the organization of VMT participation was approached.

These three aspects of the VMT activity system are important in understanding how individual participants, small groups, and the overall collectivity of teams were constituted in relation to episodic and participation discontinuities in the VMT online community. We will expand on the relevance of these three aspects as

we revisit some of the observations made while presenting the four bridging methods in Section 4.1 and concentrate on the positioning dynamics characteristic of bridging in VMT. The following excerpt will allow us to introduce the way in which we conceptualize positioning within VMT interactions:

Log 26. Design Case One, Team 3, Session 1

106 MFMod: So, to get started with the math, we will describe a situation to you and you will then explore it, make up questions about it, discuss them as a group and try to answer the ones that you find the most interesting. o.k.?

107 *templar leaves the room*

108 MFMod: Here's the basic situation:

109 #1math: K

110 MFMod: See the grid I just pasted onto the whiteboard?

111 Sancho: uh huh

112 #1math: YES

113 MFMod: 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.

114 fogs: yep

115 MFMod: 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 those two points?

116 #1math: OK

117 david: What's the minimum distance to get from A to B?

118 #1math: I THINK 10 [Points to line 117]

119 Sancho: 10 what?

120 Sancho: lines or squares?

...

130 MFMod: Looks like that was a good question.

Research on synchronous human interaction has documented amply the vivid ways in which participation is collaboratively organized through the on-going flow of joint activity (Jordan & Henderson, 1995; Schegloff, 2006). Similarly, in this excerpt MFMod, the VMT facilitator of this online session, attempts to organize the participation of all the participants in this virtual room in a unique way. She first initiates a sequence of textual postings in line 106 through which she attempts to constitute herself as the one in charge of tasking the group with what they should do in this session. Interestingly, she uses the collective pronoun "we" to separate herself from the student participants while at the same time affiliating with VMT as an institution or, at least, a collectivity of facilitators in charge of guiding the activity of the students. She also speaks of future activities that will be done by this VMT collectivity or by her on its behalf of ("*we will describe a situation to you*"). In addition, she refers to activities that the students are to do later on ("you will then explore it, make up questions about it..."). She ends her chat post with a call for assessment ("*o.k.?*"). This call, however, is not a neutral one in the sense that by positioning herself as 'the one in charge' she could have made it a dispreferred action to disagree with it (Pomerantz, 1984). However, this is just an interactional preference (i.e., contingent and derived from the sequential unfolding of this instance

of talk) since nothing structurally prevents a student participant from typing anything at all into the chat. What we can see in this opening sequence and which is representative of many interactions in VMT, whether they involved an active facilitator as in this case or just a team of student participants, is that participants visibly and in an on-going fashion attempt to place themselves, others, and specific resources (i.e. objects of reference) in relation to each other and to particular opportunities for action. We use the terms “*positioning*” to denote this aspect of interaction. In addition, we use the concept of “*participation framework*” to refer to the emerging organization of participation which results from engaging in positioning activity. We will explore these concepts in more detail throughout the rest of this section.

Interestingly, positioning work by the facilitator continues throughout the rest of this passage, for example through the presentation of the task itself in lines 113 through 115, the facilitator continues to offer a proposed organization of participation for the students—one which positions them in relation to each other as a peer group, in relation to VMT and the collectivity of facilitators expected to provide instructions and possibly assessment, and in relation to the assigned task as the ones responsible for “*figuring out the math*” of the grid world (“...*what is a math question you might ask that involves...*”). The facilitator seems to be achieving such positioning work by sequencing postings that combine a narrative of an immediate past (“*your group has gotten together...*”) with references to possible present and future activity (e.g., “*what is a math question you might ask...*”) whereby the group is also placed in a temporal trajectory of activity with a common task. In addition the task itself is placed, in a sense, as an initial object of reference in relation to which participants can be organized around. At this point in the flow of interaction, the set of possible actions available to the students is certainly wide. Interactionally, they can also put forward a new organization of action and uphold it in contrast to the current task.

If the students orient toward the participation framework put forward by the facilitator, any observer who shares the same culture could recognize this participation framework and understand that the right to assess actions and outcomes, and the duties of performing solution work have been, although contingently, allocated jointly through MFMod's sequence of postings and the students' responses to such postings. This represents a participation framework

constituted through interaction and, more specifically, positioning work. In fact, in line 117, we see that David asks a question that confirms his personal and collective orientation to the current activity as one in which he is to create and post questions, and also one in which his questions can be assessed or responded to by the facilitator (line 130) or by his peers.

This sequence of interactional turns may be seen as being part of the "teacher-student" storyline in which a teacher usually selects and provides tasks for students while they, in turn, respond with "assessable" actions that others can respond to. In fact, Positioning Theory, the study of positioning within human interaction, integrates the concept of *positions* as part of a triad of constructs which includes as well *story lines* and *speech acts* (Harré & Moghaddam, 2003, p. 9). A storyline defines the "principles or conventions that are being followed in the unfolding of an episode" (e.g., a doctor and patient storyline) and incorporates, as its central elements, positions that relate the participants to specific possibilities for story-related actions (e.g., a person positioned as a doctor has a right to prescribe treatment and one positioned as a patient has a duty to furnish faithful details about his illness). Consequently, the sensemaking of the ongoing interaction is informed by and informs, at the same time, the story line and the related positions to which the participants orient to in the interaction (e.g., a conversational turn can be oriented to as a complaint within a storyline that positions participants differently in relation to their rights and responsibilities and such orientation reveals interactionally the relevance of such rights and responsibilities). Our analysis of the instances of bridging activity that we have explored in previous sections illustrates some of the ways through which participants attempt such on-going and contingent positioning work: interactive positioning among different members of a team (individually or as a collectivity), reflexive positioning attempted by individuals and whole teams, and even moves to resist the positioning attempts of other participants by ignoring them, by explicitly challenging them, or by putting forward a new position for oneself or for others. Next we present our analysis of how such positioning work relates to constituting individual participants and collectivities in VMT.

There is one unaddressed aspect of Positioning Theory to which we want to bring attention before continuing with our presentation. Collaborative knowledge building interactions of the type characteristic of VMT involve the manipulation of task resources and the creation of reasoning artifacts that play a central role in how a

group manages its participation in joint activity. A given problem, for example constitutes a set of resources, graphical or textual, that a group of problem solvers need to make sense of, manipulate, transform, and complement with possible new resources that could lead to a solution. Access to these resources might not be symmetrical across all participants in an interaction. A diagram constructed by one participant, or a theorem that might be relevant to the problem but only known to some of the participants in a group, different participants might be constituted to occupy different positions in the interactional space of collaborative problem solving. Furthermore, the participants engage in activities that position themselves and others in specific ways in relation to such resources as we have seen even in the brief excerpt presented in Log 26. We find it essential to include such type of positioning activity to fully account for the types of interactions observed in VMT as we will explore in the next sections which describe the dynamics of positioning and the individual participant, the small group, and the collectivity of groups in VMT.

4.2.2. Positioning and the Individual

The analysis of instances of bridging activity presented in Section 4.1 illustrated how participants engaged in a series of practices through which, implicitly or explicitly, an individual participant was constituted as having or not having (or being seen to have) a certain set of possible actions—a positioning move. For instance, the first case of reporting we analyzed was initiated by drago, one of the two present team members who were the only ones who participated in that previous session (Log 5, p. 89) As a result, we were able to see how that team put forward an organization of participation so that the team would orient to him as the participant to speak on behalf of that team's past and responsible to respond to assessments of the relevance of that past which were in a sense expected of the rest of the team.

Similarly, in our analysis of a second instance of reporting activity (Log 7, p. 96), we observed in the second session of Team 2 in Design Case One how Bob resisted Mathfun's proposal for working on problem number eight because the team had already worked on it the in the prior session. The dynamics of positioning moves in this short instance of bridging are significantly rich. Initially after Mathfun's proposal for the team to initiate together the activity of working on problem eight, this open proposal made to the team as a whole calls for assessment. Everybody in the team

has equal rights or possibilities for action in terms of producing such assessment but, clearly the response will be addressed toward Mathfun—the originator of the proposal. Bob objects to Mathfun's proposal indirectly by offering a reason that makes working on the problem not necessary: they already worked on that problem in their last session. This reply positions the members of the team in two different planes. First, with respect to their current alignment toward the proposed task being a possible joint activity for the team. Second, with respect to their history together and the work that they did—which they might be accountable for (e.g., Marisol did not participate in the first session and, as such, would not be able to assess bob's claim without potential interactional trouble). Next, qwer questions bob's claim (line 146) while mathfun mitigates bob's objection (lines 147 and 149). In doing so, mathfun ratifies bob's positioning of the team's history in terms of having done the problem "so that there was only right and down" but suggests that they could do it now "with left and up?"

Throughout this instance of bridging activity, brief as it is, we can see how the participants established and managed their positions in relation to their past activity and a potential current activity as well as to certain knowledge artifacts as objects of reference. In this sense, both inter-personal and epistemic or knowledge-related stances are at play in how this interaction is unfolding. Deciding what problem to work on at a particular point in time is certainly an activity that every team has to engage in, usually enacting activities that might be externally labeled as "leadership," "coordination," or "planning." In this short passage we see the team conducting this coordination work in a joint fashion without a clear leader or coordinator role but with clear individual contributions. In terms of the positioning work that constitutes an individual participant within a bridging episode in VMT, we can clearly see that participants are literally placing themselves and attempting to place others in their relative position to each other, to the current activity, and even to their past and future activities. In doing so, they allocate and manage possible next actions, entitlements (e.g., who should respond to assessments) and the resources that are relevant to their work (e.g., problem-solving 'memories').

Turning our attention to how these dynamics of positioning intersect with the teams' collaborative problem solving activity, we noticed an interesting shift of relative positioning around the middle of this excerpt. By qwer accepting that if they do the problem in the way suggested by mathfun "*it would be almost the same*" she

has shifted her alignment from considering problem eight as a valid possibility to supporting bob in his idea that the problem was solved already. Bob then reports a candidate formula for the answer (in a sense, as proof of prior activity) and asks mathfun to check it. Mathfun declines and places himself away from his initial position tentatively —based on how sure Bob is of "his" formula. It is as a result of bob stating that he is not so sure about the correctness of his formula that mathfun can then make a bid for a new collective activity to which they can all orient to: "*then letz check it.*" This marks a visible change in the organization of participation of this team. Naturally, they are not orienting to this activity in exactly symmetrical ways. After all, this is Bob's formula and he makes the first bid for where the problem might lie ("*take out the -2 and the -1*"). The relative positioning of the team members to each other and to the resources at hand has shifted but bob is still positioned as the member in charge of assessing the way his formula is being checked. From this point on, however it is mathfun who structures the procedure through which the formula is going to be checked. He builds a series of cases, using the shared whiteboard, and asks the team to evaluate each one of them (e.g., line 160 "*k so there are two ways right?*").

The story line in this interaction has shifted from 'reporter-and-passive-audience' to 'reporter-and-interactive audience' or 'reporter-and-collaborators', in a qualitatively significant way. This new orientation toward collective activity has a different alignment of the group members toward participation especially when compared to what had been established in the preceding moments. As such, this represents a significant change in knowledge building positioning, achieved within an individual session but with linkages to a prior session, and one that has been accomplished interactively by bob, mathfun and qwer together. A total of 10 instances of reporting, projecting, and collective re-membering were identified as explicitly related to individual participants positioning themselves and other participants. Although different activities were being accomplished across these different instances of bridging activity, the positions that individual participants advanced for themselves and others as part of bridging activity were aligned across the three central elements of bridging: the organization of participation, knowledge artifacts and temporality. Table 15 illustrates these aspects of positioning and the individual participant in VMT.

Table 15. Dimensions of Positioning and the Individual Observed Across Cases

	Organization of Participation	Allocating Access and Rights to Knowledge Artifacts	Relative Position in Temporal Trajectory
Positioning and the Individual (See Appendix E for observed instances)	<p>Self-constituting one's identity in relation to the unfolding of reporting, reconstructing, or projecting problem-solving work or specified results. E.g., self-initiated narrator in reporter–interactive audience;</p> <p>Other-initiated constituting of an individual team member in relation to the unfolding of reporting, reconstructing, or projecting problem-solving work or specified results. E.g., other-requested reporter in a narrator-challengers.</p>	<p>Past participation: self-claimed or other-assigned used to allocate access and manage rights to problem-solving resources; Future participation unspecified unless attendance problematic;</p> <p>Individual team members speaking/acting on behalf of one self, on behalf of another team member;</p> <p>Individuals responsible for assessing, Responding to Assessments, Reporting/Responding to problems of understanding.</p>	<p>Individual participation organized in relation to past individual or collective problem-solving activity.</p> <p>Scope of linkages across time mostly short: previous session, next session.</p>

Positioning,' as most aspects of interaction, is a contingent and fluid phenomena. As part of bridging activity, individual participants, in summary, constituted themselves moment-by-moment in relation to their own present and past identity, as well as in relation to the small group as a whole or to particular sub-collectivities with specific trajectories of action (past and future), They attempted these particular organizations of participation specifically to link and advance bounded episodes of knowledge building in a way that allowed the teams to sustain activity over time. Although individuals clearly constituted themselves as such, it is the small group which provides in VMT that background of reference through which most positioning work is achieved. Therefore, we will continue to expand on the ways that the organization of participation in VMT was constitutive of the ongoing knowledge building activity of VMT teams in our next section.

4.2.3. Positioning and the Small Group

As we have shown in the previous section, individual participants were continuously positioned in interaction relative to each other and in ways that reflect the organization of sustained participation in VMT. Although we explored these positioning moves through the lens of individual positioning, it became clear that in VMT we can only speak of individual positioning within the backdrop of collective positioning. As Harré and Mogaddam (2003) point out, "by positioning someone in a certain way someone else is thereby positioned relative to that person" (p. 7). For instance, in revisiting the passage of interaction from the second session of Team 2 presented in the previous section, our analysis brought to the foreground the ways that Mathfun, bob, and Qwer got dynamically positioned as individuals through their unfolding interaction but it became clear that every move attempted as well an organization of the small group as a collective entity. We will explore in more detail the collective trajectory of this team to illustrate the dynamics of positioning and the small group in VMT.

In the first session held by Team 2, four participants were actively engaged in generating questions about the grid world. Following common participation patterns for first encounters, at the beginning, participation seemed very equal with all team members posting at very similar rates and orienting to each other as equal peers. Once a problem or question was proposed and a candidate answer for it had been offered assessment was a possible and very common next action. In many cases, it was the person who had proposed the question who took on the task of producing the assessment of the candidate answer but other team members participated in this as well. In this instance, after Bob posts a candidate answer Mathfun posted an acceptance token ("k") which aligns him with his participation in the production of the candidate answer. However, after this, there is a long silence of about 20 seconds followed by a type withdrawal from assessment by Sith91 and Qwer, the other two team members present in this session. Sith91 justifies his withdrawal on the basis of lack of necessary knowledge: "*im only in algebra 1.... i havent covered sine, cosine, and tangent yet.*" In doing so, Sith91 positions himself in a different sub-group relative to the rest of the team, to the knowledge needed to assess the candidate answer, and to the actual possibilities for action available to him (i.e. producing a competent assessment). Qwer seconds the withdrawal: "*neither have i.*" Bob (and to a lesser extent Mathfun) are then positioned to either accept this withdrawal and, for instance, transition to a completely new activity or to respond to it directly by trying to repair Sith91 and Qwer's lack of knowledge. Notice here how this set of 'next-

possible' actions for a participant follows from the sequential way that an interaction unfolds and the way participants position themselves as part of it not from pre-existing categories of mathematical competence. Bob quickly posts what look like formula definitions of trigonometry functions (e.g., $\text{tangent} = \text{opp}/\text{adj}$, $\text{sine} = \text{opp}/\text{hyp}$, cotangent is reciprocal of tangent, etc.) indexing some elements such as "opp," "adj," "hyp," and "reciprocal" which are never fully specified. This leads us to think that this type of explanation is done in a minimalist way to further justify one's answer and seek acceptance of it rather than to attempt to repair the team member's lack of knowledge. In fact, Sith91's attempt to engage with Bob's explanation is never acknowledged: "*so, ... that would be $6/4 = 3/2$.*" Instead, the set of conceptual definitions are followed with a procedural account of how to derive Bob's answer. A type of acknowledgment and apology are produced by Sith91 completing the explanation-assessment sequence while Qwer remains silent. This opens up the opportunity for the team to transition to a new activity which they do through a new question posted again by Mathfun. We can see this sequence as a shift in relative collective positioning of the team from equal participants to two sub-collectivities with different levels of knowledge and, consequently, different sets of possible or expected actions.

The pattern of positioning exhibited in this episode was repeated later in this session when the team works on a different question. The team enacts the "narrator-and-audience" participation framework by one participant posting an answer, followed by a procedural explanation and by requests for further explanation which receive, as a response, conceptual definitions which, in turn, fail to engage Sith91 and Qwer in constructing a visible understanding of the ideas behind the proposed answer. In this sense, we can state that the shift from equal participation to an "narrator-and-audience" participation framework (and the relative positioning of the participants related to this activity) permeates from one problem-solving episode to another within a single VMT session. Furthermore, if we consider the second team session, we could argue that this "narrator-and-audience" participation framework, has remained in effect beyond the boundary of their local engagement in one single session of collaboration. That being said, a different set of interactional conditions in that session made it possible for the team to transition again to the new "narrator-and-collaborators" participation framework. These shifts, in fact, are not uncommon in the VMT dataset. They represent more than the change in defined roles of an individual participant, the collective realignment of a team into different relative

positions with respect to each other and to certain relevant resources. In a final case, we analyze a third shift to further illustrate the dynamics of this type of positioning activity.

The fourth and last session of Team 2 finds Bob and Mathfun working as a dyad. None of the participants who had worked with them in the first three sessions joined this session. A notable shift in collective participation occurs in this final session. Toward the beginning, the facilitator presents Bob and Mathfun with a new challenge based on their prior work: finding the shortest distance between any two points along a grid that has been folded to form a triangular prism. In their previous session, bob, Mathfun, and Qwer had worked on rolling the grid to form a cylinder and, as mentioned earlier, Bob and Mathfun dominated the conversation. This time, Mathfun positions the dyad in what we have called an ‘exploratory collaborators’ framework. The following excerpt illustrates the characteristic dynamics of this framework.

Log 27. Design Case One, Team 2, Session 4

34 mathfun: so bob u there?
 35 bob: yeah
 36 mathfun: k letz get started
 37 bob: the way i see it, you do the same thing you did with the circle
 38 mathfun: alright
 39 mathfun: so letz draw the triangular prism
 40 mathfun: there
 41 mathfun: so should i make the bird's eye view?
 42 bob: yeah
 43 mathfun: k
 44 mathfun: there
 45 bob: draw a line segment
 46 bob: on it
 47 mathfun: aren't we able to find out the little segments with an arrow to them?
 48 mathfun: bob?
 49 *eModerator joins the room*
 50 bob: huh
 51 bob: oh
 52 bob: yeah
 53 bob: coordinate
 54 *jtcc joins the room*
 55 *eModerator leaves the room*
 56 mathfun: so then isn't the little length found too?
 57 bob: using law of cosines
 58 mathfun: or degrees
 59 bob: or maybe there's another way i;m not seeing
 60 bob: ?
 61 mathfun: is that x?
 62 bob: is what x?
 63 mathfun: that
 64 bob: no
 65 bob: it's a 4
 66 Moderator: x?
 67 mathfun: oh
 68 mathfun: see angle alpha?
 69 bob: yes
 70 bob: what about it?
 71 mathfun: is that 60 degrees?

72 bob: yes
 73 mathfun: can u use the degree, 2 length to find the last length of a triangle?
 74 bob: i don't get what you're saying
 75 mathfun: the two arrow pointed lengths and the angle can find the length A
 76 bob: by what?
 ...

This sequence starts with bob making a solution statement shortly after a problem has been presented, but his contribution this time makes it possible for a very different organization of the dyad's participation. Bob's proposal, in line 37, that "you do the same thing you did with the circle" explicitly references their prior session in which mathfun has conducted the problem-solving work under bob's 'expert watch.' Mathfun engages with the current problem in precisely that way, by asking for bob's to confirm that he should make "the bird's eye view" of the prism. What follows, are a series of postings that do not conform to the positioning and participation frameworks we had seen for this team. The work they are conducting seems much more exploratory with Bob being more open to considering mathfun's ideas as opposed to mathfun simply trying to test or understand bob's answers. Perhaps it is precisely because at this point the team does not have an answer to the problem but, instead, it is engaged in the actual work of organizing the problem space and exploring it to construct a solution. There is a prior procedure available which the team can reuse but no direct answer available. Line 59 is specially telling about how the dyads' relative positioning can be said to have shifted from their prior encounters. Bob is still positioned as the person to assess mathfun's postings but not necessarily on the basis of him being the author of an answer but more as a knowledgeable collaborator. This allows the dyad to engage in exploratory work that lasts for quite some time and results in a candidate answer that is constituted as a team answer.

By tracing these episodes in the trajectory of a VMT team we have attempted to illustrate how positioning work was used to constitute dynamically small groups (whole arrangements of undifferentiated team members or sub-collectivities) within specific knowledge building activities in VMT. We have also shown how common shifts in relative positioning and the related participation frameworks were common in VMT interactions. Our overall analysis of instances of bridging activity including reporting, collective re-remembering, projecting, and cross-team bridging showed that participants purposefully constituted the undifferentiated ensemble as an audience for their postings with specific opportunities for action, and also, in some cases, constituted differentiated sub-collectivities on the basis of different relevant criteria one of which was their longitudinal trajectory of participation. Table 16 presents a

summary of the observed characteristics across the 52 instances of positioning and the small group in both design cases.

Table 16. Dimensions of Small Group Positioning Observed Across Cases

	Organization of Participation	Allocating Access and Rights to Knowledge Artifacts	Relative Position in Temporal Trajectory
Positioning and Small Group (See Appendix F for observed instances)	Constituting an undifferentiated collectivity (whole team) in relation to the unfolding of reporting, reconstructing, or projecting problem-solving work or specified results. (Differentiating a sub-collectivity and constituting it as a collective actor of past problem-solving activity. Single case: 'last time me and estrick came up / that')	Teams speaking/acting on behalf of the knowledge work of their whole undifferentiated group Teams speaking/acting on behalf of the knowledge work of a sub-group collectivity within a team.	Team unfolding participation organized in relation to the past or future trajectory of collective problem-solving activity. Scope of linkages across temporal episodes vary from proximal (previous session, next session) to relatively distal (e.g., from Session 4 to Session 1)

Despite the fact that diagramming the concept of positioning can lead to significant misconceptions we offer the following diagram to illustrate our views on positioning and the small group in VMT.

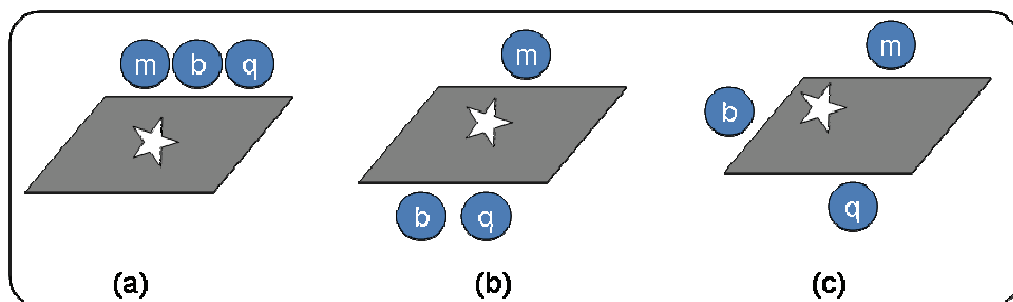


Figure 19. Schematics of group positions.

In this diagram circles represent individual participants while the table around which they interact and the star on top of it are metaphorical representations of the interactional space and the knowledge artifacts constructed. In the three arrangements depicted, the relative positioning that each individual participant holds

in relation to other participants and the knowledge artifacts are contrasted. A move to alter such relative positioning, although individual in appearance, cannot be decoupled from its effects to the overall arrangement of participation. In VMT, positioning in multi-party interactions resulted then in individual positions being always meshed within the constitution of specific situated collectivities and the organization of their collective action. These positions can change dynamically over time and represent the ways in which individuals can orient within particular group activities. In fact, although our representation seems to indicate that spatial access to resources is a predominant feature of VMT interactions, in reality it is the task of the participants to define what are the relevant dimensions that govern their space of interactional and, as we have shown, access based on the temporal history of a team's trajectory is much more consequential as part of bridging activity. As we had pointed out, collectivities are not just abstract taken-for-granted entities that aggregate individuals. In VMT small groups (whether whole teams or sub-collectivities within those teams) get actively constituted in particular ways throughout the moment-by-moment flow of interaction and over time. As with individuals, these groups get positioned in relation to (a) their own present and past identity, (b) in relation to other groups or individuals with specific trajectories of action (past and future), and (c) in relation to VMT as an organized institution.

In Design Case Two, in addition, we observed how small groups constituted relative positions in relation to other groups that did not constitute sub-collectivities of their own groups (e.g., Team C's position in relation to Team B's work). The organization of participation in Design Case Two also showed teams establishing reciprocal associations in which postings to the Wiki by an undifferentiated collectivity (i.e. a whole team like Team B) and about the prior work of a different team made other Wiki postings relevant by and about their co-recipients as an undifferentiated collectivity. In our next section, we explore how the collectivity of multiple groups was also constituted as part of VMT interactions.

4.2.4. Positioning and the Collectivity of VMT Teams

As we have pointed out before, the VMT activity system is one in which joint-participation goes beyond synchronous collective interaction to include possible linkages between the interactions of multiple teams which, over time, engage in

parallel but inter-related activities. By engaging multiple teams over time and offering different opportunities for teams to be aware of and interact with the work of such teams, VMT opens up the possibility for the organization of participation to transcend the small group level. Usually, this level of interaction is identified in the CSCL literature as the level of the online community and in other literatures with labels such as group-to-group collaboration (Mark *et al.*, 2003) or the level of the organization (Brown & Duguid, 1991). Our interest, however, is not in treating such interactional entities as given but to look at the ways in which participants constituted them through interaction, if at all.

Design Case One, as we have described, offered awareness of the fact that multiple teams were engaged in VMT but no direct ways for the participating teams to view such work or participate in it. VMT facilitators, however, made frequent references to other teams and in doing so mediated the teams' access and awareness of other collectivities. The message below from Team 3 illustrates how this type of positioning was attempted:

[8:07:56 PM] Facilitator: We are ready to start. Today, you can finish the work that you have been doing as a team in the previous three sessions. There are five teams in this project and they have all explored very interesting questions about the "grid-world" that we started with.

In some cases, these attempted linkages among groups received no visible uptake in Design Case One. A notable exception relevant to positioning work involves the resistance of Team One in session 2 to the facilitator's positioning of a compilation of questions from session 1 as being "*the questions that other groups came up with.*" The team instead reframes the list as "our questions." In doing this, Team One problematized the ownership of the artifact as being ascribed to "other teams" (without problematizing the interactional entity itself) and repositioned it as being a report of their own past work. Despite similar instances where teams in Design Case One attended to a collectivity that went beyond the realm of their own trajectory, it wasn't until Design Case Two that we were able to locate in the data more active interactional work aimed at constituting the collectivity of multiple groups as a relevant VMT entity.

The organization of participation in Design Case Two allowed teams to post reports of their work to a Wiki page where they could see as well the reports of other teams. The following snapshot of one of the Wiki pages used in Design Case Two

illustrates the way these Wiki pages were used. (For another example, see Figure 15 on page 130).

RowsOfTheTable

[HomePage](#) | [RecentChanges](#) | [Index](#) | [Preferences](#) | [Upload](#)

VMT Spring Fest

Findings of the VMT teams:
Ideas from groups on rows of the table

Row 3
Team name: B
Row 3: 28, 10
Team name: A
Row 3: 18, 6
Team name:
Row 3:

Row 4
Team name: B
Row 4: 40, 15
Team name: A
Row 4: 28, 10
Team name:
Row 4:

Row 5
Team name: B
Row 5: 54, 21
Team name: A
Row 5: 40, 15
Team name:
Row 5:

[Return to SpringFest06](#)

Done

Figure 20. Sample Wiki page from Design Case Two.

This Wiki page can be read in many different ways and although we do not have data that allows us to comment on the ways that individual participants read it we do have instances of bridging activity which allow us to observe the ways in which groups in interaction read this and other Wiki pages as to having been produced by the collectivity of multiple VMT teams (and about the work of multiple VMT teams.) For instance, at the beginning of Team D's second session the participants orient to the VMT Wiki as a reference place where their own work can be compared to the rest of the teams' work and be read in that way: *"ppl.... did u see the VMT Wiki link / its freaky / the explanations they have there are so... complicated / wats recursion? and induction."*

Not all readings of the Wiki pages exhibited this type of orientation but, in general, their uptake certainly demonstrated that the organization of participation in VMT in Design Case Two made the collectivity of all participating teams a relevant interactional entity in these interactions. In other instances of bridging work, the

collectivity of VMT teams was also constituted as a potential audience (e.g., how to write a report of a team's work for it), as a source of problem ideas, as well as a reference for how to design accounts of a team's work. Table X

Table 17. Dimensions of Positioning and the Collectivity of VMT Teams Observed Across Cases

	Organization of Participation	Allocating Access and Rights to Knowledge Artifacts	Relative Position in Temporal Trajectory
Positioning and the Collectivity of VMT Teams (See Appendix F for observed instances)	Constituting an undifferentiated aggregated collectivity of several VMT teams Constituting a named VMT team in relation to another team's trajectory of problem-solving.	Speaking/Acting on behalf of the knowledge work of whole undifferentiated group other than self-team Speaking/Acting on behalf of the knowledge work of the collectivity of several/all VMT teams.	Team interaction flow organizes its own temporal unfolding and reconstructs that of other teams. Scope of linkages across temporal episodes of multiple teams proximal (previous session, next session) or unspecified.

The interactional effects of the participation framework that emerged from the constitution of the collectivity of VMT teams as an interactional entity can be summarized by stating that participants in VMT activity system of Design Case Two expanded the set of possible and relevant entities by constituting a new form of collectivity and its potential opportunities for participation. A critical question emerges from this view and it revolves around whether a collectivity of teams can actually participate as such. As we have attempted to illustrate in the preceding subsections whether an individual or a sub-group actually assume and enact the positions that they are offered through interaction does not refute the positioning moves made through interaction. The fact that teams oriented to the collectivity of teams as relevant member categories indicates that they found it to be meaningful for the purposes of participating in VMT as a sustained and collective system engaged in collaborative and sustained knowledge building. The principle of recipient design which states that "speakers design their speech in accordance to their on-going evaluation of their recipient as a member of a particular group of class" (Duranti, 1998 /p. 299) validates this view but our analysis also suggests that the "on-going evaluation" that participants engage in can take place over diachronic trajectories of participation and encompass not just individual differentiated hearers but, as in the

case of multi-collectivity settings, associations of individuals and collectivities that are relevant to those activities and constitutive of a social setting like VMT.

Table 18 presents the number of observed cases considered during the analysis for each one of the three dimensions of positioning found.

Table 18. Observed Cases by Positioning Type

	Design Case One	Design Case Two	Total Observed Cases
Individual Positioning	7	3	10
Small Group Positioning	11	44	55
Collectivity of Teams	0	4	4
Total Observed Cases*	18*	51*	66*

(*) 3 cases exemplified two separate types of positioning. For a list of observed instances of each of these 3 dimensions of positioning see Appendices E, F, and G respectively.

One last sub-section allow us to expand our analysis of the set of resources that became relevant within the participation frameworks observed in bridging episodes in VMT so as to include not only individuals and collectivities dynamically positioned over time but also the set of artifacts that are generated and sustained as part of the team's knowledge building.

4.2.5 Knowledge Artifacts in Positioning

Knowledge building has been defined as the creation, testing, and improvement of conceptual artifacts (Bereiter & Scardamalia, 2003, p. 13) or artifacts that constitute 'knowledge-in-the-world' such as solution strategies, reasoning tactics, categories, theories, designs, and other knowledge and reasoning devices used to make sense of particular aspects of the context that situated participants engage with. Emphasis on how these resources are constructed in interaction relates directly to the need to understand the activities that individuals and collectivities engaged in when developing and maintaining their individual and collective understandings of a

subject over time. For instance, an individual might internalize conceptual artifacts developed collectively by a group and create new ones which, later on, can be used as interactional resources to do further work by the same or a completely different group (Vygotsky, 1930/1978, 1934/1986). In this sense, knowledge building is primarily interactional activity (individual and collective) comprised of a set of activities through which people-in-interaction develop and advance their understanding -of a math question, a sociological theory, a controversial decision, etc; through knowledge artifacts.

In the organization of participation put forward by the teams participating in VMT, not only are the individual and collective participants themselves and their trajectories of participation over time central interactional resources but also specific knowledge artifacts that are used, as we have suggested throughout the preceding sections, as objects of reference. We find no reason to distinguish, from an interactional perspective, these artifacts from the participants themselves, regarding the ways that different arrangements of participation are configured. For instance, toward the second session of Team Five in Design Case One, Gdo attempts to move in the grid world using diagonals, an approach explicitly discouraged by the problem statement given to the team in session one. Estrick, (who has commented on the fact that the two participants other than himself and Drago have joined them as newcomers in this session) responds to Gdo's attempt by stating that "*you can't go diagonal/ the problem before said so, but you weren't here.*" This posting attempts to indicate an invalid manipulation of the problem but also to position Gdo as a newcomer not only in relation to the rest of the team and its past but also in relation to the problem itself. So much so that the problem is given a "voice" so to speak and Gdo is positioned as a participant with no access to what the problem had said or, more directly to a relevant part of "the problem before." A few turns later, Mathwhiz treats this positioning of Gdo as an opportunity to do explanatory work and to reframe Gdo's position not only as lack of access to the past but as a problem of understanding how to move in the grid world now: "*it's like, you can't walk in water, and the lines are dry lines.*" These interactional moves indicate again that the participants were actively oriented to the use of their prior collaborative work as well as particular knowledge artifacts for organizing their own participation, their ways to relate to each other and to the possibilities for action available to them.

Commonly, the organization of participation in the study of groups and collaboration is treated only as relating to the ways that participants relate to each other but, at least within bridging activity, we see that knowledge artifacts play a central role in this aspect of collaborative interactions over time. Similarly, when knowledge artifacts are given central attention in the description of problem solving activities the ways in which they are interlinked together is attended usually the central concern without much consideration to the effects that such linkages have on the organization of participation. In the remaining part of this section we elaborate on some of the observations we have made in our descriptions of the four bridging methods found in VMT interactions especially as they relate to the ways that bridging activity seemed to reveal how the active positioning of knowledge artifacts interlinks the organization of participation and the temporal sequences attended to by VMT teams that sustained their engagement over time.

Each one of the bridging practices described in Section 4.1— Reporting, Collective Re-membering, Projecting, and Cross-team Bridging, involved the interactional co-construction of a bridging artifact used to link group knowledge building activity or discourse across different episodes or different collectivities. For instance, in our first case of reporting activity analyzed in Section 4.1.1, the group interaction involved a *reportable* with the structure of a rule-like presentation: “*you always have to move a certain amount...*” positioned in a way to make it explicit who was to be associated with it and with what possibilities for action (Drago and Estric could speak on behalf of that prior action others could engage in working out its present relevance). In addition, a reference to a particular point time (“last time”) associated the reportable and the participants with the history of the team. As we saw in our analysis of this instance and other instances of bridging activity, the intelligibility of these knowledge artifacts and their relevance for the present was something that was worked out by the team through the organization of participation that the team put forward through bridging. In fact, as we argued extensively these knowledge artifacts were not simply displays of memory but highly situated ‘bridging objects’ that responded to and link together the organization of participation of the present situation as well as the reported or reconstructed past.

In a series of episodes of bridging activity that we analyzed in Section 4.2.3 we noticed how the dyad that ends up working on the last session of this team actively uses knowledge artifacts that represent their history of joint participation not

simply as re-used knowledge but as ways of reconstructing their past forms of participating together. When Bob states that, the way he sees it, “*you do the same thing you did with the circle*” and mathfun responds by asking “*so should i make the bird’s eye view?*” the dyad is indeed using these knowledge artifacts that are closely rooted in their prior work together to co-develop a way of engaging with the problem at hand. Similarly, we commented in earlier sections on Team B’s methods for decomposing a figure and operating on the resulting sub-parts and how they were re-used over time not just as abstract artifacts but as actual ways of organizing participation for the team—ways that were visibly linked to the trajectory of participation of the team over time.

Each one of the types of positioning that we have presented in our analysis of the individual participant, the small group and the collectivity of teams as part of bridging activity in VMT has shown a dimension related to the allocation of access and rights to knowledge artifacts. Going back to our second research question — *How are individual participants, small groups, and the overall collectivity of teams constituted in relation to episodic and participation discontinuities in the VMT online community?*, we can state that knowledge artifacts play a central role as central resources for constituting the individual and collective entities that engage in interaction and managing their relative alignment to each other and to specific opportunities for action. A problem, a rule noticed by some members of the team, a reasoning procedure used previously have a central role in defining the interactional space in which participants locate themselves and their trajectories of participation over time. The summary presented in Table 19 brings together all of our observations regarding the positioning of knowledge artifacts as well as other central dimensions of positioning activity highlighted in previous sections regarding the individual participant, the small group and the collectivity of VMT teams.

Through our analysis presented in Section 4.2, we have expanded the analysis of bridging methods presented in Sections 4.1 and established the relationship between two central aspects of bridging interactions: the organization of participation through positioning and the ways that such aspect of VMT interactions is related to the knowledge artifacts that are created and manipulated by VMT teams over time. Next we will explore the third and final element of bridging interactions: the sequential and temporal unfolding of the ways teams relate the participation and knowledge dimensions.

Table 19. Summary of Positioning Dynamics in Bridging Activity

	Organization of Participation	Allocating Access and Rights to Knowledge Artifacts	Relative Position in Temporal Trajectory
Positioning and the Individual (See Appendix E for observed instances)	<p>Self-constituting one's identity in relation to the unfolding of reporting, reconstructing, or projecting problem-solving work or specified results. E.g., self-initiated narrator in reporter–interactive audience;</p> <p>Other-initiated constituting of an individual team member in relation to the unfolding of reporting, reconstructing, or projecting problem-solving work or specified results. E.g., other-requested reporter in a narrator–challengers.</p>	<p>Past participation: self-claimed or other-assigned used to allocate access and manage rights to problem-solving resources; Future participation unspecified unless attendance problematic;</p> <p>Individual team members speaking/acting on behalf of one self, on behalf of another team member;</p> <p>Individuals responsible for assessing, Responding to Assessments, Reporting/Responding to problems of understanding.</p>	<p>Individual participation organized in relation to past individual or collective problem-solving activity.</p> <p>Scope of linkages across time mostly short: previous session, next session.</p>
Positioning and the Small Group (See Appendix F for observed instances)	<p>Constituting an undifferentiated collectivity (whole team) in relation to the unfolding of reporting, reconstructing, or projecting problem-solving work or specified results.</p> <p>(Differentiating a sub-collectivity and constituting it as a collective actor of past problem-solving activity. Single case: 'last time me and estrick came up / that')</p>	<p>Teams speaking/acting on behalf of the knowledge work of their whole undifferentiated group</p> <p>Teams speaking/acting on behalf of the knowledge work of a sub-group collectivity within a team.</p>	<p>Team unfolding participation organized in relation to the past or future trajectory of collective problem-solving activity.</p> <p>Scope of linkages across temporal episodes vary from proximal (previous session, next session) to relatively distal (e.g., from Session 4 to Session 1)</p>
Positioning and the Collectivity of VMT Teams (See Appendix G for observed instances)	<p>Constituting an undifferentiated aggregated collectivity of several VMT teams</p> <p>Constituting a named VMT team in relation to another team's trajectory of problem-solving.</p>	<p>Speaking/Acting on behalf of the knowledge work of whole undifferentiated group other than self-team</p> <p>Speaking/Acting on behalf of the knowledge work of the collectivity of several/all VMT teams.</p>	<p>Team interaction flow organizes its own temporal unfolding and reconstructs that of other teams.</p> <p>Scope of linkages across temporal episodes of multiple teams proximal (previous session, next session) or unspecified.</p>

4.3. Continuity in Sustained Collaborative Knowledge Building

Our final research question, inquired about the *forms of continuity* that were *constituted by Virtual Math Teams through their building of collaborative knowledge over time* (RQ3). Although extant research has attended only in cursory ways to the sequential organization of the synchronous interactions such as the ones that VMT teams engaged in (and the ways that such sequential organization contributes to constituting local continuity within a single episode of collaboration), our interest was in exploring the forms of continuity that go beyond single encounters and which characterize sustained interaction over time. In fact, within the study of talk-in-interaction, one of the only fields which has paid substantial attention to sequential unfolding of interaction, Gumperz defines “sequential organization” as “that property of interaction by virtue of which what is said at any time sets up expectation about what is to follow either immediately afterwards or later in the interaction” (Gumperz, 1992 p. 304) but emphasizes that sequential organization of interaction is not only a local phenomenon: it can be local and global, prospective and retrospective. As we intend to explore in this final section, bridging activity seems to build on this property of interaction to allow participants to constitute different forms of continuity useful for their knowledge-building purposes.

Our analysis of all instances of bridging activity across both design cases indicates that VMT groups purposefully created and maintained a history of their on-going engagement, related knowledge artifacts, and the positioning of participants relative to each other and to such resources. This, although achieved through the turn-by-turn, moment-by-moment sequentially that governs synchronous interaction resulted in the creation of structures of sequentiality and continuity that go beyond the boundaries of the local organization of activity to establish a longitudinal trajectory of participation over time. This trajectory became relevant in specific situated moments of team interaction and for particular purposes. For instance, a member of a group might make a problem-solving proposal that contrasts with prior work making relevant a new set of features of the current problem through the lens of prior understandings, while at the same time making it possible for the current participants to organize themselves in specific ways in relationship to the proposal and its provenance (e.g., a newcomer offering an assessment addressed to prior participants and regarding prior work).

In this section we describe two unique forms of continuity in VMT which emerged as a result of considering the effects that different bridging practices had on the ways that teams organized their trajectories of participation over time: Diachronic continuity or the orientation of a team to linked sequences of their own collaborative episodes, and Expansive continuity or the constitution of linkages across collaborative episodes by multiple collectivities.

4.3.1. Diachronic Continuity

Through our analysis of bridging activity that occurred as part of knowledge-building interactions in VMT, we have been able to recognize the methods used by participants in a collectivity to evolve, over time, their current understandings of a problem world. In the cases of the different bridging practices that we have analyzed, for example, co-participants created, revised, manipulated, and monitored a set of knowledge resources, personal and collective, which allowed them to advance their understanding of the problem as such and also project relevant aspects of their activity (e.g., partial results, impasses, reasoning procedures, candidate answers, etc.) toward other team participants. The participants' orientation to the temporal or sequential organization of their collaborative experience (e.g., what was done in a different episode of activity or at a different time, how one's action relates to something done before, what possible actions might be derived from a prior doing, etc.) was made explicit and consequential in bridging interactions. This explicit orientation to temporality and sequentiality as resources for interaction, appeared, in all cases in more intricate and ways than simply referring to or marking prior or future episodes of action when using expressions such as "last Tuesday", "before", "then", "next time," and others. In fact, as we have shown previously, the use of markers related to the temporal and sequential organization of experience, e.g., temporal deictics, verb tenses, etc., was embedded in bridging practices through which the participants attended to and built sequences of interaction beyond the simple organization of local turn-taking. In doing so, they oriented to segmenting, identifying, and interlinking different bounded elements of their interactions diachronically—across multiple VMT sessions.

Figure 21, which compiles some of the elements from Team Five's work in sessions one and two, should aid us in illustrating how a team began to establish diachronic continuity by establishing linkages among both sessions.

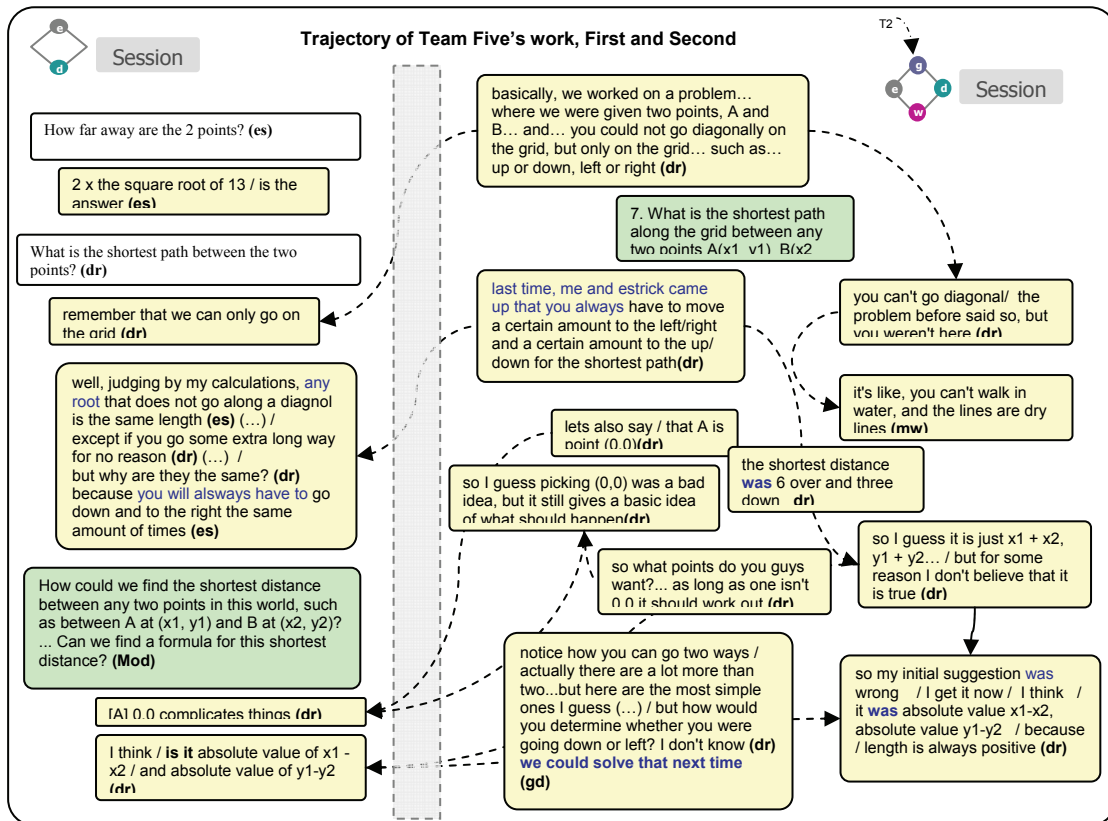


Figure 21. Team Five's trajectory of work between sessions one and two, on Design Case One.

Many of the elements depicted in this diagram were mentioned in our descriptions of the relevant cases of reporting and projecting activity in Section 4.1. Such episodes of bridging activity when traced across sessions show how knowledge work that was conducted in a session was reported or projected into another session and, in effect, used to begin the work of establishing diachronic continuity for this team. For example, the realization that “*you always have to move a certain amount to the left/right and a certain amount to the up/down*” when traveling from one point to another on the grid world, links retrospectively the newcomers in session two to the dyad who collaborated in session one and their work but also responds prospectively to the current arrangement of points chosen by the team in this session. The realization that labeling point A as the origin (0,0) “*complicates things*” when finding a formula for the distance between any two points and that such formula was “*absolute value of $x_1 - x_2$ / and absolute value of $y_1 - y_2$,*” are repeated, in a sense, in session two (and at least in one case, marked as such) for the purpose of establishing similar linkages.

By tracing the entire trajectory of bridging moves made by this team and recovering the explicit linkages among multiple episodes of collaboration, the

diagram in Figure 22 emerges. Although the actual richness of the way that this team built diachronic continuity across all four sessions is lost in the schematics of the diagram, what is truly important is to appreciate the ways in which sequences or chains of episodes of bridging activity contribute to constituting the continuity of a team's knowledge-building activity over time. By comparing, for example, similar representations for other teams participating in this design case, one can see that the diachronic continuity established by each team through its use of bridging practices differentiates each team's approach to recognizing opportunities for linkages across sessions and constructing such linkages through bridging activities.

The four different types of bridging activity presented in Section 4.1 offer a repertoire of possible moves from which to build a continuous trajectory of knowledge building over time. In some instances teams combined sequences of reporting moves across sessions or, in the most complex cases, employed reporting, projecting and collective re-membering moves purposefully. Although the projecting of possible next actions in future sessions was rarely actually paired with an instance where such projections were recovered, Team 5 comes the closest to it. At the end of session two, the noticing that you could travel multiple paths of shortest distance between two points in the grid is projected as something the team could work in the next section. The VMT facilitator included in session three a related question as one of the possible problems that the team could work on. The team orients toward the uptake of this question and works on it for most of session three. At the end of this session, after exploring several small grid cases ("2-by-two", "three-by-two", etc) in order to find a formula for the number of shortest paths between two points, the team produces a summary of all the cases and the results they have generated.

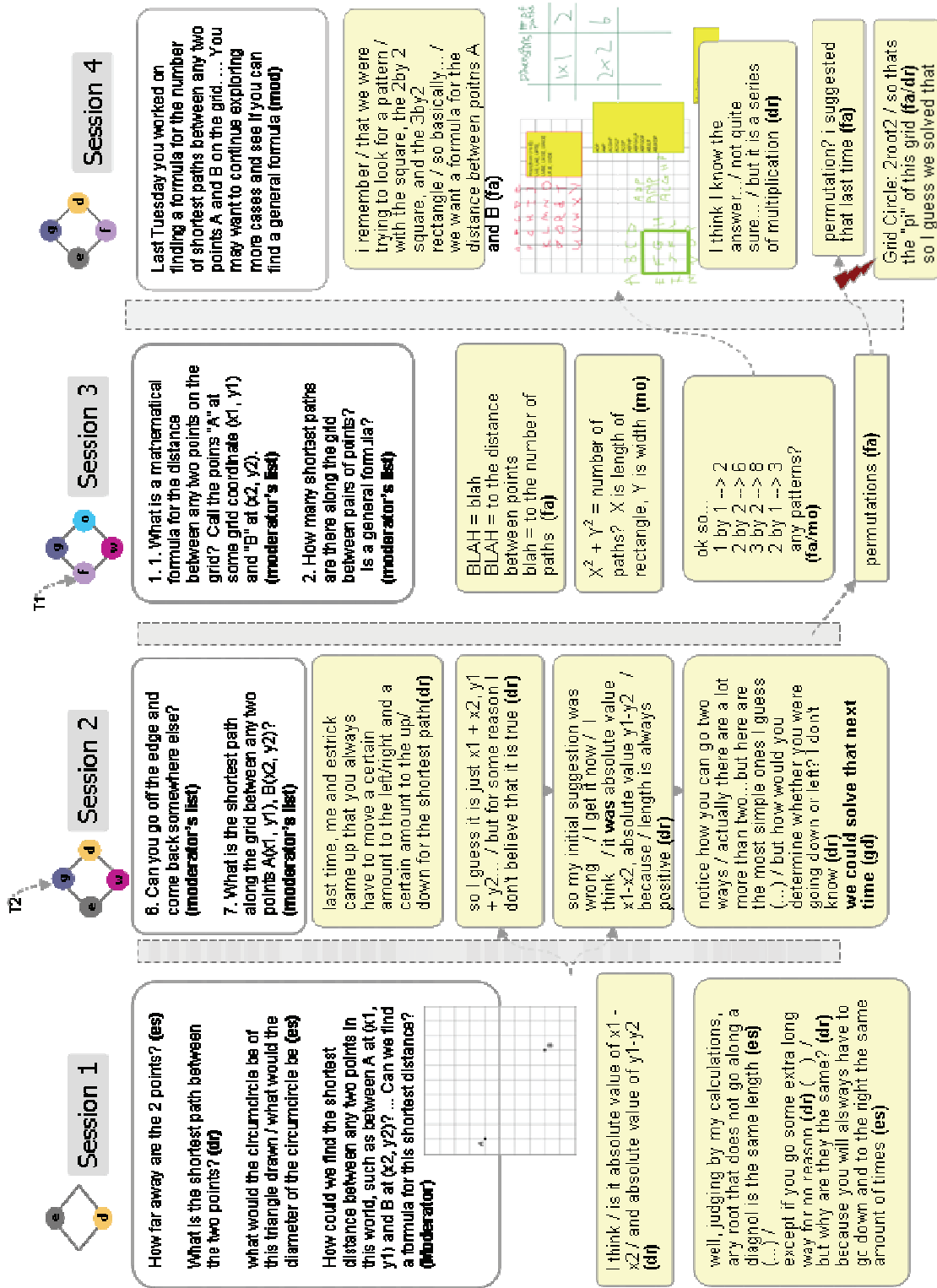


Figure 22. Team Five's trajectory of work across all four sessions, Design Case One.

Log 28. Design Case One, Team 5, Session 3

317 meets:	okay so...
318 meets:	1by1 --> 2
319 meets:	2 by 2 ..> 6
320 Mons :	2 by 1
321 meets:	3 by 2 --> 8
222 meets:	any patterns?
323 c344 :	i'm really sorry, but it's 6 o'clock an i have to go by 6 05 at latest
324 Mons :	3 (<i>Points to 319</i>)
325 meets:	?
326 c344 :	so i'll c you on thursday
327 Mons :	I mean that one (<i>Points to 320</i>)
328 c344 :	bye

This sort of collective recapitulation of work comes at the end of close to one hundred conversational turns after a proposal by Meets suggesting that in order to have a formula they needed to have something like “BLAH = blah” where “*BLAH = to the distance between the points*” and “*blah = to the number of paths*” (turns 212 to 217). In a sense, this activity seems to both report prior activity and serve as a resource for projecting what the next action could be (i.e. using this process and the results obtained so far to produce an actual successful formula). As we explored in Section 4.1.2 the organization of activity in this recapitulation passage is recovered in the final session of this team and serves as the framework through which the team engages in collective re-remembering and continues to pursue the formula for the number of paths between two points on the grid. Despite the significant achievements in the way this team organizes their exploration in this final session, the team is not able to create this formula before the end of this session. This suggests that at this level of analysis it is quite risky to link the existence of chains of bridging moves uncritically with team outputs. We can certainly argue that the team has established a densely connected trajectory of participation which represents its diachronic continuity but yet we cannot conclusively link this, negatively or positively, with the fact that the team was able to create an answer to the problem at hand within the time allocated. Similar sequences of bridging activities were observed in other teams' trajectories in both design case studies.

Design case two showed significant higher density in linkages and chains of different bridging moves. Similar diagrammatic representations to the one presented for Team 5 in Design Case One are also offered in Figure 23 through Figure 25 regarding teams A, B, and C in Design Case Two. These figures provide a graphical depiction of how reporting activities, reconstruction of prior work and projections of possible future work are threaded on the many resources and interactional activities advanced by a team in its knowledge-building engagement.

Team A (Reuk, Tcmath)

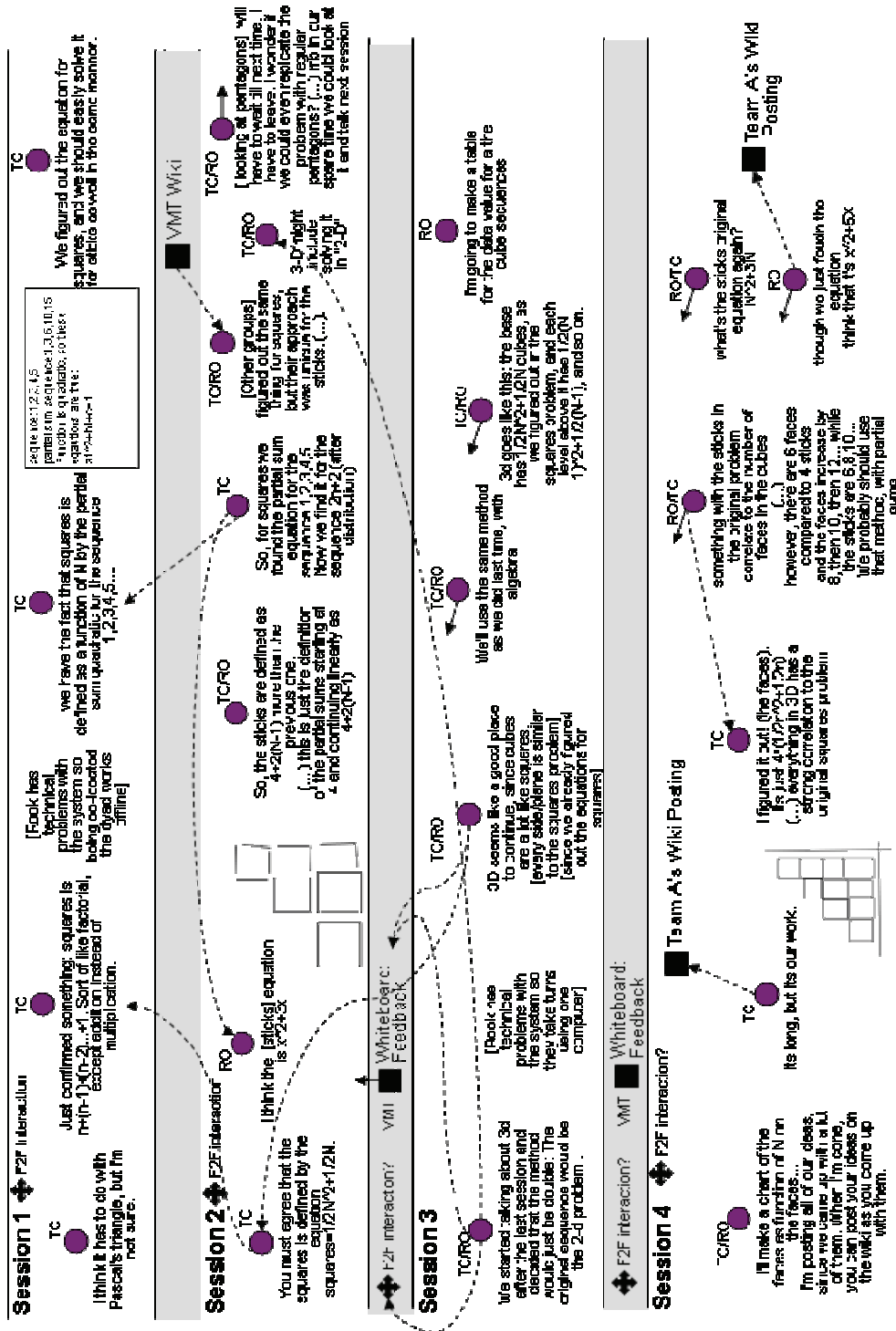


Figure 23. Team A's trajectory of work across all four sessions, Design Case Two.

Team B [Azmx, Quicksilver, Bwang]

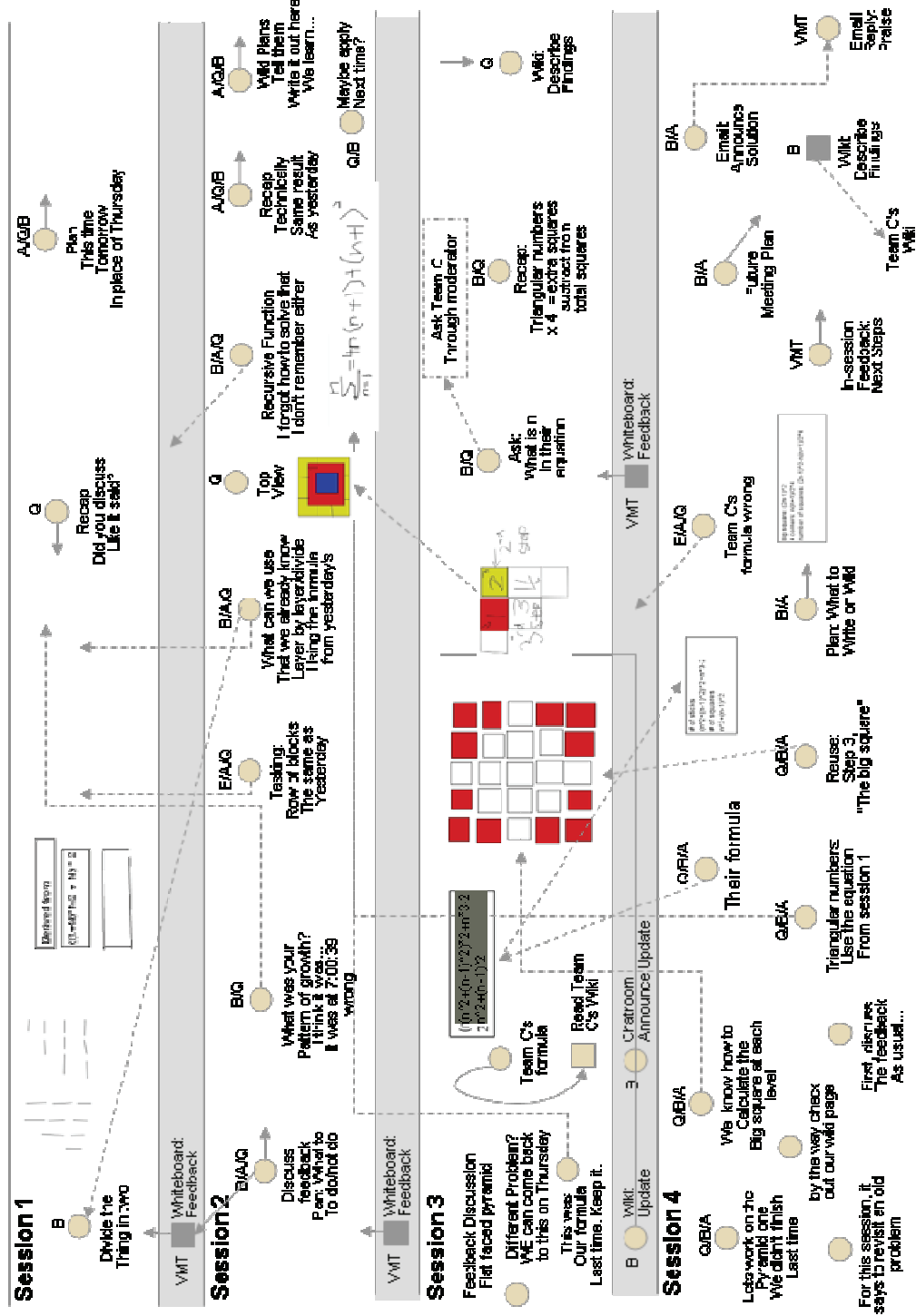


Figure 24. Team B's trajectory of work across all four sessions, Design Case Two.

Team C [Jason, Davidcy], One37, SShhlish, Qwertypap]

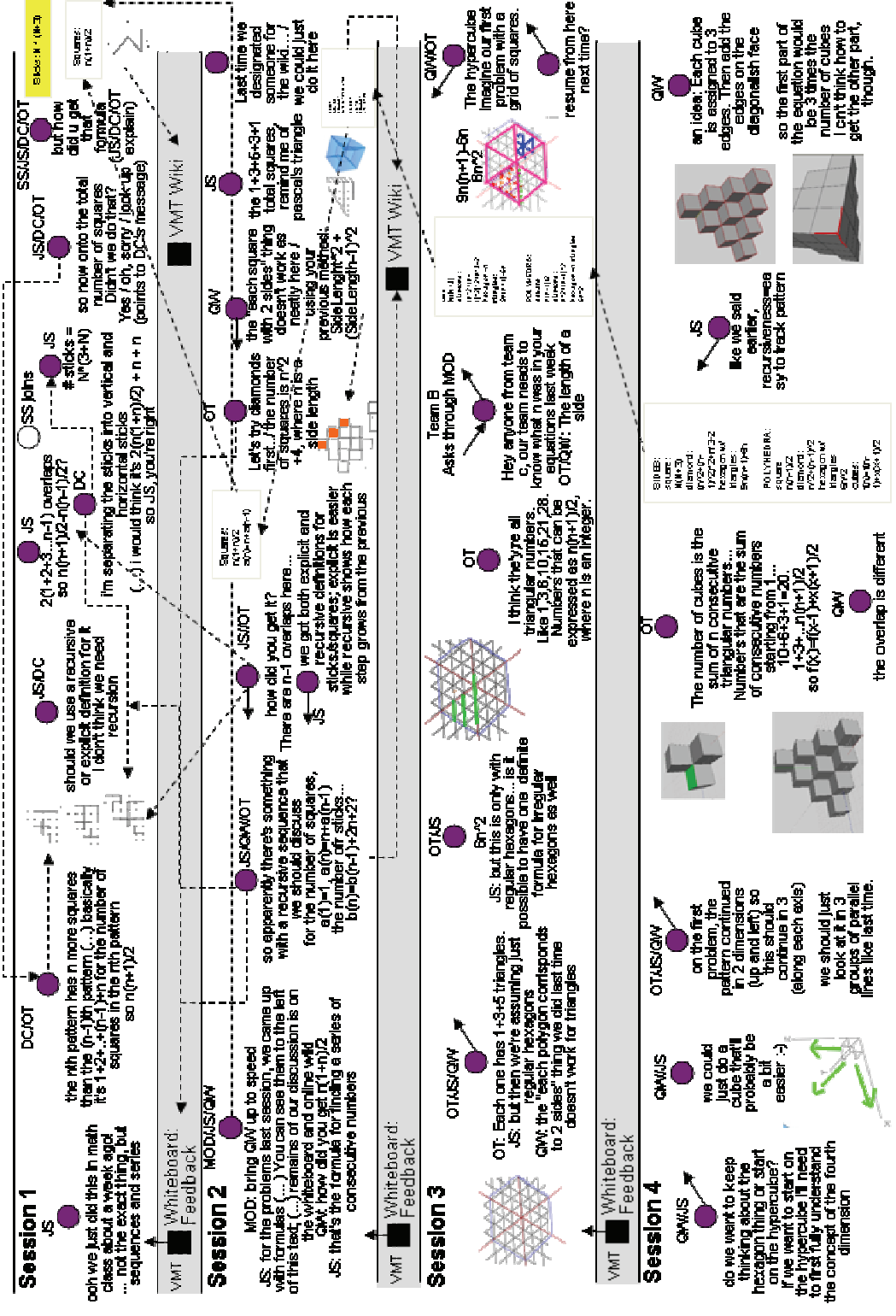


Figure 25. Team C's trajectory of work across all four sessions, Design Case Two.

The perspective that these figures, the linkages established by reporting activities, reconstruction of prior work and projections of possible future work, resonates with the statement put forward by Sawyer and based on his study of music and theater groups (Sawyer, 2003) which proposes 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., over long time spans and mediated indirectly through creative products such as recordings and performances). However, the nature of the artifacts that mediate diachronic continuity in VMT appears much more contingent and situated than the group products considered by Sawyer. Similarly, diachronic continuity in VMT seems to document a previously overlooked aspect of sustained collective sense-making. In Weick's framework of sense-making in organizations, bridging appears as the set of operations that "link the intersubjective with the generally intersubjective" (Weick, 1995 p. 73) where, as has been shown through our analysis of the individual instances of bridging activity and the sequences that we have consider in this section, interactional bridging is as important in constituting the intersubjective and its diachronic continuity. In our next section, however, we will explore aspect of our analysis of bridging activity which might resonate better with Weick's characterization. .

In summary, we would like to suggest that the integration of bridging methods, for example in cycles of projecting-reporting or projecting-reconstructing could be seen as team practices that indicate a strong orientation to continuity in their knowledge building. Despite the fact that it wasn't one of our goals to conduct comparisons across group trajectories, our overall analysis of bridging activity across all teams, seems to warrant the conjecture that those teams who did not orient to this type of activity as part of their longitudinal trajectory of problem solving and knowledge building or without the same qualitative level of engagement as others appeared to conduct their activities in fragmented ways missing out, from the point of view of the analyst, on opportunities to recognize, re-use, advance, contrast, project, or recover relevant prior work. This observation appears to be valid even for a semi-stable team such as Team One in Design Case One as well as for similar teams in Design Case Two. Supporting evidence for this conjecture includes the fact that several teams struggled repeatedly with understanding whether diagonal distances where possible in the grid world in Design Case One. In many cases the teams had had some form of agreement about this constraint (expressed in the original description of the grid world as the fact that you can only travel on the lines of the grid) and yet either they repeated its discussion in several sessions or ignored it in

subsequent sessions and worked on traditional geometry problems of angles, circles and diagonal distances. In many cases they were significantly engaged with such work and, because of this, we steer away from making external evaluative judgments about them but we do note that their trajectory of interaction did include prior consideration for this problem constraint. In a sense, from an interactional perspective, we could say that they may have advanced their synchronous problem solving activity while failing to capitalize on their team history or to constitute the diachronic continuity of their knowledge building.

Table 20. Summary of Observed Aspects of Diachronic Continuity Across Cases

	Evolving Identity	Knowledge Concern(s)/Purpose(s)	Interactional Methods
Diachronic Continuity	<p>Undifferentiated team as sustained/recurrent collectivity over time.</p> <p>Differentiated sub-collectivities affiliated with the team, its work, and its trajectory over time Single case: 'last time me and estrick came up / that')</p>	<p>Sustaining/Developing a path of situated collective action;</p> <p>Recommencing prior work, Contrasting, Reusing or revising prior work</p> <p>Alternatives: Resisting or abandoning a course of action, Repeating, Recreating prior findings/work</p>	<p>Reporting, Projecting, Collective Remembering</p>

4.3.2. Expansive Continuity

As we have noted, Design Case Two brought about a unique bridging practice that opened up the possibility for a VMT team to link prior knowledge building work by a different team to its own trajectory of participation and to project further work back to the collectivity of teams. This, in turn, made possible for teams to exhibit an orientation toward a different form of continuity that we have labeled *expansive continuity*. In contrast to the local continuity built through the unfolding of episodes of synchronous interactions and the diachronic continuity resulting from sequences of reporting, projecting, and collective-remembering episodes, expansive continuity is the result of a team's attempt to go beyond its own trajectory of participation over time and connect to other teams' work, finding relevancies for their

work and projecting possible next steps not only directly for those teams but for the entire collectivity of VMT teams.

Our detailed analysis of the trajectories of work of Teams B and C from Design Case Two presented in Section 4.1.4 is the best example of how this form of continuity was constituted in interaction. Figure 24 and Figure 25 compile the trajectory of participation of Teams B and C and present visually part of these interconnections. As we argued in our detailed presentation of these interconnections in Section 4.1.4, by linking Team C's prior work to the ongoing work of a Team B, collectively these teams expanded the trajectory of participation of the entire VMT activity system and made possible the further engagement of other collectivities to join in and continue to expand the realm of knowledge-building opportunities available. In doing this, Teams B and C engaged in coordinated bridging practices that involved the constitution of their teams mostly as undifferentiated collectivities but with a sense of evolving identity anchored on their sustained or recurrent sessions of collaborative activity as well as those of other collectivities. For instance, as we saw in our analysis of the state of the Wiki after Team B's final posting (Log 25, p. 136), their report of activities presents an undifferentiated team (e.g., "our team", "we", etc.) engaged with the work of another undifferentiated team (i.e. "Team C") in a series of sequential activities across two sessions ("So in session 3, our team tried to understand Team C's formula and...", "In session 4, we continued our progress on the diamond problem...". "We then move on to understand Team C's formula for summing up ...", "Then we tried to simplify Team C's equation to..."). Teams A and C exhibited a similar pattern early on in Session 2 when the Wiki also served as a resource for them to contrast their results (e.g., "They figured out the same thing for squares, but their approach was unique for the sticks"). In contrast in one other instances of cross-team bridging team D treated not just the work of a single other team but the work of all the rest of the teams participating in VMT as produced by an undifferentiated collectivity of teams sustained and recurrent over time and as a reference of the kind of expected outcomes that all teams were supposed to produce.

Table 21, summarizes the observed aspects of expansive continuity synthesized from our analysis of 6 instances of bridging activity related to this aspect of VMT interactions.

Table 21. Summary of Observed Aspects of Expansive Continuity Across Cases

	Evolving Identity	Knowledge Concern(s)/Purpose(s)	Interactional Methods
Expansive Continuity	<p>Undifferentiated team as sustained/recurrent collectivity over time linked to other sustained/recurrent collectivities.</p> <p>Undifferentiated collectivity of teams as sustained/recurrent collectivity over time</p>	<p>Linking the team's work with that of others</p> <p>Finding relevancies of one's work in others' and projecting possible courses of action.</p> <p>Alternatives: Isolating the team's work;</p> <p>Ignoring other's work or potentials for action</p>	<p>Cross-team Bridging, Reporting</p>

We have chosen the label of “expansive continuity” in a sense to resonate with Engeström’s idea of expansive learning (Engeström, 1987). Although in Engeström’s framework, the dimension in which the expansion takes place is that of human competence and development and the ultimate outcome of expansive learning are new forms of activity, we find our different connotation for the term appropriate in the sense that teams and the collectivity of teams in VMT Learning activity construct through bridging activity that spans multiple collaborative episodes over time, a collective field of possible trajectories of participation for all individual and collective participants which build on the existing knowledge-building of the activity system. Table 22 presents observed cases in each dimension of continuity.

Table 22. Observed Cases by Dimension of Continuity

	Design Case One	Design Case Two	Total Observed Cases
Diachronic	16	44	60
Expansive	0	6	6
Total Observed Cases	16	50	66

In summary, bridging activity builds on the local continuity that participants attempt to build through synchronous interaction and, through reporting, collective remembering and projecting bridging practices allows a virtual team to purposefully constitute its interactions as part of a punctuated but diachronic trajectory of building collaborative knowledge. In addition, cross-team bridging allows a virtual team to constitute its interactions in a field of expansive continuity which links together the activities and artifacts of multiple virtual teams.

As we have stated before, our emphasis in the sequential and temporal unfolding of interaction over time is motivated both by the results of our analysis as well by the fact that considerations of sequentiality and temporality as resources for action have not figured prominently in research on longitudinal knowledge building. In fact, time (both as a resource and as a factor) has only until very recently become an object of interest in theories of group development, specially in those that approach groups as complex activity systems (Arrow *et al.*, 2000; Arrow *et al.*, 2004; Gersick, 1988b, 1989; Gevers, Rutte, & Eerde, 2004; McGrath, 1991; McGrath & Tschan, 2004b). We believe that the type of rich descriptions such as the ones advanced in this report regarding the methods employed by teams to constitute, mark, and use temporality and sequentiality in interaction and to establish relevant dimensions of continuity, contribute to a richer theoretical framework of collective knowledge building. We will return to this issue in our final chapter.

5. SUMMARY OF FINDINGS AND FURTHER DISCUSSION

In this chapter we summarize the main high-level findings derived from the qualitative interactional/chat analysis of data from the two design cases of collaborative knowledge building in the Virtual Math Teams online community. In addition, we discuss the theoretical implications of the results presented in the previous chapter.

5.1. Four Interactional Bridging Methods

As we showed in Chapter 4, VMT teams in both design case studies visibly oriented to the episodic discontinuity or their multiple episodes of collaborative knowledge building and the participation discontinuity associated with changes in group participation over time. Evidence of this frequent orientation are the four collective bridging practices described in Section 4.1: Reporting, Collective Remembering, Projecting, and Cross-team Bridging. As we argued throughout our presentation of results, these practices illustrate the ways in which VMT teams constituted episodic and participation discontinuities as interactionally relevant to their own sustained knowledge-building by, for example, framing a current problem-solving task as explicitly linked to prior work conducted by at least some team members, linking current activity to potential future episodes of problem solving, or associating prior work of a team to the ongoing work of a different team or to the undifferentiated collectivity of all VMT teams across multiple collaborative sessions. All four bridging practices can be characterized as collective interactional activities that integrate, as resources for action, (a) the use of the temporal or sequential episodes, (b) bridging knowledge artifacts, and (c) the positioning of actors in expanded participation frameworks (See Sections 4.1.5, 4.2.1, and 4.2.5 for a complete discussion).

Our analysis of the four bridging practices identified showed how each instance of bridging activity closely integrated these three elements: knowledge artifacts, the organization of participation, and sequentiality or temporality. Two of these three elements of bridging interactions are common components of traditional theories of group collaboration: knowledge or task-oriented activities and interpersonal behaviors. For instance, ‘dual-space’ models of group collaboration usually integrate a ‘content space’ or ‘task dimension’ and a ‘relational space’ or ‘socio-emotional dimension’ (Bales, 1953; Barron, 2003). However, often these two dimensions are treated separately, instead of mutually constitutive in the ways that

our analysis of bridging practices suggest. Moreover, although a few theoretical frameworks of groups and collaboration have addressed the ways that group processes exhibit temporal and sequential patterns, time is often also treated as a separate dimension of group activity, either as a resource available to groups (e.g., time-to-task) or as a matter of coordinating individual perceptions of time. What our analysis of bridging has revealed is that the teams orientation to time in these interactions is better characterized as their actual collaborative construction of a sequential and temporal organization of their own activity over time in the ways that are relevant to their own purposes and used as a central resource for organizing participation and relating to specific knowledge artifacts over time.

These findings show that bridging practices constitute a valid way to characterize VMT as an activity system oriented to sustained knowledge building involving multiple collectivities over time. As we showed in Table 14, there were apparent quantitative variations across the two different design cases in terms of the number of observed instances of each one of the bridging practices documented (See also Appendices A through D for actual instances of all bridging practices across both design cases). These patterns have to be interpreted carefully since we lack an underlying theory of the frequency distribution of these phenomena. That being said, it is important to critically analyze plausible interpretations. Overall, Design Case Two showed a considerable increase in the total number of instances of all four types of practices over Design Case One. The proportions of each type of bridging practices relative to all the instances of bridging activity, however, do not appear so significantly different (i.e. the majority of the instances of bridging activity in both design cases were related to reporting activity while other bridging practices appeared significantly less frequently). Design Case Two gave rise to a different form of bridging practice (cross-team bridging) the reasons for which we have presented in Section 4.1.4 (central among them being the interactional possibilities for inter-team communication afforded by the use of shared Wiki). As it was argued in our initial framing of our research questions, we expected that at least three features of VMT as an activity system could be related to patterns of bridging practices: the sequential structure of the tasks addressed, the composition of the teams over time, and the features of the online collaboration environment. Since both of the tasks were, at least at face value, similar (i.e. they were both open-ended mathematical tasks which participants were encouraged to modify and expand), one could expect that frequent variation in team composition combined with the fact that teams in

Design Case One were not allowed to reuse the same persistent room for all their four sessions could be associated with more reporting bridging activity. However this was not the case. Teams in Design Case Two which had a single persistent room for all of their sessions and, in general, presented more stable patterns of participation showed a higher engagement with bridging practices, specially reporting bridging practices. On the other hand, it is possible that the persistent artifacts (e.g., chat history and whiteboard diagrams) which teams had access to in Design Case Two served as resources that motivated teams to orient to reporting activity in ways that accounted for such resources being accessible. However, actual persistent records of past interactions were only used in a few cases of reporting or cross-team bridging activity. It is also possible that perhaps team stability and persistency of resources actually leads to more reporting and other bridging activity not because it triggers awareness of past resources directly but because, in a way, it could orient the teams to the relevance of their continuity as a situated acting entity over time. From this point of view, bridging is not a compensation mechanism for discontinuities but a continuity-building response of situated teams. One way in which we could also understand these quantitative differences could be to consider the nature of the knowledge building task not as an abstract, given task but as the task addressed or constituted by the teams for themselves in each one of the design cases. From this perspective, we could see argue that teams in Design Case One oriented to their own progressive modification of the grid-world problem situation in ways that could be qualitatively different than the ways in which teams in Design Case Two constituted the different patterns of sticks and squares as related and relevant to each other. To verify this hypothesis would require a careful analysis not only of the episodes of bridging activity analyzed in our research but of the entire trajectory of problem solving of all teams. However, it seems very plausible that the fact that the orientation that the teams in Design Case Two showed to each one of their constructed problems as a series of cases and to the collection of problems as, in turn, a collection of cases itself, brings credibility to this interpretation. In this sense, again bridging constitutes continuity in terms of knowledge artifacts that share a sequential and temporal unfolding with the teams themselves and their organization of participation.

In our original review of different research perspectives on the term bridging we presented four different views which defined this construct as either a mental symbolic process (from the perspective of Linguistics and instructional Science) or as

an interactional process at the level of organizations, societies or large collectivities (from the point of view of Weick's model of Sensemaking or Putnam's theory of Social Capital. Our use and development of the term has showed that we can understand bridging and the discontinuities of collaborative knowledge building as interactional and as closely rooted in the practices that collectivities deploy to organize their participation, their creation and development of knowledge and their own sense of sequentiality and temporality. Especially important is to recognize in our analysis that this interactional phenomena is not exclusive of organizations nor simply emergent of networks of individuals, but that bridging represents as much the synchronic, ongoing and contingent establishment of a group's social order as it is of that teams constitution of its diachronic continuity over time and that of the collectivity of teams to which the team can position itself and others to be a part of. Our results and our commitment to situated action have shown how VMT teams orient to knowledge of their constituted mathematical tasks and of their ways of organizing their participation over time as to be related to the sequences and trajectories of knowledge building and of sequences of co-constructed occasions of knowing-in-action relevant to the moment at hand (Suchman, 2003).

As we pointed out in our review of the relevant literature from the field of Small Group Research the most recent research in this field points to the fact that although researchers have converged on a view of teams as 'complex, adaptive, dynamic systems' existing in particular contexts and performing across time empirical research is yet to show such dynamics in detail (Ilgen *et al.*, 2005). Our characterization of bridging as interactional and continuity-building processes supports this point of view and sheds light on its qualitative richness. For example, although the types of bridging practices that we have described could be seen as transition processes within temporally-based models such as that of Marks, Mathieu and Zaccaro in which team processes are differentiated as 'action' processes (e.g., *monitoring progress, monitoring systems, team monitoring, and coordination*), 'transition' processes (e.g., *mission analysis formulation and planning, goal specification, and strategy formulation*), and 'interpersonal' processes (*conflict management, motivation and confidence building, and affect management*) (Marks *et al.*, 2001), however we have shown that the separation between action and transition processes might not be adequate in all contexts. For contexts such as VMT and other online communities of interest and learning where processes such as those related to *planning, goal specification and strategy formulation* are deeply embedded

in the self-defined trajectories of groups evolving over time instead of programmatically separated as they might be in formalized organizations, we have shown how “*action*” and “*transition*” processes are deeply embedded within interpersonal processes which cannot be easily separated from them. The social organization of bridging activities, as we have shown, provides the underlying structure for group activity over time and is, at the same time, the emergent result of group interaction oriented toward sustaining knowledge building. We will come back to our reflection on this aspect of our analysis of bridging interactions in the next section.

Our analysis of the four bridging practices in VMT has resulted in their characterization as interactional processes which can describe the conditions of sustained knowledge building in this context in similar ways that other interactional processes such as elaboration, explanation, negotiation, argumentation, co-construction, and common ground have been postulated as explanatory of collaborative learning within the field of CSCL (Dillenbourg *et al.*, 1996). However, our analysis shows bridging processes as diachronic processes that go beyond the scope of most of these candidate interactional processes. Despite the possible similarities that bridging practices such as reporting may have with processes documented in CSCL research such as self-directed or other-directed explaining, these have been most often derived from dyadic interactions and still assume a perspective centered on the individual as the source of pre-existing knowledge. Bridging practices as described by our research might be closer to processes such as co-construction and negotiation although these have almost always been investigated in CSCL within local, single-episode phenomena. Moreover, co-construction of new knowledge, as we have argued, is not the only relevant dimension of bridging interactions but, instead, these practices are related to the integration of three central dimensions of groups: knowledge artifacts, the organization of participation, and sequentiality and temporality. Our description of bridging practices enhances the scope and nature of co-construction and negotiation process so as to integrate these three dimensions especially within the interactions that involve multiple parallel teams participating in collective activity that goes beyond single collaborative episodes. We will come back to this implication in Chapter 6 when we discuss our contribution to knowledge. Similarly, bridging practices are complementary to CSCL research where longer sequences of interaction have been the focus of inquiry but where processes at the level of the community of individuals

have taken precedence to the study of group processes contributing to knowledge building. For instance, in the study of progressive problem solving in CSCL and the theory of Knowledge Building (Scardamalia, 2002) some of the community-level 'principles' that have been advanced to characterize successful knowledge building (e.g., *idea diversity, collective responsibility, epistemic agency, and symmetric knowledge advancement*) and which have been usually associated with individual contributions to the community discourse can also be linked to the group-level processes that we have investigated under the bridging construct and which exemplify the actual processes through which progressive knowledge building is achieved by small-groups situated in an online community over time.

Finally, although Carl Weick's model of Sensemaking in Organizations is centrally concerned with the discontinuities between intersubjective interaction and the control exerted at the level of the organization to achieve "generic-subjectivity" and enforcing stability, the interactional dynamics of bridging practices related to episodic and participation discontinuities in VMT and presented in our findings offer a few possible extensions to this model. Despite the fact that in VMT there isn't necessarily a 'controlling' role comparable to that of those in charge of managing or organizing in the kinds of entities analyzed by Weick, bridging as defined by our findings represents a set of practices through which teams can be seen to be managing their own movement between intersubjectivity and generic intersubjectivity. In Weick's model this movement appeared more often linked to controlling or organizing entities and not to the "intimate" collectivities which were seen to produce innovation. In our analysis of bridging it is precisely the collectivity whose synchronic and situated interaction is extended beyond a single episode of knowledge building who, in turn, attempts interactionally to establish such generic intersubjectivity for the team over time and, in some cases, for other teams. In other words, we argue that sustained teams over time can also bridge intersubjectivity and the generically intersubjective in more egalitarian contexts such as VMT oriented to collaborative knowledge building. Although our findings directly support Weick's perspective that externalization and subjective internalization of knowledge and practices from the inter-subjective world are never perfect or complete our analysis does not identify, as Weick does, that the loss of understanding when the inter-subjective is translated into the generic inter-subjective requires necessarily that organizational forms (other than the team's own forms of organizing their own activity) to manage this loss by "keeping it small and allowing it to be negotiated." It is possible, however that if such

level of participation was available in VMT, such as for instance a set of active facilitators reviewing and actively shaping the activities of the teams, that such discontinuity and the management of the 'tensions' between inter-subjective innovation and generic intersubjective control might constitute one of the central functions of such entities. We will explore more the implications of our findings for the framing of individuals, small groups and the collectivity of VMT as part of bridging activity in the next section.

5.2. Positioning dynamics in VMT

Often, research studies treat individuals within groups and collectivities themselves as taken-for-granted or unproblematic actors such as speakers and recipients. Similarly, research often treats recurrent collectivities as established conglomerates of individuals without attending to the ways that a collectivity's relevant history or its projected future helps constitute it as such. In contrast, ethnomethodology-oriented analyses of conjoined participation have argued that various units of social organization can be approached as 'endogenous' to actual, particular occasions, situated within the course of action, and consequential for subsequent action (Gordon, 2003; Lerner, 1993). Our analysis of episodes of bridging activity within VMT took the social organization of participation in this context as a primary focus of analysis and, through the study of the bridging practices enacted by teams over time, illustrates the dynamic ways in which individuals, sub-groups and whole groups are actively constituted as interactional entities and oriented to particular knowledge-building trajectories. In both of the design cases analyzed, bridging activity was related to practices through which an individual participant, a small group (almost always an undifferentiated collectivity), and, in a few cases, the collectivity of VMT teams, were constituted as having or not having a certain set of possible actions and relations to knowledge artifacts situated within the trajectory of activity of a team over time. We have labeled this aspect of bridging interactions "positioning" to refer to the conjoined ways in which teams locate actors and knowledge resources in relation to each other. Team interactions within bridging episodes structured the participation of such individuals or collective actors around particular ongoing activities such as continuing prior work on a problem, assessing the relevancy of reports of prior work, presenting possible courses of action, or linking the work of a team to the ongoing trajectory of work of another. This

dimension of bridging activity illuminates the dynamic way in which ongoing, contingent and unfolding interaction is organized by participants in ways that, in turn, organize the relationships among actors, resources, and situated temporal frameworks.

Using the lens of Positioning Theory, our analysis of how individuals, small groups and the collectivity of teams were constituted in VMT as part of bridging activity (Section 4.2) showed that dynamic configurations of positions involving individual participants, small groups and the collectivity of VMT teams constitute the teams' evolving co-construction of reasoning routines and other forms of joint participation uniquely related to knowledge-building activities that link synchronic episodes of collaboration with longer participation in VMT. Reporting, reconstructing, or projecting problem-solving work allowed teams to locate and individual or a small group's position in relation to the unfolding of such activities and its connection to past or future activities. In addition, cross-team bridging allowed teams, in a few cases, to locate an undifferentiated aggregated collectivity of several VMT teams or to constitute several VMT teams in relation to each other's trajectory of problem-solving. However, in pursuing this analysis, we determined that Positioning Theory lacked an account of how knowledge artifacts figured in the dynamic ways in which participants attempted positioning in VMT. Collaborative knowledge building interactions of the type characteristic of VMT involve the manipulation of task resources and the creation of reasoning artifacts that play a central role in how a group manages its participation in joint activity. A given problem, for example constitutes a set of resources, graphical or textual, which a group of problem solvers needs to make sense of, manipulate, transform, and complement with possible new resources that could advance their knowledge building. Within bridging episodes, access to these resources and to possibilities for action related to such resources were not allocated symmetrical across all participants in an interaction. As we saw in our analysis of bridging cases in Sections 4.1 and 4.2, VMT teams engaged in activities that positioned individual participants and collectivities in specific ways in relation to such knowledge resources. Addressing this type of positioning activity is necessary to fully account for the types of interactions observed in VMT.

In the same way that we reflected on the apparent quantitative differences in the distribution of instances of bridging across the two designed cases studied, Table 18 also lends itself to a similar reflection (See also Appendices E through G for

all instances of positioning within bridging episodes across both design cases). Bridging activity that constituted individuals explicitly within the trajectory of action of a team appeared considerably less frequently (10 instances) than that oriented to constituting small groups (55 instances) in both design case studies. This might be seen as to validate the fact that bridging represents, primarily, a collective orientation to action which only in a few particular cases makes it relevant for teams to orient to the actions and possibilities for action of differentiated individuals who are seen as explicitly linked (via reporting and collective remembering activity, primarily) to particular problem-solving resources (e.g., proposals, past solutions, etc.). Interestingly, instances of individual positioning decreased in Design Case Two perhaps indicating that the stability of the teams in this design case and their more frequent orientation to bridging offered an even stronger orientation to collective action and collective attribution of action. Positioning of the collectivity of teams was directly associated with cases of cross-team bridging and, as such was only observed in Design Case Two where this bridging practice emerged, as we have discussed before, out of the features of the activity system that characterize such design case. The relationship between the three forms of positioning and the four bridging practices documented is summarized in the figure below:

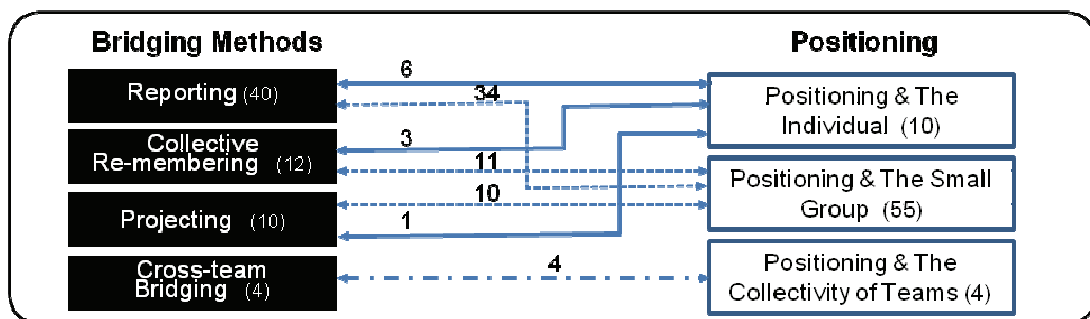


Figure 26. Mapping of Instances of Bridging Methods and Positioning.

In contrast to the frequent perspective in Small Group Research and other fields concerned with the study of groups that the interpersonal or social aspects of group dynamics can be separated from task-oriented activities, our findings highlight the ways in which, at least within bridging episodes, the social organization of collective action provides the underlying structure for a team's knowledge building activity over time. For instance, as we have shown, the interactional organization of a team's reconstruction of prior work actually structures knowledge artifacts and their current use within collective re-membering episodes. Similarly, the way a team organizes the reporting of prior activity constitutes the temporal framework through

which their current actions are to be oriented to (i.e. as past and current activities). As a result of this close interaction between the organization of participation, the creation and use of knowledge artifacts and the constitution of temporality within bridging episodes, we have found it to be very productive to think of these three dimensions as constituting three central dimensions of the interactional field that defines bridging. We based these observation on William Hanks' concept of the "deictic field" which he defines it as being comprised of the positions of communicative agents and objects of reference and the multiple dimensions whereby the participants define access to and relationships with such objects (Hanks, 2005). As part of bridging activity in VMT, participants constitute, through positioning, *knowledge* and *participation* dimensions threaded as well with the temporality and sequentiality of their constructed trajectories of participation over time. We will revisit this aspect of bridging activity when we discuss continuity in our next section. In addition, our findings complement other research on groups such as Wheelan's model of group development in organizations which gives the relational dimension a more central role by describing for instance, how changes in leadership, trust, power relationships, and external membership disruption can stifle development over time. (Wheelan, 1994, p. 18). Although VMT is a context in which no explicit leadership roles or power relationships are structured or institutionally promoted, the dynamics of positioning that we have described as part of bridging activities document the active ways in which teams manage changes in participation and their potential effects for their knowledge building.

As we mentioned before, a foundational research theory in the field of Computer-Supported Collaborative Learning and of Situated Cognition lies on the research program outlined by Vygotsky's socio-historical psychology (Vygotsky, 1930/1978, 1934/1986; Wertsch, 1985). Vygotsky's genetic law of cultural development suggests that higher psychological functions in humans originate at the interpsychological level and only later, through a long series of developmental events, these functions are internalized by the individual. Our analysis of positioning within bridging practices illustrates candidate processes through which the social organization of participation in sustained knowledge building could be seen to provide not only an interpsychological scaffold for the development of intrapsychological processes such as those related to the purposeful reconstruction of past activities (i.e. memory's work) but, also, to contribute to the historical-cultural development of the identity of the individual, the small group, and the collectivity of

teams in VMT. Vygotsky did not explicitly differentiate between the intersubjective level and the cultural or generic intersubjective level in the way that, as we commented in the previous section, Weick and others do when postulating the mediating role that organizations play between 'intimate' interactions and activity within a larger collectivity. Perhaps as we have noted, this is due to the difference in focus from informal interactions and such formal contexts of hierarchical action commonly characteristic of organizations. However, positioning dynamics within bridging activity show that it is not only at the higher level of the organization that interactional activity orients to the development of, as Weick puts it, understandings that can be "picked up, perpetuated, and enlarged" by people who did not participate in the original intersubjective construction but, also, these activities can be located in the actual longitudinal organization of sustained participation of individual teams in VMT. In addition, our analysis can be seen to support the point made by the theory of Situated Learning which argues for "the relational interdependency of agent and world, activity, meaning, cognition, learning, and knowing" (Lave & Wenger, 1991 p. 50) and the related claim of Group Cognition which characterizes small group interaction as the "engine" of knowledge building where the collaborative knowledge of a team can be internalized by individual members and later on transformed and externalized in their communities as "certifiable knowledge" (Stahl, 2006a p. 16). As our analysis has shown bridging practices illustrate the interdependency between the situated individual and the small group interacting over time in VMT and organizing collective participation around the evolution of collaborative knowledge.

5.3. Continuity in Sustained Collaborative Knowledge Building

Our analysis of bridging activity in VMT shows how these interactional practices allowed teams to constitute over time their one situated temporal field which built on and expanded the sequentiality of their synchronous interactions. Bounded episodes and constructed sequences of interaction were used by teams to manage their dynamic patterns of participation and to constitute and expand specific knowledge artifacts, e.g., discovered rules, possible future problems, related problem observations, etc. Through this aspect of bridging activity individuals and collectivities are positioned in particular temporal frameworks and knowledge artifacts get constituted in networks of meaning over time (See Sections 4.1.5. and 4.3). The diagram below, for instance, represents the way that Team Two in Design Case One

established explicit linkages across sessions and episodes of collaborative action over time through the use of bridging practices.

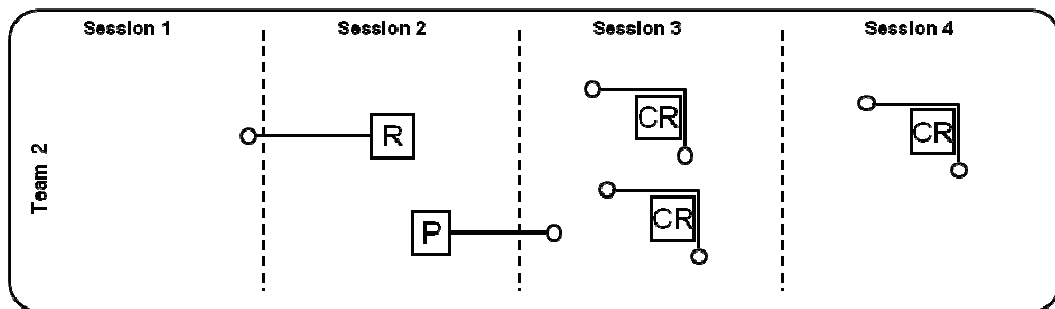


Figure 27. Team Two's bridging instances over time.

Although in this schematic representation we cannot see the interactional richness of Team Two's use of bridging practices, the diagram illustrates this team's overall diachronic sequencing of reporting, projecting and collective remembering practices and their orientation to constructing their collective trajectory of participation in ways that unite the elements of their own past and present experience with present and future possibilities for action. A similar schematic representation for Team A's trajectory in Design Case Two illustrates, also at a high level, a richer set of linkages and a wider engagement with bridging activity.

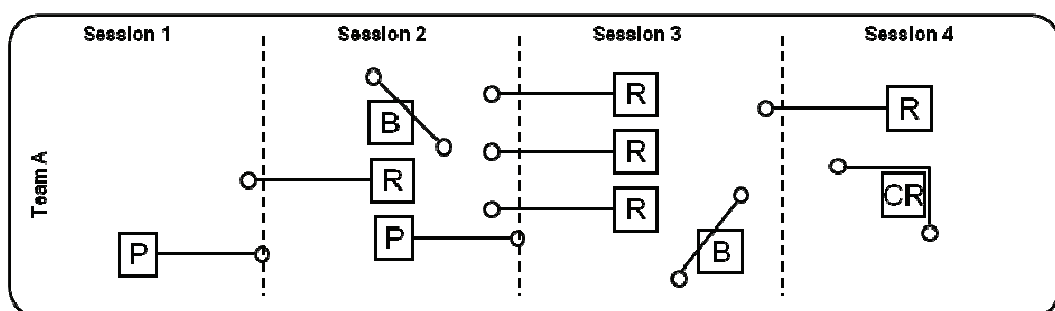


Figure 28. Team A's bridging instances over time.

It is in this sense that we have argued that bridging practices are central to the creation and maintenance of a "Joint Knowledge Field" —an extended interactional space of collaborative knowledge building with three dimensions that are of primary concern to participants: knowledge artifacts, positioning in participation, and temporality. The interactional relationships among these elements are critical to constituting not only the diachronic continuity of knowledge building for an individual

virtual team over time but also, what we have labeled the “expansive” continuity of the larger collective of virtual teams (Section 4.3). This distinctive orientation to continuity was characteristic of Design Case Two and is also schematically visible in the diagram of bridging episodes for Teams B and C provided below.

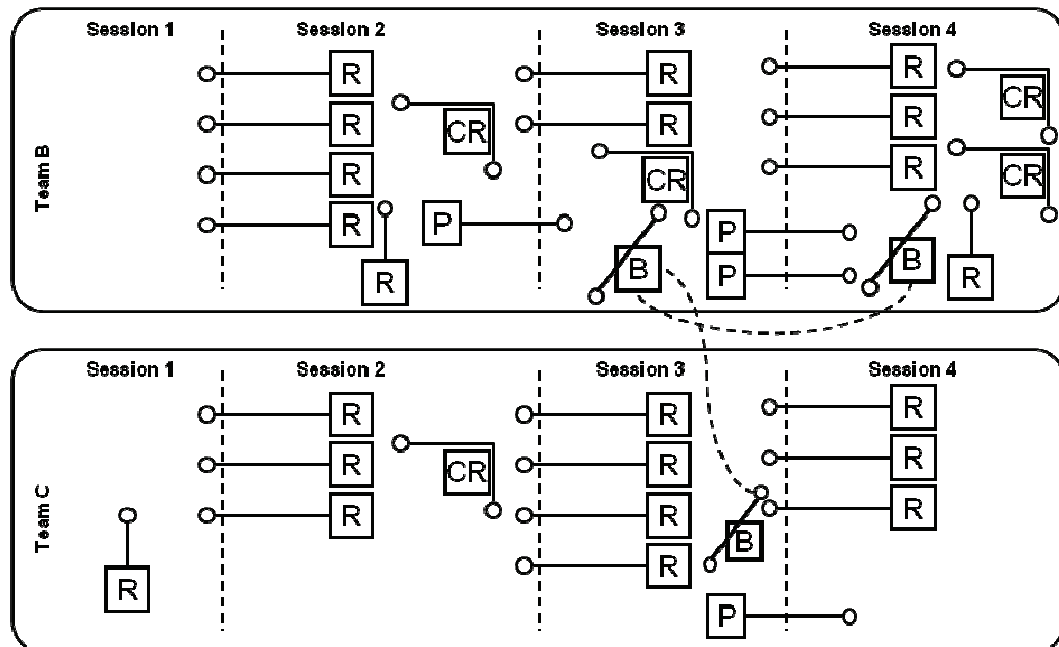


Figure 29. Team B's and C's bridging instances over time.

Not only do the individual trajectories of these two teams appear richer in episodes of bridging activity when compared to other teams but they also depict how linkages across the trajectories of two teams opened up opportunities for a different type of continuity to be constituted. By engaging in cross-team bridging, Teams B and C constituted each other (mostly as undifferentiated collectivities) with a sense of a common evolving identity anchored on their sustained and interrelated episodes of collaborative knowledge-building activity and expanded it as well to the trajectories of other collectivities. As we have noted previously, although this type of continuity was numerically not as frequent as the practices oriented to diachronic continuity, team activities related to constituting expansive continuity could be seen to have a unique and consequential value in that they represent the actual interactional potential of a conglomerate of teams oriented, in interrelated ways, to common knowledge building.

As we noted previously, the choice of the word “expansive” is, at least in part, motivated by Engeström’s notion of expansive learning (1987). In our analysis of VMT interactions, however, expansion alludes to the interconnection of several trajectories of collaborative knowledge building which, over time and through bridging activity, constitute a collective field of possible participation for all individual and collective participants in relation not such knowledge building. For Engeström’s, the dimension in which the expansion takes place is that of human competence and the ultimate outcome of expansive learning are new forms of activity. Similarly, in the fields of CSCW and related fields, the notion of ‘articulation work’ —the ‘meshing of tasks, actors, and efforts (Strauss, 1985)— resonates with our vision of expansive and diachronic continuity. The actual work of articulating activities, actors, and object, is clearly represented by the dynamics of bridging activity in VMT. The backdrop in which this work takes place is not the passage of abstract time but the active and purposeful construction of temporal “rhythms” and trajectories closely related to the participants’ ongoing practices” (Orlikowski & Yates, 2002). Similarly, in the study of group creativity, Sawyer (2003) had proposed that individual groups engage in both synchronic and diachronic dimensions of interaction by using improvisation and artifact mediation to sustain collective creations over time. Our analysis expands this framework by suggesting that multiple teams can enhance the possibilities of their creativity to include a larger realm of action.

6. CONCLUSIONS AND CONTRIBUTION TO KNOWLEDGE

At the inception of our research, we stated that one of our core interests was to advance current knowledge, from the perspective of situated cognition, regarding collaborative knowledge building over time. In exploring the practices that VMT teams engaged when orienting to episodic and participation discontinuities we have attempted, in fact to take on the challenge of situative research and describe to what extent and in what ways practices such as those related to collective reasoning, and the creation and manipulation of knowledge artifacts are constituted in and through the social, cultural and material aspects of situations. In this final chapter, we attempt to integrate the results presented in the previous chapters within the evolution of the concept of the problem space in the study of Situated Cognition within the Learning Sciences.

6.1. Emerging Theory: Sustaining Collaborative Knowledge Building in VMT

The original concept of "*problem space*" was advanced within the information processing perspective on individual problem solving by Allan Newell and Herbert Simon (Newell & Simon, 1972). Newell and Simon were concerned with building a "process theory" describing the performance of individual "intelligent adults in our own culture," working on short and "moderately difficult problems of a symbolic nature," (p. 3) where "motivation is not a question and emotion is not aroused" (p. 53). To achieve this, the authors explicitly excluded group activity as well as "long-term integrated activities" involving multiple episodes of action over longer periods of time (p.4). Central to this theory is the idea that to solve a task or problem, one must "adapt" to the environment presented by the problem (the "*task environment*") by constructing an internal representation of the problem's relevant elements (a "*problem space*"). The concept of *problem space* was introduced as a "neutral and objective way of talking about the responses of the subject, including his internal thinking responses, as he goes about dealing with the stimulus situation" (p.59).

This space is commonly presented as a graph with nodes and links and is mostly viewed as internal or mental although sometimes related to external resources as well (e.g., Kotovsky & Simon, 1990). A person is assumed to understand a task correctly when she has successfully constructed a problem space

representation containing or “encoding”: a set of *states of knowledge* including the *initial state* of the problem, the *goal state*, and the necessary intermediate states, as well as *operators* for changing from one state into another, *constraints* determining allowable states and moves, and any other encodings of knowledge such as problem solving heuristics and the like (pp. 59, 810). The problem space of the Towers of Hanoi problem, one of the most classical examples of a problem within this theory, is presented in Figure 30

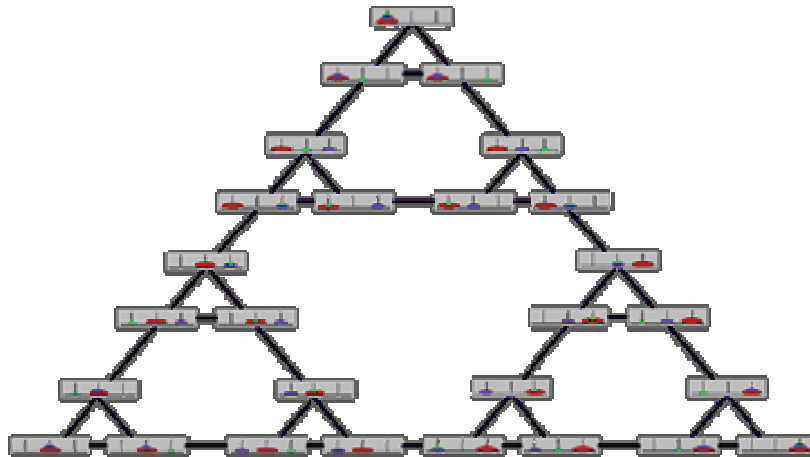


Figure 30. Tower of Hanoi's problem space.
Adapted from (Newell & Simon, 1972).

Problem solving proceeds as the subject works from the initial state in her mental space in a process commonly characterized as “search” on the problem space. Representation and search, as activities, become the central phenomena theorized and, search methods such as *breadth first*, *depth first*, *branch and bound*, *heuristic best first*, etc. have been offered as descriptions of the processes followed by human problem solvers in different contexts (Newell, 1980). Notice how the sequential aspect of this search process is usually left completely encoded within the set of search strategies and rarely investigated as a central concern of the problem solver. In addition, from this perspective, the foundational activities which contribute to the creation of a problem are, in fact, poorly understood. Considerable criticism has been directed of this model (Kirsh, 2009) while others have opted for revising or expanding the model to accommodate other settings of human activity. As a recent review of psychological research on problem solving stated, “problem-solving research has not revealed a great deal about the processes involved in problem recognition, problem definition, and problem representation (Pretz *et al.*, 2003, p. 9). It is only after a *problem space* has been constructed internally in the mind of a subject, at least partially, that one can start to trace the solution process as a *search process*. However, using the possibility of observing group interactions to explore

these early phases of problem solving and the evolution of such interactional activity time can inform us a great deal about how problem spaces are constituted in interaction and how some of the features of collaborative activity contribute to this important phase. Our research results indicate that VMT teams actually construct and explore a rich interactional problem space synchronously and diachronically as we will argue in the rest of this chapter as we continue to trace the evolution of the concept of the problem space.

Joint Activity and Joint Problem Spaces

Joint activity, the kind of activity that takes place when multiple participants engage with each other, offers a unique context for the investigation of human reasoning. Not only are the reasoning processes that characterize joint activity visibly distributed across multiple participants (e.g., Hutchins, 1995; Salomon, 1993), but they are also highly shaped by the way that material and conceptual artifacts are integrated into activity (e.g., Perkins, 1993; Schwartz, 1995) and the way that activity evolves over time (e.g., Brown & Campione, 1994; Lave & Wenger, 1991; Scardamalia & Bereiter, 1991). For instance, in Roschelle (1992) and Teasley & Roschelle's (1993) highly influential publications, the authors analyze dyads using a physics software simulation to explore concepts such as velocity and acceleration, and propose the notion of a *joint problem space* (JPS) to explain how collaborative activity gets structured in this context. This "knowledge structure" integrates *goals*, *descriptions of the current problem state*, and *awareness of available problem solving actions*. In addition, this space is characterized as being "shared" in the sense that both members of the dyad oriented to its construction and maintenance.

At first glance, the concept of a "*joint problem space*" may appear strongly related to the original concept of "*problem space*" advanced within the information processing perspective on individual problem solving by Newell and Simon. However, the characterization of the *joint problem space* advanced by Teasley and Roschelle, despite superficial similarities, goes beyond simply being a collective reformulation of the information processing concept of *problem space*. From their perspective, social interaction in the context of problem-solving activity occurs *in relation to* a shared conception of the problem which is in itself *constituted through* the collaborative process of coordinating communication, action, and representation in a particular context of activity; not restricted to or primarily driven by individual mental states. This perspective as well as the authors' method of analysis are closely

related with the ethnomethodological position regarding the nature of shared agreements as “*various social methods for accomplishing the member's recognition that something was said-according-to-a-rule, and not the demonstrable matching of substantive matters*” (Garfinkel, 1967, p.30). A common understanding becomes a feature of an interaction (an operation, in Garfinkel's terms) “*rather than a common intersection of overlapping sets*” (Ibid). A "shared agreement" or a "mutual conception of the problem" is then the emergent and situated result of the participant's interactions tied to their context of activity. In the words of Roschelle and Teasley, it is “*the coordinated production of talk and action by two participants (that) enabled this construction and maintenance (of the joint problem space) to succeed.*”

Beyond the sole identification of relevant resources, an effective account of the problem solving process requires a description of the fundamental activities involved. Roschelle (1992) presents the most compelling description of such activities associated with the joint problem space when he states that the process of the students' incremental achievement of convergent meaning through interaction can be characterized by the four primary features of activity synthesized in Figure 31.

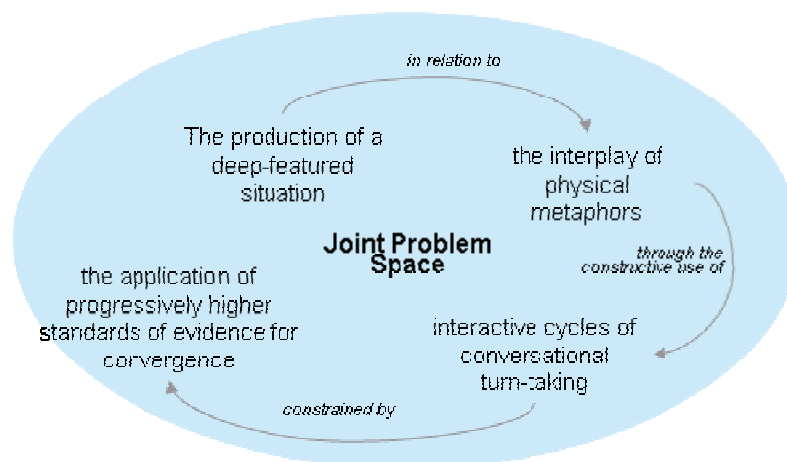


Figure 31. Primary features of the process of achieving convergent conceptual change. From (Roschelle, 1992).

Testing the *joint problem space* construct empirically requires, then, the ability to recognize these features in interaction. As part of the bridging interactions that we have described within the Virtual Math Teams online community participants were often challenged with the creation of that “deep-featured situation” and such orientation was not restricted to a single episode of collaboration but extended over time and involved, in a few cases, other participating teams as well. Through bridging practices, VMT teams often identified and appropriated specific elements of a prior

task, and purposefully and iteratively structured them into a new problematic situation. Resources such as graphical manipulations (e.g., grid annotations, case diagrams, etc.), related mathematical concepts (e.g., straight distance, triangular numbers, permutations, recursive functions, etc.), constraints (e.g., you can only travel on the lines of the grid, break it down, etc.), or analogous problems were used to construct and evolve a set of possible inquiries about the grid world in Design Case One. Similar constructions were clearly seen in Design Case Two as well. We can characterize these constructions as creating a “*deep-featured situation*” in the sense that they embody the sustained exploratory activities of the participants over time. As an example, many groups in Design Case One promptly oriented to finding the shortest distance between points A and B in the grid world, a familiar problem to school-aged students. Some purposefully attended to the constraints of the grid world while others ignored them and proceeded to explore diagonal distances. Building on this initial problem, many groups embarked on the problem of finding the number of shortest paths between any two points on the grid. Figure 32 contains some snapshots of the artifacts the different groups created to help constitute a problem from the original situation.

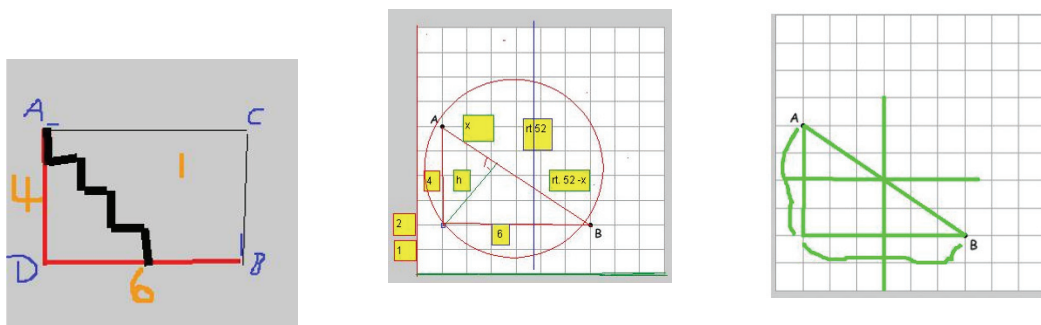


Figure 32. Snapshots of grid-world problem resources created by VMT groups.

In the two VMT design cases investigated, potential problems were constantly defined as sets of artifacts with specific properties sometimes constituted as “discoverables” and through bridging, often, reconstituted as reportables, reconstructables or projectables. Multiple trajectories of reasoning were explored, sometimes in concerted fashion, others in parallel. A central aspect of the group’s activity was concerned with “adding structure” to the resources used to think with. From an interactional perspective it certainly does not seem appropriate to characterize such activities as search, although, on the other hand, one could certainly agree that a “space” or network of problem objects and relations was being constructed and that specific features of the resources available were being attended

to. Although representations emerged out of these interactions, they were not preconditions for the joint work of the groups. Metaphors played a role in some instances but collective positioning, or socially organized ways of viewing and manipulating knowledge artifacts, seemed more interactionally relevant. In this context, the groups did not necessarily orient to the application of “progressively higher standards of evidence for convergence” as Roschelle and Teasley suggested but, within those teams that seemed more intensively engaged with the grid world and the patterns of sticks and squares over time, they seemed to orient strongly to the diachronic and expansive continuity that we have described in prior sections. Next, we continue to trace the evolution of the concept of problem space within the Learning Sciences and extend our empirical exploration of the relevant elements that characterize engagement with problem-solving and knowledge-building activity VMT.

A Dual Model of Collaboration: Content and Relational Spaces

Barron (2000; 2003) investigated triads of 6th grade students engaged in face-to-face, collaborative mathematical problem solving. Her analysis proposed that it was necessary to differentiate between the *social* and *cognitive* aspects of the interactions observed and investigate the ways in which both are interwoven in the establishment of a joint problem-solving space (especially, when attempting to characterize successful and unsuccessful collaborations). Both cognitive and social aspects were, in a sense, integrated in the features of collaborative activity described by Roschelle (1992). However, Barron’s analysis illuminates a new set of specific activities that the participants engaged in, when attending to social and cognitive factors in the development and maintenance of a “between-person state of engagement” (p. 349). Interestingly, patterns of interaction related to a group’s inability to attend to their common views of the problem or to coordinate their reciprocal participation were particularly salient in groups that failed to achieve and maintain “mutual engagement.” As a result, such groups were unable to capitalize on the ideas and proposals of their members (p. 311). Based on this, Barron proposes a *dual-space model* of collaboration integrating a *content space* pertaining to the problem being solved and a *relational space* pertaining to the ways that participants relate to each other (Figure 33).

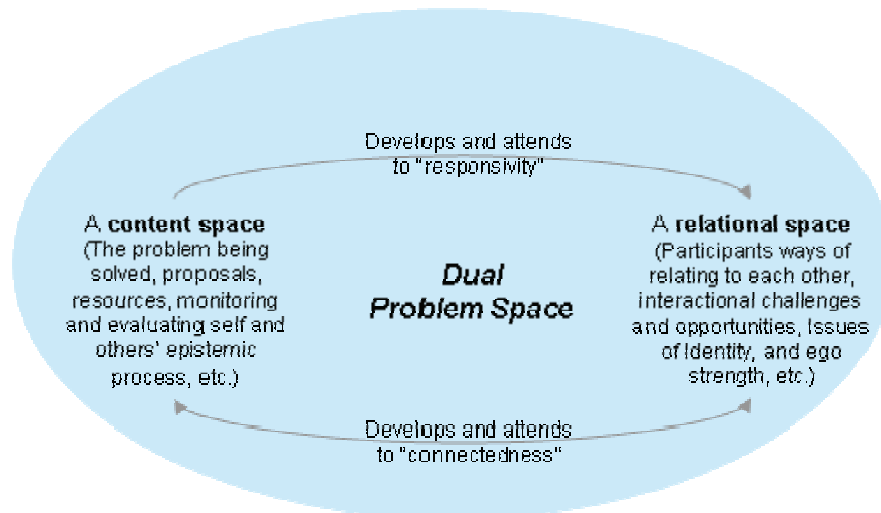


Figure 33. Primary Barron's Dual Space Model of Joint Activity. From (Barron, 2003).

These two spaces can be conceptualized as separate aspects of the team's experience or as mutually constitutive team dimensions in which participants simultaneously attend to and develop such spaces. As we have commented before, similar 'dual' schemes have been proposed, among other areas of study, within the field of Small Group Research. For instance, Robert Bales (1953) integrated these two aspects of a group's life in his principle of "equilibrium" which states that a group continuously divides its attention between *instrumental* (task-related) needs and *expressive* (socio-emotional) concerns. More recently, McGrath (1991) suggested in his "Time, Interaction, and Performance" theory that work groups orient toward three "inseparably intertwined" functions: working on the common task together (*production function*), maintaining the communication and interaction among group members (*group well-being function*), and helping the individual member when necessary (*member support function*, p. 151). Poole (2004) also suggested that group decision-making discussions can be characterized by three intertwining "tracks" of activity and interaction: *task progress* (goal oriented), *relational track* (interpersonal relationships), and *topical focus* (issues and concerns). Interspersed within these tracks are *breakpoints*, marking changes in the development of strands of work.

The power that these 'dual' proposals have to advance our understanding of group activity lies, however, not in their ability to appropriately label dimensions of group interaction but in their ability to characterize and describe the practices that groups engage in. Consequently, the value of Barron's proposal, in our opinion, lies on her careful way of calling our attention to the interactional methods employed by the students in orienting to and constituting the "responsivity" and "connectedness"

(p. 353) of their content and relational spaces while engaged in learning activity. In her descriptions, we see the participants' degrees of competence in attending and relating to their own "epistemic process" while "tracking and evaluating others' epistemic processes" (p. 310). Similar descriptions have been provided by Engle and Conant as "positioning" (Engle, 2006; Engle & Conant, 2002). Based on our research, next we extend the notion of the dual problem space in light of our findings regarding online, collaborative interactions involving longitudinal sequences of joint activity and multiple teams. We explore whether in which the concepts of "joint problem space" and "dual problem space" are sufficient to understand them.

Continuity of Joint Problem Spaces in Virtual Math Teams

Undoubtedly, the difficulty of constructing and maintaining a "cognitive" and "social" joint problem space—the intersubjective space of interaction emerging from the active engagement of collectivities in problem solving— represents a central challenge of effective collaborative knowledge building and learning. Several studies in addition to Barron's have shown that what determines the success of the collaborative learning experience is the interactional manner in which this intersubjective problem space is created and used (Barron, 2003; Dillenbourg *et al.*, 1996; Hausmann, Chi, & Roy, 2004; Koschmann, Zemel *et al.*, 2005; Wegerif, 2006). Furthermore, the complexity of the challenge of maintaining a joint problem space rises when, as in many naturalistic settings, joint activity is dispersed over time (e.g., multiple episodes of joint activity, 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, as we have shown, requires that co-participants "bridge" multiple elements of their interactions continuously as they interact over time.

As we have seen in Chapters 4 and 5, teams participating in VMT engaged in multiple, collaborative sessions over time and worked on several related tasks over time. In some cases, teams also came in contact with the work of other teams. Our analysis of bridging practices identified four methods aimed at overcoming discontinuities emerging from the multiple episodes of interaction and the related changes in participation. Our analysis of the dynamics of bridging activity echoes the construction and maintenance of a "*joint problem space*" (Teasley & Roschelle, 1993) and also agrees with the proposal that such a space integrates "*content*" and

“*relational*” dimensions (Barron, 2003). However, our analysis of bridging activity indicates that a third element of interaction reoccurred as a central resource and a relevant concern of the participants: The temporal and sequential unfolding of activity. This third element present in episodes of bridging activity captured our attention both because of its centrality in the interactions analyzed as well as its novelty within the theoretical frameworks considered (See Figure 34)

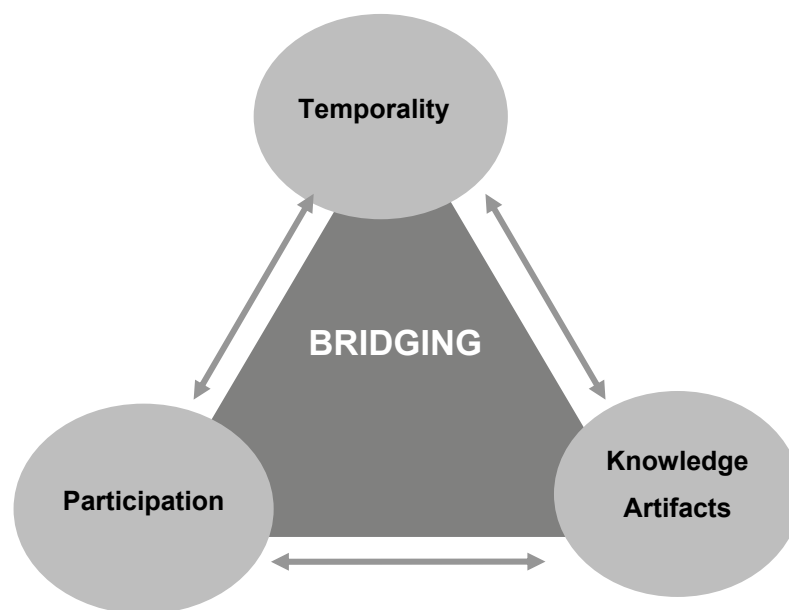


Figure 34. Three interrelated dimensions of the field of continuity in knowledge building.

As we pointed out in Chapters 4 and 5, temporality and sequentiality are constructs that are often taken for granted and which have only until recently recovered their centrality in analyses of joint activity (e.g., Arrow *et al.*, 2004; Lemke, 2001; Reimann, 2007; Sawyer, 2003). Our analysis confirms, however, that in the types of interactions that we observed, participants orient to time and sequences as central resources for the organization of their collaborative activity. As can be clearly seen throughout our analyses of bridging activity in Section 4.1, participants visibly oriented to what was done in a different episode of activity, to the relationship between what was done before and what is being done now, or to what possible actions might be available at a particular moment as related to what had been achieved so far by the same team or by a different one. Not only was this a concern

of the teams, but their own constitution of sequences of episodes provided the structure through which participation was organized and knowledge artifact were linked to each other and expanded. Vygotsky, for instance argue that in addition to reorganizing the visual-spatial field, speech was a crucial cultural tool to create a 'time field' which could be 'just as perceptible and real' as the visual one. By using speech, problem solvers have the ability to direct their individual attention in a dynamic way and coordinate the orientation of others in order to transform and 'detach', as Vygotsky hypothesized, the perceptual field and expand it in time. This is, in fact, the kind of interactional work that we have described VMT teams accomplishing through bridging.

As previously discussed, the concept of "deictic field" developed by William Hanks seems especially useful for defining an integrated view of the three dimensions of bridging interaction observed in VMT. Hanks describes the deictic field as composed first by "*the positions of communicative agents relative to the participant frameworks they occupy,*" for example, who occupies the positions of speaker and addressee as well as other relevant positions (Hanks, 2005). Second, the deictic field integrates "*the positions occupied by objects of reference*", and finally "*the multiple dimensions whereby the former have access to the latter*" (p. 193). From this perspective, participants constitute, through interaction, the relevant relative dimensions whereby they are to manage the positioning of agents and relevant objects of reference. In our analysis, we have confirmed that the *content* and *relational* dimensions are, in fact, relevant to collaborative problem-solving teams. However, in expanding the range of phenomena analyzed to longitudinal interactions, we have also uncovered time and the sequential unfolding of interaction as a third relevant and important dimension of activity. The instances of VMT interactions analyzed in detail in Chapter 4 have illustrated how the interactional field was constituted by the participants so as to include problem-related objects and communicative agents associated with prior and possible interactions and in doing so, participants positioned themselves and those resources within specific participation frameworks. Our central claim has been that this third dimension is essential to understanding collaborative interactions of this type. This dimension is essentially interwoven with the content and relational dimensions of the joint problem space. Such interdependency can be seen as characterizing the longitudinal knowledge building of activity systems like the Virtual Math Teams as we saw in Section 4.3.

The theory of knowledge building (Scardamalia & Bereiter, 2006) and the study of group cognition (Stahl, 2006a) take as one of its central principles the dialectical relationship between social interaction and the construction of meaning. From this perspective, the organization of action and the knowledge embedded in such action is an emergent property of moment-by-moment interactions among actors, and between actors and the activity system in which they participate collectively. The *content* space and the *relational* space, in Barron's terms, are mutually constitutive from this perspective. Group Cognition offers a candidate description for how the dynamic process of building knowledge might intertwine the content and relational spaces: "Small groups are the engines of knowledge building. The knowing that groups build up in manifold forms is what becomes internalized by their members as individual learning and externalized in their communities as certifiable knowledge." (Stahl, 2006a p. 16). On the one hand, the collaborative activity involved in solving a problem can be "spread across" numerous of micro-level interactions. On the other hand, individuals might internalize the meaning co-constructed through interactions and 'sustain' the group cognition by engaging in later individual or group work. In either case, groups are described as sustaining their social and intellectual work by "building longer sequences of math proposals, other adjacency pairs and a variety of interaction methods." (Stahl, 2006d). As we have shown, the collaborative constitution of interactional time and the sequential organization of activity are central resources and aspects of VMT interactions. The analyses we have presented extend our understanding of how groups and larger collectivities interweave their episodes of interaction and suggests that these characteristic features of the longitudinal interactions in VMT allowed teams to construct and maintain a joint knowledge field and to constitute it as continuous in two dimensions: diachronic and expansive. Our analysis gave interaction the full sense ethnomethodologists give it, as the ongoing, contingent co-production of a shared social/material world (Schegloff, 2006) which, as Suchman has argued "cannot be stipulated in advance, but requires an autobiography, a presence, and a projected future (Suchman, 2003)..

Although the attention to dynamic unfolding of interactions provides especially rich descriptions of human activity, it should be noted that the use the three-dimensional interactional field that we have offered to understand knowledge building interactions over time is not free from a range of assumptions. We may be seen as

suggesting that all determinants of structure and agency occur within fluid conversational situations. As such identity, personhood, social structure are always fluid and in the process of construction at each moment by the interactants. A more compromising view would suggest that there are larger structures within a field of social relationships and that such field is comprised of more stable social symbols such as competence and expertise, social status, etc. So while there is a great deal of fluidity to positioning and collaborative knowledge building in the interactional field, some conversations exist in larger fields of power and control that can indeed be changed but are much more resistant to change.

VMT is a unique social field where there has been a concerted effort on the part of the project staff to flatten the field and make participation more self-governing. In this more democratic environment where differential access to knowledge and social capital is limited and all students are given problems that are more open ended and encourage thought. It is certainly the case that students come into the VMT environment with different amounts of mathematical knowledge and a different sense of their own agency around math problem solving. Nevertheless the VMT environment encourages students to share knowledge and engage in open dialogue. In such an environment the concept of positioning is particularly useful in that there is less of a hierarchical institutional structure to limit the forms of interaction that students engage in.

6.2. Future Research

At the onset of our research, we identified the crucial need in the field of Computer-supported collaborative learning and its related fields of understanding from an interactional perspective the practices that teams engaged in when participating in an online community of knowledge building over time. Based on our review of the literature and the analysis of sustained team interactions within the Virtual Math Teams community we proposed that bridging —the purposeful crossing of episodic and participation boundaries made relevant by teams in interaction— was a consequential and often weakly understood aspect of the collaborative user experience of virtual teams and online communities. As a result, these types of interactions had the risk of being unsupported by the kinds of online environments

usually offered for supporting online teams engaged in collaborative knowledge building.

The ultimate goal of the research plan presented in the preceding sections was that of increasing our understanding of how virtual teams establish and sustain continuity of their knowledge-building work. Research in the field of Computer-supported collaborative learning and in related fields interested in understanding the sustained knowledge work of virtual teams had pointed out to the need to better understand the actual interactional processes or practices that teams engaged in throughout their collective activity (Arrow *et al.*, 2000; Dillenbourg *et al.*, 1996; Martins *et al.*, 2004). By presenting a detailed analysis of bridging practices oriented to episodic and participation discontinuities, we have contributed to a foundational framework for the understanding of bridging as an interactional phenomenon central to the establishment of continuity of online collaborative knowledge building. We expect this knowledge to contribute also to be applicable to the design of effective online collaboration environments.

Given the fact that our work was highly localized within the context of the Virtual Math Teams project at the Math Forum online community, our results should have significantly applicability for the members of this online entity. The products of the research work outlined in this report empower the Math Forum to continue to provide richer mechanisms for community participation to its members and to support the complex and diverse knowledge-building work that has characterized it since its inception. In addition, the further development and evaluation of the analytical methods proposed for the study of bridging in team-based online problem solving will be a very valuable outcome to other researchers interested in similar contexts and research questions.

A particular reflection is needed regarding the use of the design-based research framework in combination with the method of chat/interaction analysis. This dissertation offers a test of the theoretical and practical value for interactional studies conducted with this approach. The rich descriptions provided as a result of the use of chat/interaction analysis in combination with the iterative examination of the nature of such team dynamics over different but related activity systems in the two design case studies offered a fruitful model to develop significant theoretical descriptions of bridging interactions, their social order as constructed by participants, and their role

as part of knowledge building sustained over time. By providing detailed analysis of the interactional unfolding of representative instances of bridging activity and inquiring about patterns across teams, sessions, and both design cases, we were able to achieve a level of rigor of analysis that represented well, despite its complex demands on the analysts, the social reality from the point of view of the participants. This experience points to the value of such approach for research conducted in areas that include the learning sciences and the field of computer-supported collaborative learning as well as other areas such as social informatics, information science, and the general study of knowledge building in online environments.

Because continuity in itself is important to the success of many collectivities involved with knowledge work and in particular those related to distributed virtual teams and online communities, the knowledge developed through this research will significantly contribute to emergent theories and designs for collaborative knowledge building. By understanding the structural significance of “bridging,” researchers interested in this area will be better able to understand how members of online collectivities recognize, constitute, and use the boundaries emerging from their interactions (e.g., those related to multiple online sessions, sub-collectivities, and knowledge-perspectives). In addition, designers of online environments will be in a better position to support bridging activities and to produce activity systems (social and technical) that take into account this very consequential phenomenon. In this way, collaboration environments will be in a better position to realize the potential of new forms of collective interaction to generate and advance learning and knowledge in organizations, communities of interest, academic disciplines, societies, and many other types of collectivity.

Some of the limitations of our research include the fact that the sequences of team interaction studied constituted relatively short sequences in comparison to those expected of teams engaged in long-term activity in online communities. For instance, it is possible that additional bridging practices would emerge as teams continue to extend the diachronic trajectory of their participation in an online community. However, the results reported here still constitute a solid foundation over which such further studies can be built. In addition, our close study of the Virtual Math Teams online community in particular requires that the transferability to other contexts and situations be taken with careful consideration. Throughout the presentation of our results we have made a number of observations regarding the ways in which the

different aspects of VMT as an activity system were related to the observed practices. For instance, we described the ways in which the organization of the sequential tasks constructed by the teams based on the open-ended problem situation provided at the start of their collaborative sessions was central to bridging as was access to the Wiki environment through which teams had access to the work of all other teams in Design Case Two. In contexts in which these aspects have radically different configurations, it would be expected that the presence and nature of bridging practices might be significantly different. It is also possible that different types of team members (e.g., teams in corporate organizations or interdisciplinary professional teams) who might not orient to each other in the relatively equal ways that the secondary studies participating in this study did, might present significant patterns of positioning as part of their engagement with bridging activity and their overall orientation to knowledge building. Finally, as we have remarked in several of the sections in Chapter 4, although it was beyond the scope of our research to test the quantitative differences in the engagement with bridging activity across different teams from the point of view of statistical significance, it is possible that these differences have a unique meaning, for instance, associated to aspects of competence with teamwork skills or with the subject matter expertise or to other aspects of the activity system such as those documented in our analysis and related to the availability of a cross-team Wiki space in Design Case Two which made it relevant for teams to engage with the work of other teams indirectly but in a qualitatively different way than in Design Case One. These are aspects that need to be investigated further and which the author intends to consider as possible next steps. The strong foundation presented in this dissertation offers up ample opportunities not only to address these limitations but also to extend the observations made as a result of the analysis of bridging in Virtual Math Teams.

References

- Ackerman, M., Swenson, A., Cotterill, S., & DeMaagd, K. (2003). I-diag: From community discussion to knowledge distillation, *International Conference on Communities and Technologies*.
- Ackerman, M. S., & Halverson, C. (1999). *Organizational memory: Processes, boundary objects, and trajectories*. Paper presented at the In Proceedings of the 32nd Annual Hawaii International Conference on Systems Sciences, HICSS-32, Los Alamitos, CA, USA, 1999. IEEE Computer Society.
- Adams, F., & Aizawa, K. (2007). *The bounds of cognition*. Oxford: Blackwell.
- Amelsvoort, M. v., Andriessen, J., & Kanselaar, G. (2008). How students structure and relate argumentative knowledge when learning together with diagrams. *Computers in Human Behavior, 24* (3), 1293-1313.
- Ancona, D. G., & Chong, C. L. (1996). Entrainment: Pace, cycle, and rhythm in organizational behavior. In B. M. Staw & L. L. Cummings (Eds.), *Research in organizational behavior* (Vol. 18, pp. 251-284).
- Anderson, A. H., Mullin, J., Mcewan, R., Bal, J., Carletta, J., Grattan, E., et al. (2005). Exploring why virtual teamworking is effective in the lab but more difficult in the workplace. In R. Bromme, F. W. Hesse & H. Spada (Eds.), *Barriers and biases in computer-mediated knowledge communication, and how they may be overcome*. (pp. 119-142). New York, NY: Springer.
- Anderson, M. H. (2006). How can we know what we think until we see what we said?: A citation and citation context analysis of Karl Weick's the social psychology of organizing. *Organization Studies, 27* (11), 1675-1692.
- Andriessen, J., Baker, M., & Suthers, D. (Eds.). (2003). *Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments*. Dordrecht, Netherlands: Kluwer Academic Publishers. Computer-supported collaborative learning book series, vol 1.
- Arrow, H., Bouas, H. K., Scott-Pole, M., Wheelan, S., & Moreland, R. (2005). Traces, trajectories and timings: The temporal perspective on groups. In M. Scott-Pole & A. Hollingshead (Eds.), *Theories of small group: Interdisciplinary perspectives* (pp. 313-367): Sage Publications.
- Arrow, H., McGrath, J., & Berdahl, J. (2000). *Small groups as complex systems: Formation, coordination, development, and adaptation*. Thousand Oaks, CA: Sage Publications, Inc.
- Arrow, H., Poole, M. S., Henry, K. B., Wheelan, S., & Moreland, R. (2004). Time, change, and development: The temporal perspective on groups *Small Group Research, 35* (1), 73-105.
- Atkinson, M. A., Cuff, E. C., & Lee, J. R. E. (1978). The recommencement of a meeting as a member's accomplishment. In J. Schenkein (Ed.), *Studies in the organization of conversational interaction*. New York: Academic Press.

- Azmitia, M. (1988). Peer interaction and problem solving: When are two heads better than one? *Child Development*, 59 (1), 87-96.
- Baker, M., Hansen, T., Joiner, R., & Traum, D. (1999). The role of grounding in collaborative learning tasks. In P. Dillenbourg (Ed.), *Collaborative learning: Cognitive and computational approaches* (pp. 31-63). Oxford, UK: Pergamon.
- Baker, M. J. (1991). The influence of dialogue processes on the generation of students' collaborative explanations for simple physical phenomena, *International Conference on the Learning Sciences*. Evanston Illinois, USA.
- Bales, R. F. (1951). *Interaction process analysis. A method for the study of small groups*. Cambridge, MA: Addison-Wesley.
- Bales, R. F. (1953). The equilibrium problem in small groups. In T. Parsons, R. F. Bales & E. A. Shils (Eds.), *Working papers in the theory of action* (pp. 111-161): Free Press.
- Bales, R. F., & Strodtbeck, F. L. (1951). Phases in group problem-solving. *J. Abnorm. Soc. Psychol* (46), 485-495.
- Barab, S. (2006). Design-based research: A methodological toolkit for the learning scientist. In R. K. Sawyer (Ed.), *The cambridge handbook of the learning sciences* (pp. 153-169). Cambridge: Cambridge University Press.
- Barab, S., & Kirshner, D. (2001). Guest editors' introduction: Rethinking methodology in the learning sciences. *Journal of the Learning Sciences*, 10 (1-2), 5-15.
- Barron, B. (2000). Achieving coordination in collaborative problem-solving groups. *Journal Of The Learning Sciences*, 9 (4), 403-436.
- Barron, B. (2003). When smart groups fail. *Journal Of The Learning Sciences*, 12 (3), 307-359.
- Bereiter, C. (2002). *Education and mind in the knowledge age*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Bereiter, C., & Scardamalia, M. (2003). Learning to work creatively with knowledge. In E. D. Corte, L. Verschaffel, N. Entwistle & J. v. Merrienboer (Eds.), *Powerful learning environments: Unraveling basic components and dimensions of powerful learning environments*: Pergamon.
- Bielaczyc, K., & Blake, P. (2006). Shifting epistemologies: Examining student understanding of new models of knowledge and learning. In *Proceedings of the 7th international conference on learning sciences* (pp. 50 - 56). Bloomington, Indiana.
- Bodker, S., & Christiansen, E. (2006). Computer support for social awareness in flexible work. *Journal of Computer Supported Cooperative Work (CSCW)*, 15 (1), 1-28.
- Bowker, G. C., & Star, S. L. (2002). *Sorting things out: Classification and its consequences*. Cambridge, MA: MIT Press.

- Bromme, R., Hesse, F. W., & Spada, H. (Eds.). (2005). *Barriers and biases in computer-mediated knowledge communication, and how they may be overcome*. New York, NY: Springer. Computer-supported collaborative learning book series, vol 5.
- Brooks, A. K. (1994). Power and the production of knowledge: Collective team learning in work organizations. *Human Resource Development Quarterly*, 5 (3), 213-235.
- Brown, A. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences*, 2 (2), 141-178.
- Brown, A., & Campione, J. (1994). Guided discovery in a community of learners. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice* (pp. 229-270). Cambridge, MA: MIT Press.
- Brown, D., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Factors influencing understanding in a teaching experiment. *Instructional Science* (18), 237-261.
- Brown, J. S., & Duguid, P. (1991). Organizational learning and communities-of-practice: Toward a unified view of working, learning, and innovation. *Organization Science*, 2 (1), 40-57.
- Brown, S. L., & Eisenhardt, K. M. (1997). The art of continuous change: Linking complexity theory and time-paced evolution in relentlessly shifting organizations. *Administrative Science Quarterly*, 42, 1 - 34.
- Bunderson, J. S., & Sutcliffe, K. M. (2003). Management team learning orientation and business unit performance. *Journal of Applied Psychology*, 88 (3), 552-560.
- Burt, R. S. (2004). Structural holes and good ideas. *American Journal of Sociology*, 110 (2), 349-399.
- Button, G. (Ed.). (1993). *Technology in working order: Studies of work, interaction, and technology*. London & New York: Routledge.
- Button, G., & Dourish, P. (1996). *Technomethodology: Paradoxes and possibilities*. Paper presented at the ACM Conference on Human Factors in Computing Systems (CHI '96), Vancouver, Canada. Proceedings pp. 19-26.
- Cairns, P., & Cox, A. L. (Eds.). (2008). *Research methods for human-computer interaction*. Cambridge, UK: Cambridge University Press.
- Campos, M. (2004). A constructivist method for the analysis of networked cognitive communication and assessment of collaborative learning and knowledge building. *Journal of Asynchronous Learning Networks*, 8 (2), 1-29.
- Cannon-Bowers, J. A., Salas, E., & Converse, S. (1993). Shared mental models in expert team decision making. In J. Castellan (Ed.), *Current issues in individual and group decision making* (pp. 221-246). Hillsdale, NJ: Erlbaum.

- Carlile, P. R. (2002). A pragmatic view of knowledge and boundaries: Boundary objects in new product development. *Organization Science*, 13 (4), 442-455.
- Carlile, P. R. (2004). Transferring, translating, and transforming: An integrative framework for managing knowledge across boundaries. *Organization Science*, 15, 555-568.
- Chi, M. (2000). Self-explaining expository texts: The dual processes of generating inferences and repairing mental models. In R. Glaser (Ed.), *Advances in instructional psychology* (pp. 161-238). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Chi, M., Siler, S., & Jeong, H. (2004). Can tutors monitor students' understanding accurately? *Cognition and Instruction*, 22 (3), 363-387.
- Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal Of The Learning Sciences*, 6 (3), 271-315.
- Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, 5, 121-152.
- Clark, H. (1975). Bridging. In R. C. Schank & B. L. Nash-Webber (Eds.), *Theoretical issues in natural language processing*. New York: Association for Computing Machinery.
- Clark, H., & Brennan, S. (1991). Grounding in communication. In L. Resnick, J. Levine & S. Teasley (Eds.), *Perspectives on socially-shared cognition* (pp. 127-149). Washington, DC: APA.
- Clark, H., & Schaefer, E. (1989). Collaborating on contributions to conversations. In R. Dietrich & C. F. Graumann (Eds.), *Language processing in social context*. North-Holland: Elsevier Science Publishers.
- Cobb, P., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher*, 32 (1), 9-13.
- Cohen, G. (1996). Memory for discourse: Conversation, texts, and stories. In G. Cohen (Ed.), *Memory in the real world*: Psychology Press.
- Collins, A. (1992). Toward a design science of education. In E. Scanlon & T. O'Shea (Eds.), *New directions in educational technology*. Berlin: Springer-Verlag.
- Dansereau, D. F. (1988). *Learning and study strategies: Issues in assessment, instruction, and evaluation*. New York: Academic Press.
- Davidson, J. E., & Sternberg, R. J. (Eds.). (2003). *The psychology of problem solving*. Cambridge, MA: Cambridge University Press.
- Design-based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, 32 (1), 5-8.
- Dillenbourg, P., Baker, M., Blaye, A., & O'Malley, C. (1996). The evolution of research on collaborative learning. In P. Reimann & H. Spada (Eds.), *Learning in humans and machines: Towards an interdisciplinary learning science* (pp. 189-211). Oxford, UK: Elsevier.

- Diodato, V. P. (1994). *Dictionary of bibliometrics*: Haworth Press.
- diSessa, A. A. (1991). Local sciences: Viewing the design of human-computer systems as cognitive science. In J. M. Carroll (Ed.), *Designing interaction: Psychology at the human-computer interface*. Cambridge: Cambridge University Press.
- Dourish, P. (2001). *Where the action is: The foundations of embodied interaction*. Cambridge, MA: MIT Press.
- Duranti, A. (1998). *Linguistic anthropology*. Cambridge, UK: Cambridge University Press.
- Edelson, D. C. (2001). Design research: What we learn when we engage in design. *Journal Of The Learning Sciences*, 11 (1), 105-121.
- Edmondson, A. C., Bohmer, R. M., & Pisano, G. P. (2001). Disrupted routines: Team learning and new technology implementation in hospitals. *Administrative Science Quarterly*, 46 (4), 685-716.
- Edmondson, A. C., Pisano, G. P., Bohmer, R., & Winslow, A. (2003). Learning how and learning what: Effects of tacit and codified knowledge on performance improvement following technology adoption. *Decision Sciences*, 34 (2), 197-223.
- Edmondson, A. C., & Singer, S. J. (2008). Confronting the tension between learning and performance. *The Systems Thinker*, 19 (1).
- Ellis, D., Oldridge, R., & Vasconcelos, A. (2004). Community and virtual community. In B. Cronin (Ed.), *Annual review of information science and technology* (pp. 145-186): American Society of Information Science and Technology (ASIS&T).
- Engeström, Y. (1987). *Learning by expanding: An activity-theoretical approach to developmental research*. Helsinki, Finland: Orienta-Kosultit Oy.
- Engestrom, Y., & Middleton, D. (1998). *Cognition and communication*. Cambridge: Cambridge University Press.
- Engle, R. A. (2006). Framing interactions to foster generative learning: A situative explanation of transfer in a community of learners classroom. *Journal of the Learning Sciences*, 15 (4), 451-498.
- Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, 20 (4), 399-483.
- Erickson, T., D., S., Kellogg, W., Laff, M., Richards, J., & Bradner, E. (1999). Socially translucent systems. Social proxies, persistent conversation, and the design of babble In *Proceedings of chi 99: Human factors in computing systems*. (pp. 72). New York: ACM Press.
- Erickson, T., & Kellogg, W. (2001). Social translucence: An approach to designing systems that mesh with social processes. *Transactions of Computer-Human Interaction*, 7 (1), 59-83.

- Ericsson, K. A., Krampe, R. T., & Tesch-Roemer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review*, *100*, 363-406.
- Farrell, R., Fairweather, P., & Snyder, K. (2001). Summarization of discussion groups. In *Proceedings of the tenth international conference on information and knowledge management* (pp. 532-534).
- Fisher, B. A. (1970). Decision emergence: Phases in group decision making. *Speech Monographs* (37), 53-66.
- Fitzpatrick, G. (2003). *The locales framework: Understanding and designing for wicked problems*: Kluwer Academic Publishers.
- Foushee, H. C., Lauber, J. K., Baetge, M. M., & Acomb, D. B. (1986). *Crew factors inflight operations iii: The operational significance of exposure to short-haul air transport operations*. Moffett Field, CA: NASA-Ames Research Center.
- Garfinkel, H. (1967). *Studies in ethnomethodology*. Englewood Cliffs, NJ: Prentice-Hall.
- Garfinkel, H. (2002). *Ethnomethodology's program: Working out durkheim's aphorism*. Lanham, MD: Rowman & Littlefield.
- Gasson, S. (2003). Rigor in grounded theory research: An interpretive perspective on generating theory from qualitative field studies. In M. E. Whitman & A. B. Woszczynski (Eds.), *The handbook of information systems research* (pp. 79-102): Idea Group Inc.
- Gasson, S. (2005a). Boundary-spanning knowledge-sharing in e-collaboration, *38th Annual Hawaii International Conference on System Sciences (HICSS'05) - Track 8*. Hawaii.
- Gasson, S. (2005b). The dynamics of sensemaking, knowledge, and expertise in collaborative, boundary-spanning design. *Journal of Computer-Mediated Communication*, *10* (4), article 14. Retrieved from <http://jcmc.indiana.edu/vol10/issue4/gasson.html>.
- Gersick, C. J. (1988a). Time and transition in work teams: Toward a new model of group development. *The Academy of Management Journal*, *31* (1), 9-41.
- Gersick, C. J. G. (1988b). Time and transition in work teams: Toward a new model of group development. *The Academy of Management Journal*, *31* (1), 9-41.
- Gersick, C. J. G. (1989). Marking time: Predictable transitions in task groups. *The Academy of Management Journal*, *32* (2), 274-309.
- Gersick, C. J. G. (1991). Revolutionary change theories: A multilevel exploration of the punctuated equilibrium paradigm. *The Academy of Management Review*, *16* (1), 10-36.
- Gevers, J., Rutte, C., & Eerde, W. v. (2004). How project teams achieve coordinated action: A model of shared cognitions on time. In S. Blount (Ed.), *Time in groups* (pp. 67-85). San Diego, CA: Elsevier.

- Gibson, C., & Vermeulen, F. (2003). A healthy divide: Subgroups as a stimulus for team learning behavior. *Administrative Science Quarterly*, 48 (2), 202-239.
- Gilbert, N. J., & Driscoll, M. P. (2002). Collaborative knowledge building: A case study. *Educational Technology Research and Development*, 50 (1), 59-79.
- Gillam, C., & Oppenheim, C. (2006). Reviewing the impact of virtual teams in the information age. *Journal of Information Science*, 32 (2), 160-175.
- Gittell, R., & Vidal, A. (1998). *Community organizing: Building social capital as a development strategy*. Thousand Oaks, CA: Sage.
- Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. New York, NY: Aldine de Gruyter.
- Goffman, E. (1981). *Forms of talk*. Philadelphia: University of Pennsylvania Press.
- Gordon, C. (2003). Aligning as a team: Forms of conjoined participation in (stepfamily) interaction. *Research On Language And Social Interaction*, 36 (4), 395-431.
- Granott, N., Fischer, K. W., & Parziale, J. (2002). Bridging to the unknown: A transition mechanism in learning and development In N. Granott & J. Parziale (Eds.), *Microdevelopment : Transition processes in development and learning* (pp. 131-156). Cambridge: Cambridge University Press.
- Greenberg, S., & Roseman, M. (2003). Using a room metaphor to ease transitions in groupware. In M. Ackerman, V. Pipek & V. Wulf (Eds.), *Sharing expertise: Beyond knowledge management* (pp. 203--256): MIT Press.
- Greeno, J. (2006). Learning in activity. In R. K. Sawyer (Ed.), *The cambridge handbook of the learning sciences* (pp. 79-96). Cambridge: Cambridge University Press.
- Greeno, J., & The Middle School Mathematics Through Applications Project Group. (1998). The situativity of knowing, learning, and research. *American Psychologist*, 53 (1), 5-26.
- Grudin, J. (1990). *Why CSCW applications fail: Problems in design and evaluation*. Paper presented at the CSCW '90, Los Angeles, CA. Proceedings pp. 85-93.
- Grudin, J. (2002). Group dynamics and ubiquitous computing. *Communications of the ACM*, 45 (12), 74-78.
- Gumperz, J. (1992). Interviewing in intercultural situations. In P. Drew & J. Heritage (Eds.), *Talk at work* (pp. 302-327). Cambridge: Cambridge University Press.
- Hanks, W. F. (2005). Explorations in the deictic field. *Current Anthropology*, 46 (2), 191-220.
- Hare, A. P. (1976). *Handbook of small group research* (2nd ed.). New York: Free Press.
- Hare, A. P. (1992). *Groups, teams, and social interaction : Theories and applications*. New York: Praeger.

- Hare, P. (2003). Roles, relationships, and groups in organizations: Some conclusions and recommendations. *Small Group Research*, 34 (2), 123-154.
- Harré, R., & Lagenhove, L. v. (1999). *Positioning theory: Moral contexts of intentional action*. Malden: Blackwell Publishing.
- Hausmann, R., Chi, M., & Roy, M. (2004). *Learning from collaborative problem solving: An analysis of three hypothesized mechanisms*. Paper presented at the 26th annual conference of the Cognitive Science society Proceedings pp. 547-552.
- Hellström, C., & Hellström, T. (2003). The present is less than the future. *Time & Society*, 12, (2-3), 263-279.
- Heritage, J. (1984). *Garfinkel and ethnomethodology*. Cambridge, UK: Polity Press.
- Herrenkohl, L. R., Palincsar, A. S., DeWater, L. S., & Kawasaki, K. (1999). Developing scientific communities in classrooms: A sociocognitive approach. *Journal Of The Learning Sciences*, 8 (3-4), 451-493.
- Herring, S. C. (2001). Computer-mediated discourse. In D. Schiffrin, D. Tannen & H. Hamilton (Eds.), *The handbook of discourse analysis* (pp. 612-634). Malden: Blackwell.
- Herring, S. C. (2004). Computer-mediated discourse analysis: An approach to researching online communities. In S. A. Barab, R. Kling & J. H. Gray (Eds.), *Designing for virtual communities in the service of learning* (pp. 338-376). Cambridge, New York: Cambridge University Press.
- Hill, W. F., & Gruner, L. (1973). A study of development in open and closed groups. *Small Group Behavior*, 4 (3), 355-381.
- Hmelo-Silver, C., & O'Donnell, A. (2007). *CSCL 2007: Of mice, minds, and society*. Paper presented at the CSCL 2007, New Brunswick, NJ. .
- Hollingshead, A. B. (1998a). Communication, learning, and retrieval in transactive memory systems. *Journal of Experimental Social Psychology* (34), 423-442.
- Hollingshead, A. B. (1998b). Distributed knowledge and transactive processes in decision-making groups. In M. Neale, E. Mannix & D. Gruenfeld (Eds.), *Research on managing groups and teams* (Vol. 1, pp. 105-125). Greenwich, CT: JAI.
- Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.
- Hutchins, E. (1999). Cognitive artifacts. In *MIT encyclopedia of the cognitive sciences*. Cambridge, MA: MIT Press.
- Hutchins, E., & Palen, L. (1998). Constructing meaning from space, gesture and speech. In L. B. Resnick, R. Saljo, C. Pontecorvo & B. Burge (Eds.), *Discourse, tools, and reasoning: Situated cognition and technologically supported environments* (pp. 23-40). Heidelberg, Germany: Springer Verlag.

- Ilgén, D. R., Hollenbeck, J. R., Johnson, M., & Jundt, D. (2005). Teams in organizations: From input-process-output models to IMOI models. *Annual Review of Psychology*, *56*, 517-543.
- Ishii, H., Kobayashi, M., & Grudin, J. (1993). Integration of interpersonal space and shared workspace: Clearboard design and experiments. *ACM Transactions on Information Systems (TOIS)*, *11* (4), 349-375.
- Johnson, D. W., & Johnson, R. T. (1989). *Cooperation and competition: Theory and research*. Edina, MN: Interaction Book Company.
- Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences*, *4* (1), 39-103.
- Kaptelinin, V. (1996). Computer-mediated activity: Functional organs in social and developmental contexts. In B. Nardi (Ed.), *Context and consciousness: Activity theory and human-computer interaction* (pp. 45-68). Cambridge, MA: MIT Press.
- Kirsh, D. (2009). Problem solving and situated cognition. In P. Robbins & M. Aydede (Eds.), *Cambridge handbook of situated cognition*. Cambridge: Cambridge University Press.
- Koschmann, T. (2002). Dewey's contribution to the foundations of CSCL research. In G. Stahl (Ed.), *Computer support for collaborative learning: Foundations for a CSCL community: Proceedings of CSCL 2002* (pp. 17-22). Boulder, CO: Lawrence Erlbaum Associates.
- Koschmann, T., Hall, R., & Miyake, N. (Eds.). (2002). *CSCL2: Carrying forward the conversation*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Koschmann, T., & LeBaron, C. (2003). *Reconsidering common ground: Examining clark's contribution theory in the operating room*. Paper presented at the European Computer-Supported Cooperative Work (ECSCW '03), Helsinki, Finland. Proceedings pp. 81-98.
- Koschmann, T., LeBaron, C., Goodwin, C., & Feltovich, P. (2001). Dissecting common ground: Examining an instance of reference repair. In J. D. Moore & K. Stenning (Eds.), *Proceedings of the twenty-third annual conference of the cognitive science society* (pp. 516-521). Mahwah, NJ: Lawrence Erlbaum Associates.
- Koschmann, T., LeBaron, C., Goodwin, C., & Feltovich, P. (2001, August). Dissecting common ground: Examining an instance of reference repair. In J. D. Moore & K. Stenning (Eds.), *Proceedings of the twenty-third annual conference of the cognitive science society* (pp. 516-521). Mahwah, NJ: Lawrence Erlbaum Associates.
- Koschmann, T., Suthers, D., & Chan, T. W. (Eds.). (2005). *Computer supported collaborative learning: The next 10 years!* : Lawrence Erlbaum Associates.
- Koschmann, T., Zemel, A., Conlee-Stevens, M., Young, N., Robbs, J., & Barnhart, A. (2005). How do people learn? In F. H. R. Bromme & H. Spada (Eds.), *Barriers and biases in computer-mediated knowledge communication*. Amsterdam: Kluwer Academic Press.

- Kotovsky, K., & Simon, H. A. (1990). Why are some problems really hard: Explorations in the problem space of difficulty. *Cognitive Psychology*, 22, 143-183.
- Lacoursiere, R. B. (1980). *The life cycle of groups*. New York: Human Sciences Press.
- Lancaster, F. W., Diodato, V., & Li, J. (1988). Identifying the seminal bridge papers of engineering. *Applied Mechanics Review*, 41 (297).
- Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life*. Cambridge, UK: Cambridge University Press.
- Lave, J. (1991). Situating learning in communities of practice. In L. Resnick, J. Levine & S. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 63-83). Washington, DC: APA.
- Lave, J. (1996). The practice of learning. In S. Chaiklin & J. Lave (Eds.), *Understanding practice*: Cambridge University Press.
- Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.
- Leedom, D. K., & Simon, R. (1993). *Improving team coordination: A case for behavior-based training*: U. S. Army Institute.
- Lemke, J. L. (2001). The long and the short of it: Comments on multiple timescale studies of human activity. *Journal Of The Learning Sciences*, 10 (1-2), 17-26.
- Lerner, G. (1993). Collectivities in action: Establishing the relevance of conjoined participation in conversation. *Text*, 13 (2), 213-245.
- Levine, J., & Moreland, R. (1990). Progress in small group research. *Annual Review of Psychology*, 41, 585-634.
- Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*: CA:Sage Publishing, Inc.
- Lipponen, L. (2000). Towards knowledge building discourse: From facts to explanations in primary students' computer mediated discourse. *Learning Environments Research*, 3, 179-199.
- Livingston, E. (1986). *The ethnomethodological foundations of mathematics*. London, UK: Routledge & Kegan Paul.
- Malone, T. W., & Crowston, K. (1990). *What is coordination theory & how can it help design cooperative work systems?* Paper presented at the Proceedings of the Conference in Computer Supported Cooperative Work, Los Angeles. Proceedings pp. 357-370.
- Mark, G., Abrams, S., & Nassif, N. (2003). Group-to-group distance collaboration: Examining the 'space between'. In K. Kuutti, E. H. Karsten, G. Fitzpatrick, P. Dourish & K. Schmidt (Eds.), *Proceedings of the 8th european conference of computer-supported cooperative work (ecscw 2003)* (pp. 99 - 118). Helsinki, Finland.

- Marks, M. A., Mathieu, J. E., & Zaccaro, S. J. (2001). A temporally based framework and taxonomy of team processes. *Academy of Management Review*, 26 (3), 356-376.
- Markus, M. L., Manville, B., & Agres, C. E. (2000). What makes a virtual organization work? *Sloan Management Review*, 42 (1), 13-26.
- Martins, L. L., Gilson, L. L., & Maynard, M. T. (2004). Virtual teams: What do we know and where do we go from here? *Journal of Management*, 30 (6), 805-835.
- Massey, A. P., Montoya-Weiss, M. M., & Hung, Y.-T. (2003). Because time matters: Temporal coordination in global virtual project teams *Journal of Management Information Systems*, 19 (4), 129-155
- Mathieu, J. E., Heffner, T. S., Goodwin, G. F., Cannon-Bowers, J., & Salas, E. (2005). Scaling the quality of teammates' mental models: Equifinality and normative comparisons. *Journal of Organizational Behavior*, 26, 37-56.
- Matsui, T. (2001). Experimental pragmatics: Towards testing relevance-based predictions about anaphoric bridging inferences. In *Modeling and using context - lecture notes in computer science 2116/2001* (pp. 248-260). Berlin / Heidelberg: Springer
- Maxwell, J. A. (2004). Using qualitative methods for causal explanation. *Field Methods*, 16 (3), 243-264.
- Mayer, R. E. (1999). Fifty years of creativity research. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 449-460). Cambridge, UK: Cambridge University Press.
- McCain, K. W. (1990). Mapping authors in intellectual space: A technical overview. *Journal of the American Society for Information Science*, 41 (6), 433-443.
- McCarthy, J., Miles, V., & Monk, A. (1991). An experimental study of common ground in text-based communication. *Proceedings of the ACM Conference on Human Factors in Computing Systems*, 209-215.
- McGrath, J. E. (1984). *Groups: Interaction and performance*. Englewood Cliffs, N.J: Prentice Hall.
- McGrath, J. E. (1991). Time, interaction, and performance (tip): A theory of groups. *Small Group Research*, 22 (2), 147-174.
- McGrath, J. E., & Arrow, H. (1995). Introduction: The jemco-2 study of time, technology, and groups. *Computer Supported Cooperative Work (CSCW)*, 4 (2/3), 107-126.
- McGrath, J. E., & Tschan, F. (2004a). Dynamics in groups and teams. In M. S. Poole & A. H. Van de Ven (Eds.), *Handbook of organizational change and innovation* (pp. 50-72). Oxford: Oxford University Press.
- McGrath, J. E., & Tschan, F. (2004b). *Temporal matters in social psychology: Examining the role of time in the lives of groups and individuals*. Washington, DC: American Psychological Association.

- Miao, Y., & Haake, J. (1998). Flexible support for group interactions in collaborative design, *CSCWID98*. Tokyo, Japan.
- Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed.). Newbury Park, CA: Sage Publications.
- Montoya-Weiss, M. M., Massey, A. P., & Song, M. (2001). Getting it together: Temporal coordination and conflict management in global virtual teams. *Academy of Management Journal*, 44 (6), 1251-1262.
- Moreland, R. (1999). Transactive memory: Learning who knows what in work groups and organizations. In D. M. L. Thompson, & J. Levine (Ed.), *Sharing knowledge in organizations* (pp. 3-31). Hillsdale, NJ: Lawrence Erlbaum.
- Moreland, R., Argote, L., & Krishnan, R. (1996). Socially shared cognition and work: Transactive memory and group performance. In J. L. Nye & A. M. Brower (Eds.), *What's social about social cognition? Research on socially shared cognition in small groups* (pp. 57-84). Thousand Oaks, CA: Sage.
- Moreland, R., & Myaskovsky, L. (2000). Exploring the performance benefits of group training: Transactive memory or improved communication? *Organizational Behavior and Human Decision Processes* (82), 117-133.
- Morgan, B. B., Salas, E., & Glickman, A. S. (1994). An analysis of team evolution and maturation. *The Journal of General Psychology*, 120 (3), 277-291.
- Mühlpfordt, M., & Wessner, M. (2005). *Explicit referencing in chat supports collaborative learning*. Paper presented at the international conference on Computer Support for Collaborative Learning (CSCL 2005), Taipei, Taiwan.
- Nardi, B. A. (2005). Beyond bandwidth: Dimensions of connection in interpersonal communication. *Computer Supported Cooperative Work (CSCW)*, 14 (2), 91 - 130.
- Newell, A. (1980). Reasoning, problem solving and decision processes: The problem space as a fundamental category. In R. Nickerson (Ed.), *Attention and performance viii*. Hillsdale, NJ: Erlbaum.
- Newell, A., & Simon, H. A. (1972). *Human problem solving*. Englewood Cliffs, NJ: Prentice-Hall.
- Nonaka, I. (1994). A dynamic theory of organizational knowledge creation. *Organization Science*, 5 (1), pp. 14-37.
- Nunamaker, J., Dennis, A., Valacich, J., Vogel, D., & George, J. (1991). Electronic meeting systems to support group work. *Communications of the ACM*, 34 (7), 40-61.
- Orlikowski, W. J. (2002). Knowing in practice: Enacting a collective capability in distributed organizing. *Organization Science*, 13 (3), 249-273.
- Orlikowski, W. J., & Yates, J. (2002). It's about time: Temporal structuring in organizations. *Organization Science*, 13 (6), 684-700.

- Patton, M. Q. (1990). *Qualitative evaluation and research methods*: (2nd ed.) Mewbury Park, CA: Sage Publications, Inc.
- Perkins, D. N. (1993). Person-plus: A distributed view of thinking and learning. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 88-110). Cambridge, UK: Cambridge University Press.
- Ploetzner, R., Fehse, E., Kneser, C., & Spada, H. (1999). Learning to relate qualitative and quantitative problem representations in a model-based setting for collaborative problem solving. *Journal Of The Learning Sciences*, 8 (2), 177-214.
- Pomerantz, A., & Fehr, B. J. (1991). Conversation analysis: An approach to the study of social action as sense making practices. In T. A. van Dijk (Ed.), *Discourse as social interaction: Discourse studies, a multidisciplinary introduction, volume 2* (pp. 64-91). London, UK: Sage.
- Poole, M. S. (1983). Decision development in small groups iii: A multiple sequence model of group decision development. *Communication Monographs* (50), 321-341.
- Poole, M. S., & Roth, J. (1989). Decision development in small groups v: Test of a contingency model. *Human Communication Research* (15), 549-589.
- Poole, M. S., & Van de Ven, A. H. (2004a). Central issues in the study of change and innovation. In M. S. Poole & A. H. V. d. Ven (Eds.), *Handbook of organizational change and innovation* (pp. 3-31). Oxford: Oxford University Press.
- Poole, M. S., & Van de Ven, A. H. (2004b). Theories of organizational change and innovation processes. In M. S. Poole & A. H. Van de Ven (Eds.), *Handbook of organizational change and innovation* (pp. 374-398). Oxford: Oxford University Press.
- Popper, K. (1979). *Objective knowledge: An evolutionary approach*. Oxford: Oxford University Press.
- Powell, A., Piccoli, B., & Ives, B. (2004). Virtual teams: A review of current literature and directions for future research. *Advances in Information Systems*, 35 (1).
- Pretz, J. E., Naples, A. J., & Sternberg, R. J. (2003). Recognizing, defining, and representing problems. In J. E. Davidson & R. J. Sternberg (Eds.), *The psychology of problem solving* (pp. 3-30). Cambridge, UK: Cambridge University Press.
- Putnam, R. (1990). *Realism with a human face*. Cambridge, MA: Harvard University Press.
- Putnam, R. (2002). *Bowling alone: The collapse and revival of american community*: Simon & Schuster.
- Rafal, C. T. (1996). From co-construction to takeovers: Science talk in a group of four girls. *Journal Of The Learning Sciences*, 5 (3), 279-293.

- Reimann, P. (2007). Time is precious: Why process analysis is essential for CSCL, *International Conference on Computer-supported Collaborative Learning 2007*. New Brunswick, NJ.
- Renninger, K. A., & Shumar, W. (2002). *Building virtual communities*. Cambridge, UK: Cambridge University Press.
- Rentsch, J. R., & Klimoski, R. (2001). Why do 'great minds' think alike?: Antecedents of team member schema agreement. *Journal of Organizational Behavior* (22), 107-120.
- Resnick, L., Levine, J., & Teasley, S. (Eds.). (1991). *Perspectives on socially shared cognition*. Washington, DC: American Psychological Association.
- Robbins, P., & Aydede, M. (Eds.). (2009). *Cambridge handbook of situated cognition*. Cambridge, UK: Cambridge University Press.
- Robey, D., & Newman, M. (1996). Sequential patterns in information systems development: An application of a social process model. *ACM Transactions on Information Systems (TOIS)*, 14 (1), 30-63.
- Rogoff, B. (1990). *Apprenticeship in thinking: Cognitive development in social context*. Oxford: Oxford University Press.
- Rogoff, B. (1995). Observing sociocultural activity on three planes: Participatory appropriation, guided participation, and apprenticeship. In J. V. Wertsch, P. D. Rio & A. Alvarez (Eds.), *Sociocultural studies of mind* (pp. 252). Cambridge UK: Cambridge University Press.
- Roschelle, J. (1992). Learning by collaborating: Convergent conceptual change. *Journal of the Learning Sciences*, 2 (3), 235-276.
- Roschelle, J. (1996). Learning by collaborating: Convergent conceptual change. In T. Koschmann (Ed.), *CSCL: Theory and practice of an emerging paradigm* (pp. 209-248). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Sacks, H. (1992). *Lectures on conversation*. Oxford, UK: Blackwell.
- Sacks, H., Schegloff, E. A., & Jefferson, G. (1974). A simplest systematics for the organization of turn-taking for conversation. *Language*, 50 (4), 696-735.
- Salas, E., & Fiore, S. M. (Eds.). (2004). *Team cognition: Understanding the factors that drive process and performance*. Washington, DC: American Psychological Association.
- Salomon, G. (1993). *Distributed cognitions: Psychological and educational considerations*. Cambridge, UK: Cambridge University Press.
- Salomon, G., & Globeson, T. (1989). When teams do not function the way they ought to. *International Journal of Educational Research*, 13, 89-99.
- Sarin, S., & McDermott, C. (2003). The effect of team leader characteristics on learning, knowledge application, and performance of cross-functional new product development teams. *Decision Sciences*, 34 (4), 707-739.

- Savinainen, A., Scott, P., & Viiri, J. (2005). Using a bridging representation and social interactions to foster conceptual change: Designing and evaluating an instructional sequence for Newton's third law. *Science Education*, 89 (2), 175-195.
- Sawyer, R. K. (2003). *Group creativity: Music, theater, collaboration*. Mahwah, NJ: Lawrence Erlbaum.
- Sawyer, R. K. (2006). Preface. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. xi-xiv). Cambridge: Cambridge University Press.
- Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67-98). Chicago: Open Court.
- Scardamalia, M., & Bereiter, C. (1991). Higher levels of agency in knowledge building: A challenge for the design of new knowledge media. *Journal of the Learning Sciences*, 1, 37-68.
- Scardamalia, M., & Bereiter, C. (1996). Computer support for knowledge-building communities. In T. Koschmann (Ed.), *CSCW: Theory and practice of an emerging paradigm* (pp. 249-268). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences*. Cambridge, UK: Cambridge University Press.
- Schatzki, T. R. (2001). Introduction: Practice theory. In T. Schatzki, K. Cetina & E. Savigny (Eds.), *The practice turn in contemporary theory*. London: Routledge.
- Schegloff, E. (1979). Identification and recognition in telephone conversation openings. In G. Psathas (Ed.), *Everyday language*. New York: Irvington Publishers.
- Schegloff, E. (1991a). Conversation analysis and socially shared cognition. In L. Resnick, J. Levine & S. Teasley (Eds.), *Perspectives on socially shared cognition* (pp. 150-171). Washington, DC: APA.
- Schegloff, E. (1991b). Reflections on talk and social structure. In E. Boden & D. Zimmerman (Eds.), *Talk and social structure: Studies in ethnomethodology and conversation analysis* (pp. 44-70). Berkeley, CA: University of California Press.
- Schegloff, E. A. (1995). Discourse as an interactional achievement .3. The omnirelevance of action. *Research On Language And Social Interaction*, 28 (3), 185-211.
- Schegloff, E. A. (2006). Interaction: The infrastructure for social institutions, the natural ecological niche for language, and the arena in which culture is enacted. In N. J. Enfield & S. C. Levinson (Eds.), *Roots of human sociality: Culture, cognition and interaction*. Oxford: Berg Publishers.
- Schmidt, K., & Bannon, L. (1992). Taking CSCW seriously: Supporting articulation work. *Computer Supported Cooperative Work (CSCW)*, 1 (1-2), 7-40.

- Schmidt, K., Wagner, I., & Tolar, M. (2007). *Permutations of cooperative work practices: A study of two oncology clinics*. Paper presented at the GROUP '07 Conference: The 2007 international ACM Conference on Supporting Group Work, Sansibel Island, FL.
- Schwartz, D. L. (1995). The emergence of abstract representations in dyad problem solving. *Journal Of The Learning Sciences*, 4 (3), 321-354.
- Schwartz, D. L., Varma, S., & Martin, L. (2008). Dynamic transfer and innovation. In S. Vosniadou (Ed.), *Internation handbook of research on conceptual change* (pp. 479-506). New York: Taylor & Francis.
- Shaw, R., & Kitzinger, C. (2007). Memory in interaction: An analysis of repeat calls to a home birth helpline. *Research on Language and Social Interaction*, 40 (1), 117-144.
- Siegler, R. S. (1996). *Emerging minds: The process of change in children's thinking*. New York: Oxford University Press.
- Siegler, R. S., & Chen, Z. (2002). Development of rules and strategies: Balancing the old and the new. *Journal of Experimental Child Psychology*, 81, 446-457.
- Slavin, R. E. (1980). Cooperative learning. *Review of Educational Research*, 50 (3), 15-42.
- Slavin, R. E. (1983). *Cooperative learning*. New York: Longman.
- Slavin, R. E. (1995). *Cooperative learning: Theory, research, and practice* (2nd ed.). Boston: Allyn & Bacon.
- Slavin, R. E. (1996). Research on cooperative learning and achievement: What we know, what we need to know. *Contemporary Educational Psychology*, 21 (1), 43-69.
- Smith, M. F. (2002). Tools for navigating large social cyberspaces. *Communications of the ACM*, 45, 51.
- Stahl, G. (1993). *Supporting situated interpretation*. Paper presented at the Annual Meeting of the Cognitive Science Society (CogSci '93), Boulder, CO. Proceedings pp. 965-970. Retrieved from <http://www.cis.drexel.edu/faculty/gerry/cscl/papers/ch13.pdf>.
- Stahl, G. (2003). *Knowledge negotiation in asynchronous learning networks*. Paper presented at the Hawai'i International Conference on System Sciences (HICSS '03), Hawaii, HA. Retrieved from <http://www.cis.drexel.edu/faculty/gerry/cscl/papers/ch12.pdf>.
- Stahl, G. (2004a). *Collaborating with relational references [contribution to the workshop on representational support for knowledge building discourse]*. Paper presented at the Annual Meeting of the American Educational Research Association (AERA 04), San Diego, CA. Retrieved from <http://www.cis.drexel.edu/faculty/gerry/publications/conferences/2004/aera.pdf>.
- Stahl, G. (2004b). Mediation of group cognition. *SigGroup Bulletin*, 24 (4), 13-17.

- Stahl, G. (2005a). *Group cognition: The collaborative locus of agency in CSCL*. Paper presented at the international conference on Computer Support for Collaborative Learning (CSCL '05), Taipei, Taiwan.
- Stahl, G. (2005b). *Sustaining online collaborative problem solving with math proposals*. Paper presented at the International Conference on Computers and Education (ICCE 2005), Singapore, Singapore.
- Stahl, G. (2006a). *Group cognition: Computer support for building collaborative knowledge*. Cambridge, MA: MIT Press.
- Stahl, G. (2006b). Perspectives on collaborative learning. In *Group cognition: Computer support for building collaborative knowledge* (pp. 119-153). Cambridge, MA: MIT Press.
- Stahl, G. (2006c). Shared meaning, common ground, group cognition. In *Group cognition: Computer support for building collaborative knowledge* (pp. 347-360). Cambridge, MA: MIT Press. Retrieved from <http://www.cis.drexel.edu/faculty/gerry/mit/>.
- Stahl, G. (2006d). Sustaining group cognition in a math chat environment. *Research and Practice in Technology Enhanced Learning*, 1 (2), 85-113.
- Stahl, G. (Forthcoming). The VMT vision. In G. Stahl (Ed.), *Studying Virtual Math Teams*.
- Stahl, G. (Ed.). (2002). *Computer support for collaborative learning: Foundations for a CSCL community. Proceedings of CSCL 2002. January 7-11. Boulder, Colorado, USA*. Hillsdale, NJ: Lawrence Erlbaum Associates Retrieved from <http://isls.org/cscl/cscl2002proceedings.pdf>.
- Stahl, G., & Herrmann, T. (1999). *Intertwining perspectives and negotiation*. Paper presented at the International Conference on Supporting Group Work (Group '99), Phoenix, AZ. Proceedings pp. 316-324. Retrieved from <http://www.cis.drexel.edu/faculty/gerry/cscl/papers/ch07.pdf>.
- Stahl, G., Koschmann, T., & Suthers, D. (2006). Computer-supported collaborative learning. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences*. Cambridge, UK: Cambridge University Press.
- Star, S. L. (1989). The structure of ill-structured solutions: Boundary objects and heterogeneous distributed problem solving. In L. Gasser & M. N. Huhns (Eds.), *Distributed artificial intelligence* (Vol. II, pp. 37-54): Morgan Kaufmann Publishers.
- Star, S. L., & Griesemer, J. R. (1989). Institutional ecology, 'translations' and boundary objects: Amateurs and professionals in Berkeley's museum of vertebrate zoology, 1907-39. *Social Studies of Science*, 19 (3), 387-420.
- Steiner, I. D. (1972). *Group process and productivity*. New York: Academic Press.
- Sternberg, R. J. (Ed.). (1999). *Handbook of creativity*. New York: Cambridge University Press.

- Stout, R. J., Cannon-Bowers, J. A., & Salas, E. (1996). The role of shared mental models in developing team situational awareness: Implications for training. *Training Research Journal* (2), 86-116.
- Strauss, A. (1985). Work and the division of labor. *The Sociological Quarterly*, 26 (1), 1-19.
- Suchman, L. (1987). *Plans and situated actions: The problem of human-machine communication*. Cambridge, UK: Cambridge University Press.
- Suchman, L. (2003). Writing and reading: A response to comments on plans and situated actions. *Journal Of The Learning Sciences*, 12 (2), 299-306.
- Suchman, L., & Trigg, R. (1991). Understanding practice: Video as a medium for reflection and design. In J. Greenbaum & M. Kyng (Eds.), *Design at work: Cooperative design of computer systems* (pp. 65-90). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Suthers, D. (1999). *Representational support for collaborative inquiry*. Paper presented at the 32nd Hawai'i International Conference on the System Sciences (HICSS-32), Maui, HA.
- Suthers, D. (2005). *Technology affordances for intersubjective learning: A thematic agenda for CSCL*. Paper presented at the international conference of Computer Support for Collaborative Learning (CSCL 2005), Taipei, Taiwan.
- Suthers, D., & Hundhausen, C. (2003). An empirical study of the effects of representational guidance on collaborative learning. *Journal of the Learning Sciences*, 12 (2), 183-219.
- Sutton, J. (2009). Remembering. In P. Robbins & M. Aydede (Eds.), *Cambridge handbook of situated cognition*. Cambridge, UK: Cambridge University Press.
- Teasley, S. D., & Roschelle, J. (1993). Constructing a joint problem space: The computer as a tool for sharing knowledge. In S. P. Lajoie & S. J. Derry (Eds.), *Computers as cognitive tools* (pp. 229-258). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
- ten Have, P. (1999). *Doing conversation analysis: A practical guide*. Thousand Oaks, CA: Sage.
- Traum, D. (1998). Clark and schaefer's contribution model and its applicability to human-computer collaboration. *Proceedings of the COOP'98 Workshop on Use of Clark's Models of Language for the design of Cooperative Systems*.
- Tulving, E., & Donaldson, W. (Eds.). (1972). *Organization of memory*. New York: Academic Press.
- Viégas, F. B., Wattenberg, M., & Mckee, M. (2007). *The hidden order of wikipedia*. Paper presented at the Second International Conference on Online Communities and Social Computing. Proceedings pp. 445-454.
- Vygotsky, L. (1930/1978). *Mind in society*. Cambridge, MA: Harvard University Press.
- Vygotsky, L. (1934/1986). *Thought and language*. Cambridge, MA: MIT Press.

- Waibel, A., Bett, M., Metze, F., Ries, K., Schaaf, T., Schultz, T., et al. (2001). Advances in automatic meeting record creation and access, *ICASSP-2001*. Salt Lake City, UT.
- Wasson, B., Ludvigsen, S., & Hoppe, U. (Eds.). (2003). *Designing for change in networked learning environments: Proceedings of the international conference on computer support for collaborative learning 2003*. Dordrecht, Netherlands: Kluwer Academic Publishers. Computer-supported collaborative learning book series, vol 2.
- Watson-Manheim, M. B., Crowston, K., & Chudoba, K. M. (2002). Discontinuities and continuities: A new way to understand virtual work *Information, Technology and People*, 15 (3), 191-209.
- Webb, N. (1985). *Learning to cooperate, cooperating to learn*. New York: Plenum Publishing.
- Webb, N. (1991). Task-related verbal interaction and mathematics learning in small groups. *Journal of Research in Mathematics Education*, 22 (5), 366-389.
- Webb, N. (1992). Testing a theoretical model of student interaction and learning in small groups. In R. Hertz-Lazarowitz & N. Miller (Eds.), *Interaction in cooperative groups: The theoretical anatomy of group learning* (pp. 102-119). New York: Cambridge University Press.
- Wegerif, R. (2006). A dialogic understanding of the relationship between CSCL and teaching thinking skills. *International Journal of Computer-Supported Collaborative Learning (ijCSCL)*, 1 (1), 143-157.
- Wegner, D. M. (1986). Transactive memory: A contemporary analysis of the group mind. In B. Mullen & G. R. Goethals (Eds.), *Theories of group behavior* (pp. 185-208). New York: Springer-Verlag.
- Wegner, D. M. (1995). A computer network model of human transactive memory. *Social Cognition*, 13 (3), 319-339.
- Wegner, D. M., Giuliano, T., & Hertel, P. T. (1985). Cognitive interdependence in close relationships. In W. J. Ickes (Ed.), *Compatible and incompatible relationships* (pp. 253-276). New York: Springer-Verlag.
- Weick, K. (1969). *The social psychology of organizing*. Reading, MA: Addison-Wesley.
- Weick, K., & Sutcliffe, K. (2005). Organizing and the process of sensemaking. *Organization Science*, 16 (4), 409-421.
- Weick, K. E. (1995). *Sensemaking in organizations*. Newbury Park, CA: Sage.
- Weick, K. E., & Quinn, R. E. (1999). Organizational change and development. *Annual review of psychology* (50), 361-386.
- Wenger, E. (1998). *Communities of practice*. Boston, MA: Cambridge University Press.

- Wertsch, J. V. (1985). *Vygotsky and the social formation of mind*. Cambridge, MA: Harvard University Press.
- Wertsch, J. V. (1998). *Mind as action*. Oxford, UK: Oxford University Press.
- Wessner, M., Shumar, W., Stahl, G., Sarmiento, J., Muhlfordt, M., & Weimar, S. (2006). *Designing an online service for a math community*. Paper presented at the International Conference of the Learning Sciences (ICLS 2006), Bloomington, Indiana.
- Wheelan, S. (1994a). *The group development questionnaire: A manual for professionals*. Provincetown, MA: GDQ Associates.
- Wheelan, S. (1994b). *Group processes: A developmental perspective*. Boston: Allyn & Bacon.
- Wheelan, S., Davidson, B., & Tilin, F. (2003). Group development across time: Reality or illusion? *Small Group Research*, 34 (2), 223-245.
- Wheelan, S., & Hochberger, J. (1996). Validation studies of the group development questionnaire. *Small Group Research*, 27, 143-170.
- White, H. D., & McCain, K. W. (1989). Bibliometrics. In *Annual review of information science and technology* (Vol. 24, pp. 119-186). Amsterdam: Elsevier.
- White, H. D., & McCain, K. W. (1998). Visualizing a discipline: An author co-citation analysis of information science 1972-1995. *Journal of the American Society for Information Science*, 49 (4), 327-355.
- Wiley, N. (1988). The micro-macro problem in social theory. *Sociological Theory*, 6 (2), 254-261.
- Wiley, N. (1994). *Semiotic self*. Chicago: The University of Chicago Press.
- Winograd, T., & Flores, F. (1986). *Understanding computers and cognition: A new foundation of design*. Reading, MA: Addison-Wesley.
- Wong, S. S. (2004). Distal and local group learning: Performance trade-offs and tensions. *Organization Science*, 15 (6), 645-656.
- Yuan, Y. C., & Gay, G. (2006). Homophily of network ties and bonding and bridging social capital in computer-mediated distributed teams. *Journal of Computer-Mediated Communication*, 11 (4), article 9.

Appendix A. Observed Instances of Reporting Bridging Activity

Case	Design Case	Session	Team	Description	Episodic Discontinuity Oriented to	Participation Discontinuity Oriented to
'we already did that yesterday'	Case I	2	2	Reporting on prior work which invalidates current action proposal	Previous Session	Stable Team. One newcomer
'as we discussed on Tuesday'	Case I	2	4	Reporting on prior discussion and building on it	Previous Session	Stable Team. One newcomer
'last time me and estrick came up / that'	Case I	2	5	Reporting on prior work conducted by dyad in previous session	Previous Session	Two newcomers join dyad
' I think - it *was**'	Case I	2	5	Reporting on prior solution which invalidates current solution proposal	Previous Session	Two newcomers.
'ITS A PERMUTATION!!!'	Case I	3	1	Reporting on previous observation about problem	In-between sessions	Four participants missed previous session
'IH: So i thought of another question'	Case I	4	4	Reporting of individual work between sessions adding to prior group work	In-between sessions	Stable Team.
'we arent getting anything done'	Case I	4	5	Reporting evaluation of current problem solving	Current Episode	Team treated as single collectivity.
'permutation? i suggested that last time'	Case I	4	5	Reporting on history of suggestion	Previous Session	Two returning participants from Session 2 missed Session 3
'We figured out the equation for squares, and we should easily solve it for sticks as well in the same manner'	Case II	1	A	Reporting on prior solution and its use for current-next problem to facilitator	Current Online Episode and Co-located Interaction	Stable Co-located Dyad and VMT facilitator
'basically, we've figured out that ...// then, to find the number of sticks, I divided...'	Case II	1	C	Reporting on team outcomes in current session	Current Episode	None

'If this happened, then our method would still work'	Case II	2	A	Reporting on usefulness of prior method	Current Session	Stable Co-located Dyad
'what was your pattern of growth, quicksiler? ... yea that's wrong'	Case II	2	B	Reporting (based on feedback and request) on prior individual idea	Previous Session	Stable Triad, Individual
'The problem from yesterday, but only 3-d'	Case II	2	B	Reporting on previous sessions' problem, avoiding repetition	Previous Session	Stable Triad
'What can we use that we already know? Layer by Layer/Break it down'	Case II	2	B	Reporting on what is to be oriented to as known by the group	Previous Sessions	Stable Triad
'same result / as yesterday/ may mean that these types of problems all are similar in one way'	Case II	2	B	Reporting on similarity of results with prior problem and significance	Previous Session	Stable Triad
'we learned that divide the problem up can make it simpler and easier to solve'	Case II	2	B	Reporting on learnings	Previous and Current Session	Stable Triad
'for the problems last session, we came up with formulas to find.../ remains of our discussion are on the whiteboard and online Wiki'	Case II	2	C	Reporting on past activities to newcomer	Previous Session	Stable Team. One newcomer
'the "each square with 2 sides" thing doesn't work as neatly here / using your previous method: SideLength ² + (SideLength-1) ² '	Case II	2	C	Reporting on failure of past strategy in current situation	Previous Session	Stable Team
'u know the formula we got the previous time? / it works / they said u need a common formula'	Case II	2	D	Reporting on prior solution resource	Previous Session	Stable Team
'are there other problems to do? "WHAT IF? Mathematicians do not just solve other people's problems"'	Case II	2	C	Reporting on previously received problem information	Current Session	Stable Team
'We started talking about 3d after the last session and decided that the method would just be double'	Case II	3	A	Reporting on topic mentioned in prior session and local conversation in-between sessions	Previous Session, In-between Interaction	Stable Co-located Dyad and VMT facilitator
'the base has 1/2N ² +1/2N cubes, as we figured out in the squares problem'	Case II	3	A	Reporting on prior solution to different problem	Previous Session	Stable Co-located Dyad
'The 3-d seems like a good place to start / We'll use the same method as we did last time, with algebra'	Case II	3	A	Reporting on prior problem similar to current one	Previous Sessions	Stable Dyad

'This was our formula last time (Whiteboard)'	Case II	3	B	Reporting on prior solution resource, persistent on whiteboard	Previous Session	Stable Triad
'How about squares as you had mentioned?'	Case II	3	B	Reporting prior problem suggestion	Previous Session	Stable Triad, Individual
'So we do what we did last time again?'	Case II	3	C	Reporting on prior approach and activities as possible fit for current problem	Previous Sessions	Stable Team
the "each polygon corresponds to 2 sides" thing we did last time doesn't work for triangles'	Case II	3	C	Reporting on failure of past strategy in current situation	Previous Session	Stable Team
'Mod: Hey anyone from team c, our team needs to know what n was in your equations last week / The length of a side.'	Case II	3	C	Reporting explanation of prior work as requested	Previous Session	Stable Team, Other Team
'Imagine our first problem with a grid of squares.'	Case II	3	C	Reporting on how past problem can be transformed into new one	Previous Sessions	Stable Team
'we saw the pattern'	Case II	3	D	Reporting prior activity and what the dyad is to orient to as known	Previous Session	Stable Team
'let's continue the cubes version of the problem / the faces should be similar to the squares problem... it's just "magnified" times 4!'	Case II	4	A	Reporting on prior problem similar to current one	Previous Sessions	Stable Dyad
'the pyramid one that we didn't finish last time... we worked on it longer'	Case II	4	B	Reporting on prior unfinished problem	Previous Session	Stable Triad
'what is the pattern / Triangular numbers / we can use the equation from session 1'	Case II	4	B	Reporting on possible use of prior solution resource	Previous Session	Stable Triad
'But that's not what it ends up to be (Point to Team C's formula on Whiteboard)'	Case II	4	B	Reporting on another teams' past solution resource in contrast to current solution	Previous Session	Stable Triad, Other Team
'do we want to keep thinking about the hexagon thing or start on the hypercube?'	Case II	4	C	Reporting on prior mentioned observation regarding value of a strategy	Previous Sessions	Stable Team
'like we said earlier, recursiveness=easy to track pattern of growth'	Case II	4	C	Reporting on prior work in contrast to possible new activity	Current Session	Stable Team
'Wouldn't this work? I think we should just look at it in 3 groups of parallel lines like last time.'	Case II	4	C	Reporting on how prior strategy could be use for current problem	Previous Session	Stable Team

'let's continue the cubes version of the problem / the faces should be similar to the squares problem... it's just "magnified" times 4!' 'We first determined ... Then'	Case II	4	A	Reporting on prior problem similar to current one	Previous Sessions	Stable Dyad
	Case II	Wiki 2	B	Reporting on sequence of solution steps and results	Previous Episode, Wiki	Stable Triad
'In session 4, we continued our progress on the diamond problem. // the same pattern as the triangle number in the first session'	Case II	Wiki 4	B	Reporting on longitudinal sequence of activity across multiple sessions	Previous Episodes, Wiki	Stable Triad

Appendix B. Observed Instances of Collective Re-remembering Activity

Case	Design Case	Session	Team	Description	Episodic Discontinuity Oriented to	Participation Discontinuity Oriented to
'I'm not too sure what the formula i made up last week is'	Case I	3	2	Reconstructing personal formula with team	Previous Session	Stable Team
'so do we go through the same steps again?'	Case I	3	2	Reconstructing previous process	Current Episode	Stable Team
'ok so ... 1 by 1 --> 2...'	Case I	3	5	Reconstructing sequence of cases investigated with their findings. Individual participants worked on different cases.	Current Episode	Team members treated as single collectivity.
'you do the same thing you did with the circle/so should I make the bird's eye view?'	Case I	4	2	Reconstructing previous process and strategies		Stable Team
'I remember...we were trying to look for a pattern...'	Case I	4	5	Reconstructing previous session's work	Previous Session	Team members treated as single collectivity.
'What was a recursive sequence again? we got both explicit and recursive definitions for sticks/squares.'	Case II	2	C	Reconstructing the teams orientation to problem element	Previous Session	Stable Team, One newcomer
'So first, we started off with the basic problem...'	Case II	2	B	Reconstructing session activities for Wiki posting	Current Episode	Stable Triad
'Lets explain it together right here... but that is not in their equation'	Case II	3	B	Reconstructing session activities for Wiki posting	Current Episode	Stable Triad
'As usual, what do you guys think'	Case II	4	B	Reconstructing team routine	Previous Sessions	Stable Triad
'so right now we know that we must calculate the number of...'	Case II	4	B	Reconstructing what is to be oriented to as the agreed upon next action and supportive knowledge	Previous Session	Stable Triad
'we stopped on the part where we were doing the triangles / finding the no of sticks used / but i cant see the connection between them'	Case II	4	D	Reconstructing prior work and current next steps	Previous Session	Stable Team
'what's the sticks original equation again?'	Case II	4	A	Reconstructing prior solution(again)	Previous Sessions	Stable Dyad

Appendix C. Observed Instances of Projecting Activity

Case	Design Case	Session	Team	Description	Episodic Discontinuity Oriented to	Participation Discontinuity Oriented to
'I guess we should ask him next time...'	Case I	Session 2	Team 2	Projecting needed explanation to future session and a specific group member	Next Session	One group member leaves the session early.
'we could solve that next time'	Case I	Session 2	Team 5	Projecting new found problem for next session	Next Session	Team members treated as single collectivity.
'then we may be able to find out a formula'	Case I	Session 3	Team 4	Projecting possible path to solution	Next Episode/Session	Stable Team
'We figured out the equation for squares, and we should easily solve it for sticks as well in the same manner'	Case II	Session 1	Team A	Projecting possible next step	Next Session	Stable Dyad
'next discussion we'll start with the 1st pattern and find the possible combos like $2(2)=4$ etc'	Case II	Session 1	Team D	Project next initiation point and resources	Next Session	Stable Team
'next time...I wonder if we could even replicate the problem with regular pentagons?'	Case II	Session 2	Team A	Projecting next possible challenge	Next Session	Stable Dyad
'maybe we can apply it next time'	Case II	Session 2	Team B	Projecting potential future activity and use of result	Next Session	Stable Triad
'resume from here next time?'	Case II	Session 3	Team C	Projecting possible starting point	Next Session	Stable Team
'We can come back to this on Thursday'	Case II	Session 3	Team B	Projecting unfinished problem for next session	Next Session	Stable Triad
'lets pick it up next time when bwang can explain it'	Case II	Session 3	Team B	Projecting missing explanation for next session	Next Session	Stable Triad and Individual

Appendix D. Observed Instances of Cross-team Bridging

Case	Description	Episodic Discontinuity Oriented to	Participation Discontinuity Oriented to
<p>Session 2, Team A: 'They figured out the same thing for squares, but their approach was unique for the sticks.'</p>	<p>Bridging to uniqueness of other team's reports on Wiki</p>	<p>Prior Sessions</p>	<p>Stable Dyad, Other Teams</p>
<p>Session 2, Team D: 'they thing its too complicated / the explanations they have there are so... complicated / wats recursion? and induction'</p>	<p>Bridging from all other team's Wiki posting, establishing relevance for the complexity of formula resources and explanations</p>	<p>Previous Session</p>	<p>Stable Team, Other Teams</p>
<p>Session 3, Team A: 'I'm posting all of our ideas since we came up with a lot of them. When I'm done, you can post your ideas on the Wiki'</p>	<p>Bridging by coordinating multiple Wiki postings responsive to other teams' reports</p>	<p>Prior Sessions, Next possible episodes</p>	<p>Stable Dyad, Other Teams</p>
<p>'How did team C get its formula for the diamonds?... The 3n has to do with the growing outer layer'</p>	<p>Bridging across teams around problem and solution resources</p>	<p>Previous Sessions</p>	<p>Stable Teams</p>

Appendix E. Observed Instances of Positioning and the Individual

Case ID	Case	Team Session	Team
4	' I think - it *was*'	Session 2	Team 5
6	'H: So i thought of another question'	Session 4	Team 4
8	'permutation? i suggested that last time'	Session 4	Team 5
9	'i'm not too sure what the formula i made up last week is'	Session 3	Team 2
12	'you do the same thing you did with the circle/so should I make the bird's eye view?'	Session 4	Team 2
13	'I remember...we were trying to look for a pattern...'	Session 4	Team 5
14	'I guess we should ask him next time...'	Session 2	Team 2
28	'what was your pattern of growth, quicksiler? ... yea that's wrong'	Session 2	Team B
36	'How about squares as you had mentioned?'	Session 3	Team B
49	'the "each square with 2 sides" thing doesn't work as neatly here / using your previous method: $SideLength^2 + (SideLength-1)^2$ '	Session 2	Team C

Appendix F. Observed Instances of Positioning and the Small Group

Case ID	Case	Team	
		Session	Team
1	'we already did that yesterday'	Session 2	Team 2
2	'as we discussed on Tuesday'	Session 2	Team 4
3	'last time me and estrick came up / that'	Session 2	Team 5
5	'ITS A PERMUTATION!!!'	Session 3	Team 1
7	'we arent getting anything done'	Session 4	Team 5
10	'so do we go through the same steps again?'	Session 3	Team 2
11	'ok so ... 1 by 1 --> 2...'	Session 3	Team 5
13	'I remember...we were trying to look for a pattern...'	Session 4	Team 5
14	'I guess we should ask him next time...'	Session 2	Team 2
15	'we could solve that next time'	Session 2	Team 5
16	'then we may be able to find out a formula'	Session 3	Team 4
17	'We figured out the equation for squares, and we should easily solve it for sticks as well in the same manner'	Session 1	Team A
18	'We figured out the equation for squares, and we should easily solve it for sticks as well in the same manner'	Session 1	Team A
19	'If this happened, then our method would still work'	Session 2	Team A
20	'next time...I wonder if we could even replicate the problem with regular pentagons?'	Session 2	Team A
22	'We started talking about 3d after the last session and decided that the method would just be double'	Session 3	Team A
23	'the base has $1/2N^2+1/2N$ cubes, as we figured out in the squares problem'	Session 3	Team A
24	'The 3-d seems like a good place to start / We'll use the same method as we did last time, with algebra'	Session 3	Team A
26	'let's continue the cubes version of the problem / the faces should be similar to the squares problem... it's just "magnified" times 4!'	Session 4	Team A
27	'what's the sticks original equation again?'	Session 4	Team A

29	'The problem from yesterday, but only 3-d'			Team B
30	' What can we use that we already know? Layer by Layer/Break it down'	Session 2	Session 2	Team B
31	'same result / as yesterday/ may mean that these types of problems all are similar in one way'	Session 2	Session 2	Team B
32	'we learned that divide the problem up can make it simpler and easier to solve'	Session 2	Session 2	Team B
33	'So first, we started off with the basic problem...'	Session 2	Session 2	Team B
34	'maybe we can apply it next time'	Session 2	Session 2	Team B
35	'This was our formula last time (Whiteboard)'	Session 3	Session 3	Team B
37	'Le'ts explain it together right here... but that is not in their equation'	Session 3	Session 3	Team B
38	'We can come back to this on Thursday'	Session 3	Session 3	Team B
39	'lets pick it up next time when bwang can explain it'	Session 4	Session 4	Team B
40	'the pryamid one that we didn't finish last time... we worked on it longer'	Session 4	Session 4	Team B
41	'what is the pattern / Triangular numbers / we can use the equation from session 1'	Session 4	Session 4	Team B
42	'But that's not what it ends up to be (Point to Team C's formula on Whiteboard)'	Session 4	Session 4	Team B
43	'As usual, what do you guys think'	Session 4	Session 4	Team B
44	'so right now we know that we must calculate the number of...'	Wiki 2	Session 4	Team B
45	'We first determined ... Then'	Wiki 4	Session 4	Team B
46	'In session 4, we continued our progress on the diamond problem. // the same pattern as the triangle number in the first session'	Session 1	Session 1	Team C
47	'basically, we've figured out that ...// then, to find the number of sticks, I divided...'	Session 2	Session 2	Team C
48	'for the problems last session, we came up with formulas to find.../ remains of our discussion are on the whiteboard and online Wiki'	Session 2	Session 2	Team C
50	'What was a recursive sequence again? we got both explicit and recursive definitions for sticks/squares.'	Session 2, Feedback 1	Session 2	Team C
51	'are there other problems to do? "WHAT IF? Mathematicians do not just solve other people's problems"	Session 3	Session 3	Team C
52	'So we do what we did last time again?'	Session 3	Session 3	Team C
53	the "each polygon corresponds to 2 sides" thing we did last time doesn't work for triangles'	Session 3	Session 3	Team C
54	'Mod: Hey anyone from team c, our team needs to know what n was in your equations last week / The length of a side.'	Session 3	Session 3	Team C
55	'Imagine our first problem with a grid of squares.'	Session 3	Session 3	Team C

56	'resume from here next time?'	Session 3	Team C
57	'do we want to keep thinking about the hexagon thing or start on the hypercube?'	Session 4	Team C
58	'like we said earlier, recursiveness=easy to track pattern of growth'	Session 4	Team C
59	'Wouldn't this work? I think we should just look at it in 3 groups of parallel lines like last time.'	Session 4	Team C
60	'u know the formula we got the previous time? / it works / they said u need a common formula'	Session 2	Team D
61	'we saw the pattern'	Session 3	Team D
62	'we are always stuck at 1st pattern'	Session 4	Team D
63	'we stopped on the part where we were doing the triangles / finding the no of sticks used / but i cant see the connection between them'	Session 4	Team D
64	'next discussion we'll start with the 1st pattern and find the possible combos like $2(2)=4$ etc'	Session 1	Team D

Appendix G. Observed Instances of Positioning and the Collectivity of VMT Teams

Case ID	Case	Team Session	Team
21	'They figured out the same thing for squares, but their approach was unique for the sticks.'	Session 2	Team A, Team C
25	'I'm posting all of our ideas since we came up with a lot of them. When I'm done, you can post your ideas on the Wiki'	Session 3	Team A, All other Teams
65	they thing its too complicated / / the explanations they have there are so... complicated / wats recursion? and induction'	Session 2	Team D, Team B
66	'How did team C get its formula for the diamonds?... The 3n has to do with the growing outer layer'	Session 3, 4	Teams B and C