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Chapter 31

Achieving Productive Multivocality in the Analysis of Group Interactions

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Abstract (for e-Book ONLY!)

This chapter reports on the productive multivocality project, a five-year collaboration among researchers exploring the basis for productive dialogue between multiple analytic traditions in the analysis of group interaction, focusing on educational settings. The project was motivated by the need to bring cohesion to multidisciplinary fields such as the learning sciences in a manner that respects and leverages their diversity. Five data corpora were each analyzed by several analyst teams representing various theoretical and methodological traditions, and we explored strategies for engaging these teams in productive dialogue. This chapter offers a self-contained summary of the project and its major insights and lessons, and can serve as a starting-point for further reading. After briefly reviewing the motivations and history of the project, we then summarize the five data corpora, the analyses done on them, and the challenges for productive multivocality that we encountered and what we learned from these case studies. The chapter concludes with a list of strategies for productive multivocality.

Achieving Productive Multivocality in the Analysis of Group Interactions

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This chapter summarizes the outcomes of a long-term research collaboration in the analysis of group interaction, reported in detail in the other chapters of the volume within which this chapter is contained (Suthers, Lund, Rosé, Teplovs, & Law, in press). We call this collaboration the "productive multivocality project", as it involved an effort to bring the various "voices" of multiple theoretical and methodological traditions into productive dialogue with each other. This project had multilayered goals. In addition to individual participants' goals, our collective goals were to bring these various traditions to bear on the problem of understanding interaction in educational settings, while deliberately reflecting on and modifying our collaborative research practices to learn how multiple traditions might "speak to" each other in a manner that transcends yet leverages their differences. That is, our efforts at multivocal analysis of interaction not only produced research results concerning the interactions of students being studied, but also served as the setting for a research program concerning our own interactions as researchers, intended to inform other attempts at collaboration in multi-disciplinary areas of study. Therefore this chapter (and the volume within which it is contained) can be read for different purposes. It is primarily a report on what we learned from the productive multivocality project: how to bring different traditions into dialogue with each other in a manner that is beneficial to the participating researchers and to progress in the field. It also contains a condensed report of a number of studies of interaction in educational settings (32 distinct analysts conducting 17 analyses across 5 data corpora), so can be read to survey their research results. The full volume (which contains detailed descriptions of data and analytic methods) may also be of value to students and researchers who want to learn about the range of analytic approaches available for their own data, perhaps to expand beyond the disciplinary boundaries of their own training.

We begin our report in this chapter by establishing the context: who we are, what we were trying to accomplish, how we went about it, and to whom else this work might be of interest. The project comprises five collaborations, each consisting of several researchers analyzing a shared data corpus. The body of this chapter contains summaries from the editors who facilitated each of these data-focused collaborations. We then step back from these specific analytic efforts and consider the lessons learned for productive multivocality in multidisciplinary areas of study.

Motivations for Multivocal Analysis

The nearly forty researchers involved in this project work in the areas of collaborative learning, technology enhanced learning, and cooperative work, and share an interest in understanding group interactions, including interactions mediated by various technologies ranging from paper and pencil to online environments. We approach this topic from a variety of disciplinary homes and theoretical and methodological traditions that converge in research communities such as the *learning sciences* (Kolodner, 1991; R. Keith Sawyer, 2006), the study of human learning and instructional innovations for furthering learning, and its subfield of *computer supported collaborative learning* (CSCL) (Koschmann, Hall, & Miyake, 2001; Stahl, Koschmann, & Suthers, 2006), the study of how interaction leads to learning with the support of designed artifacts. Representatives of diverse disciplines, such as education,

psychology, computer and information sciences, applied linguistics, pragmatics, anthropology, sociology and others, are found within these areas of study and their communities, and bring their associated research traditions. Methods include statistical analyses of experimental data, iterative design-based research, conversation analysis, grounded theory, and social network analysis, among many other approaches. Theoretical traditions such as cognitivism, ethnomethodology, socioculturalism and others may be found side by side in the same journal or conference proceedings. This state of affairs is found in many other fields as well, particularly in the social and behavioral sciences in which no single tradition has established primacy. The challenge is to convert multidisciplinarity—disciplines contributing independently, in an additive manner, into interdisciplinarity—disciplines in discourse with each other, contributing in an integrative manner (Choi & Pak, 2006).

One can argue that interdisciplinarity is *essential* for fields that focus on how social settings foster learning. Consider the range of conceptions about learning in social settings (Suthers, 2006). Theories differ on who or what they identify as the agent that learns. The agent of learning may be individuals, small groups, or networks (including networked individuals, communities, cultures, and societies). Theories also differ in epistemologies or what they identify as the process of learning. Prominent epistemologies include learning as acquisition of knowledge or skills (e.g., Anderson, 1981; Wenger, 1987); learning as intersubjective meaning-making (Koschmann et al., 2005; Suthers, 2006) such as argumentation (Andriessen, Baker, & Suthers, 2003), co-construction (Weinberger & Fischer, 2006), transactivity (Sionti, Ai, Rosé, & Resnick, 2011), or group cognition (Stahl, 2006); or learning as the process through which communities expand their collective capital (Scardamalia & Bereiter, 1991) or sustain themselves through changes in social participation and identity (Lave & Wenger, 1991; Rogoff, 1995; Wenger, 1998). Although our research may focus on only one of these levels of agency and epistemologies at a time, it is highly plausible that individuals and collectives participate in the foregoing forms of learning simultaneously. This raises a larger question of how learning takes place through the interplay between individual and collective agency, a question that *requires* coordinated analyses and theorizing from multiple perspectives.

Yet, the need to make a multidisciplinary field interdisciplinary does not automatically make it so, or even possible. We are still faced with the question: is diversity of methodological and theoretical perspectives in multidisciplinary fields, such as the learning sciences and CSCL, a blessing or a curse? Are multidisciplinary areas of study doomed to be "balkanized," with independent strands of thought and investigation co-existing in journals and conferences based only on their common concern with a nominal phenomenon (such as "learning"), itself being variously conceived? Or is productive interaction among the traditions possible such that diversity becomes strength, and if so, through what strategies?

The "productive multivocality project" has taken on this challenge by deliberately attempting to bridge theoretical and methodological divides for the analysis of interaction in learning oriented settings. We take the term *multivocal* from Bahktin (Bakhtin, 1981), who used it to describe the presence of multiple "voices" that can be discerned in texts (see also Koschmann, 1999). Here the "text" is the collective discourse of a field such as the learning sciences. Our working assumption is that scientific and practical advances in the social sciences (where there is often no one dominant paradigm as in the physical sciences) can be enhanced if researchers working in multiple traditions – including traditions that some assume to be incompatible – make a concerted effort to engage in dialogue with each other, comparing and contrasting their understandings of a given phenomenon and how these different understandings can either complement or mutually elaborate each other. We do not expect to eliminate our differences and achieve full unification, but rather hope to find

productive tensions in this dialogue. “Productive” does not necessarily mean “agreement” (Matusov, 1996), and controversies can be “deployed” towards productive ends (Latour, 2005). Diversity enables us to explore alternate approaches to understanding learning in interaction. However, this diversity is advantageous only to the extent that there is sufficient commonality to support dialogue between the “voices” and reach some degree of coherence in our discourse. We need strategies and *boundary objects* (Star & Griesemer, 1989) that form the basis for dialogue between theoretical and methodological traditions applied to the analysis of learning in and through interaction. This project undertook to find what constitutes effective boundary objects and how they may be leveraged.

Evolution of the Project

The multivocality project developed over a period of five years through a series of workshops at the International Conference on the Learning Sciences (ICLS) in 2008 and 2010, the Computer Supported Collaborative Learning (CSCL) conference in 2009, and the STELLAR Alpine Rendez-Vous (ARV) in 2009 and 2011, as well as ongoing collaborations between the authors of this volume and other colleagues extending through 2013. Here we briefly consider the evolution of our thinking; a more detailed history of the project may be found in Chapter 1 (Suthers, this volume-b).

Initially we had different goals. In our first workshop (ICLS 2008), motivated by the observation that advances in shared representations, methods and tools lead to progress in many scientific disciplines, we sought to establish a common conceptual model and abstract transcript that might also form the requirements for shared analytic software. Workshop participants presented analyses conducted on their own data, and we used a collection of dimensions (see below) to describe commonalities across our analytic approaches. Commonalities were difficult to identify, and we found that the dimensions were more helpful for describing ways in which our approaches *differed* from each other. Yet, participants were excited about the opportunity to compare analyses and tools.

In our second workshop (CSCL 2009), we decided to provide a stronger basis for comparison of our approaches by having analysts from different traditions analyze the same data (two corpora not represented in the present volume). We again tried to find “common objects” between our analyses along a refined set of dimensions, but again found that the dimensions highlighted how the analyses differed rather than their commonalities. Although we had hoped that multiple analyses of shared data corpora would provide a basis for dialogue, the analyses presented were disconnected in part because the analysts were approaching these corpora with entirely different questions (colleagues have reported that this is a common point of failure in other similar efforts). This observation led to the innovation of “pivotal moments” in the next workshop.

Our third workshop (ARV 2009) continued the prior strategy of having researchers from different theoretical and methodological traditions analyze shared data corpora. We used data from a Knowledge Forum discussion in education (the basis of the case study in Chapters 20-24 of this volume), and from a Japanese primary school mathematics class (Chapters 4-8 of this volume). As before, we deliberately paired up analysts from different methodological traditions, in some cases challenging them with forms of data to which they were not accustomed. Most importantly, we addressed the prior mismatch in analytic objectives by asking analysts to identify the *pivotal moments* in the interactions recorded in the data. The definition of pivotal moments was purposefully left unspecified, providing a projective stimulus (as it were) that drew out different researchers' assumptions and insights and in some

cases led to exciting comparative and integrative discussion. As expected, analysts differed in their conception and identification of pivotal moments, but these differences (as well as some congruencies) generated productive discussion of how learning arises from interaction.

In this third workshop we first articulated our core strategy for productive multivocality: assign diverse analysts to shared corpora and charge them with analytic objectives that are deliberately open to interpretation (e.g., "pivotal moments"). Also, our emphasis shifted from seeking "common objects" to seeking *boundary objects* (such as the corpora and pivotal moments) that support dialogue between different traditions. Boundary objects "have different meanings in different worlds but their structure is common enough to more than one world to make them recognizable, a means of translation" (Star & Griesemer, 1989, p. 393). We also found it to be useful to align various analytic results (e.g., to find overlaps and differences in pivotal moments identified), so wanted to explore tools for juxtaposing analyses for comparison.

In our fourth workshop (ICLS 2010), we recruited new analysts and new data corpora from a Group Scribbles mathematics classroom in Singapore (subsequently replaced) and university level chemistry study groups in the U.S (Chapters 9-13 of this volume). We replicated the core strategy of having deliberately diverse analysts identify pivotal moments in shared corpora, although another analytic objective, that of identifying "leadership", played a similar role across some of the chemistry corpus analyses. Also, we used a software tool (Tatiana; Dyke, Lund, & Girardot, 2009) to support data sharing and more detailed comparisons of analyses. The primary strategy again proved to be productive, surfacing issues and insights exemplified by the case studies; see for example (Dyke et al., 2011; Suthers et al., 2011).

The final formal workshop of this project (ARV 2011) brought in additional analysts and two more data corpora. At our request, our Singapore colleagues replaced the mathematics corpus with another corpus on learning about electric circuits with multimodal use of Group Scribbles and physical manipulatives (Chapters 14-19, this volume). A final corpus was introduced involving iterative design of a software agent supporting accountable talk in discovery learning of 9th grade Biology (Chapters 25-30, this volume). The end of the two-day workshop was structured to identify themes common across the case studies and thus surface practical, methodological and theoretical issues and strategies for productive multivocality that are highlighted in the present volume (especially in Chapters 32-35).

Subsequent collaborations continued beyond ARV 2011, resulting in a number of papers (e.g., Chiu & Fujita, in press; Dyke, Adamson, Howley, & Rosé, in press-b; Dyke, Howley, Adamson, & Rosé, 2012; Dyke, Kumar, Ai, & Rosé, 2012; Dyke et al., 2011; Howley, Mayfield, & Rosé, 2013; Jeong, Chen, & Looi, 2011; Medina & Suthers, 2013; Oshima, Matsuzawa, Oshima, Chan, & van Aalst, 2012; Oshima, Oshima, & Matsuzawa, 2012; Oshima, Oshima, Matsuzawa, van Aalst, & Chan, 2011; Reynolds & Chiu, 2012; Schwarz et al., 2010; Suthers et al., 2011; Wise & Chiu, 2011a, 2011b).

Dimensions

The dimensions we used for describing analytic approaches are as follows: details may be found in Chapter 2 (Lund & Suthers, this volume):

Theoretical assumptions underlying the analysis. What ontological and epistemological assumptions are made about phenomena worth studying, and how we can come to know about them?

Purpose of analysis. What is the analyst trying to find out about interaction?

Units of action, interaction and analysis. In terms of what fundamental *relationships* between actions do we conceive of interaction? What is the relationship of these units to the unit of analysis? A unit of *inter*action relates two actions (at some level of description) in a manner that constructs a model of interaction informative for the desired unit of analysis.

Representations of data and analytic interpretations. What representations of data and representations of analytic constructs and interpretations are used to capture these units in a manner consistent with the purposes and theoretical assumptions?

Analytic manipulations taken on those representations. What are the analytic moves that transform a data representation into successive representations of interaction and interpretations of this interaction? How do these transformations lead to insights concerning the purpose of analysis?

The last two dimensions essentially treat analysis as a form of distributed cognition (Hutchins, 1995) by describing how analyses are achieved through transformations of representations in a system of analysts and analytic representations. These dimensions will be referred to occasionally in the summary that follows.

Analytic Traditions and Data Corpora

Diversity of theoretical and methodological traditions is a necessity for a project on productive multivocality. The persons we were able to recruit use methods as diverse as various forms of content analysis, conversation analysis, polyphonic analysis, semiotic and multimodal analysis, social network analysis, statistical discourse analysis, computational linguistics, and uptake analysis. Theoretical traditions include cognitivism, constructivism, dialogism, ethnomethodology, group cognition or intersubjective meaning-making, knowledge building, progressive inquiry, semiotics, and systemic functional linguistics.

Chapters	***Topic***	***Age and Institutional Setting***	***Interactional Setting and Media***
4-8	Mathematics	6th Grade Japanese Classroom	Face-to-face with origami paper and blackboard
9-13	Chemistry	Undergraduate Peer-led Team Learning	Face-to-face with paper and whiteboard
14-19	Electricity	Primary school in Singapore	Primarily face-to-face with circuit components and Group Scribbles software
20-24	Education	Graduate Level in Toronto	Asynchronous discussions in Knowledge Forum
25-30	Biology	Secondary school in Pittsburgh	Mixed face-to-face and online with Concert Chat & conversational agents in support of collaborative learning

Table 1. Summary of Data Corpora

In selecting the data corpora (case studies) and analysts for this project, we were entirely dependent on what participants were willing and able to make available, but sought individual data corpora that had potential to show learning through interaction, and were compelling as evidenced by the desire and willingness of multiple analysts to spend time analyzing that data. We were also cognizant of collective criteria for the corpus as a whole, seeking diversity of age levels, settings (formal and informal learning in schools, workplaces, and elsewhere), interactional media (face to face, synchronous, and asynchronous computer mediated communication), and domains or topics of study. The result is summarized in Table 1. We were successful in obtaining a diversity of topics, age groups, and interactional media within formal educational settings. The emphasis is on science and mathematics. We are missing (and unsuccessfully solicited) case studies in informal settings or workplaces, and representatives of sociocultural traditions. Also, most of our data involves small group interactions rather than large-scale networks or communities of learners. Yet, we believe that we have sufficient diversity to have encountered and grappled with major issues in achieving productive multivocality in the analysis of interaction.

In the following five sections, we summarize each data corpus, the analyses undertaken for each corpus, and the most salient lessons learned from reflecting on and sometimes revising our attempts to engage in multivocal discourse about our analyses.

Case Study 1: Pivotal Moments in Origami

Section Editor: Kristine Lund, CNRS, University of Lyon

The earliest data corpus we used that survived to be represented in this project was the Japanese 6th grade fractions data corpus gathered by Shirouzu (Chapter 4, this volume). Shirouzu wanted to track conceptual change by exploring the diversity of the paths learners take and the goals they pursue while participating in a collaborative learning task of understanding fractions by folding origami paper. Specifically, Shirouzu (Chapter 5, this volume) analyzed (1) where personal foci of learners originated, (2) what happened next in the interaction once a learner focused on something (were learners "doing" or "monitoring" tasks?) and (3) what learning outcomes these foci and interactions led to, including what learners remembered six months later. The editors of this volume chose two other researchers to analyze Shirouzu's corpus, on the basis that such data would challenge each of them (for different reasons). We hypothesized that getting researchers to work outside of their comfort zone could lead to innovative results.

The second analyst, Trausan-Matu had previously worked only with on-line chat data and was asked to use his approach on video data of face-to-face interactions (Chapter 6, this volume). He used a framework centered around the concept of "voice" (Bakhtin, 1981) to look for patterns of interaction where learners converged or diverged (called inter-animation patterns). His goals were (1) to understand how group interactions could scaffold individual learning, (2) to evaluate different collaborative situations in terms of what the inter-animation patterns revealed about the quality of collaboration, thus giving us an indicator for choosing them and (3) to leverage these inter-animation patterns as a way for teachers to manage students' activity.

The third analyst, Chiu, had developed his own quantitative method called Statistical Discourse Analysis (SDA). We challenged him to apply this method to a corpus that more typically lent itself to qualitative analyses (Chapter 7, this volume-a). Although Chiu's specific goal for this corpus was to statistically model how cognitive and social metacognitive processes influence the likelihoods of new ideas, correct ideas and justifications, his statistical

method is a general one that (1) identifies breakpoints that divide the data into distinct time periods according to changes in variables, (2) tests whether these variables are linked to greater or reduced likelihoods of dependent variables of interest and (3) tests whether these links differ across time periods.

Two different lenses were used as ways to compare analysts' results, and both catalyzed lessons for productive multivocality (Lund, Chapter 8, this volume): the five methodological dimensions, and the comparison of "pivotal moments". The next two sections discuss each lens in turn.

Comparing Analyses on Methodological Dimensions

Theoretical assumptions

Both Shirouzu and Trausan-Matu made inferences about learners' intra and inter-mental activities in the contexts of their respective frameworks. This prompted discussion on the extent to which inferences and interpretations are substantiated only by direct observables, or may also be substantiated by a narrative that is compatible with direct observables. Another point of discussion dealt with causality: which types of explanatory schema are more substantiated in the data, those that attribute causes to individual characteristics or those that attribute causes to the unfolding situation? A third issue dealt with being influenced to redefine key analytical concepts in existing frameworks (e.g. "voices" in the Bakhtinian framework, "utterance" and "adjacency pair" (Schegloff & Sacks, 1973) in conversation analysis). For example, Trausan-Matu redefined utterances to be not only verbal, but also inferred thought as well as different types of actions; and instead of being essentially individual or co-elaborated, they could be group generated, such as when all students moved their chairs in chorus in order to get closer to their origami papers. Pairs of utterances were considered to be adjacent even if shared ordering could just be inferred, for example between an external utterance (talk or action) and an internal one that was presumed by the researcher to be "thought" by the learner. However, the ramifications of such redefinitions were not discussed with recognized representatives of those frameworks. Indeed, being influenced to modify important analytical concepts without the benefit of within-tradition scrutiny of these modifications may be a danger of multivocality.

Purpose of Analysis

Each analyst sought in part to understand the role of individual participants or their contributions in the group interaction. But the way each researcher chose to qualify those roles or contributions was different. Shirouzu assessed the role of the individual in terms of task doer or task monitor during group work. Trausan-Matu assessed the individual's contributions indirectly through "adjacency pairs" of utterances in interaction with interlocutors, which were classified as either converging or diverging. Chiu assessed the individual's contributions through how a particular utterance type can lead to other or the same utterance types coming from others in the group (or from the same individual). Taking these different ways of qualifying the nature of the individual contribution together gives a more complete picture and incites an integrative approach that remains open to still other definitions of the individual's roles or contributions within the group.

Unit of Analysis / Unit of Interaction

All three researchers shared a focus on sequences of related turns in their analysis of the learners' interaction, but they each had a unique approach to this focus. Re-definitions of utterance and adjacency pair were first considered, and discussions about collaborative utterances also prompted Chiu to re-examine the pivotal moments he had originally defined as single conversation turns that divided the interaction into distinct periods. He now looked at

them as longer more contextualized moments that when analyzed qualitatively, could be more fully understood.

Data Representations and Manipulations

The group working on the fractions dataset benefitted from being one of our earlier data corpus collaborations, providing them with sufficient time to compare and refine analyses. They also benefited from the fact that the data gathered was adequate for the requirements of all the researchers. It is not surprising that our assumptions about the phenomena we study influence how we collect data to represent those phenomena. It may be somewhat more surprising that researchers who are satisfied with the way data is collected and readied for analysis yet have different methodological and theoretical assumptions, as was the case for the researchers of this section. However, being able to refer jointly to the interaction being studied helped us to tease out the differences in both theory and method. One result of this joint reference came about after the three researchers realized they had all defined the same moment (of varying duration) as pivotal. Chiu in turn realized that this pivotal moment had the greatest impact on producing justifications in his framework and this information enabled him to discover his model had additional analytical power.

Comparing Pivotal Moments

Shirouzu's definition of pivotal moments evolved as he was continuously taking into account the other researchers' points of view and integrating their results into his own (Chapter 5). For example he originally defined pivotal moments as occurring when the student monitor reflects upon externalized traces, but upon seeing other analysts' results, he modified that to when the student monitor or the student doer reflects upon externalized traces. Trausan-Matu identified pivotal moments as changes in the degree of inter-animation of voices as illustrated by converging and diverging utterances (Chapter 6). Chiu operationalized a pivotal moment as a conversation turn that separates a portion of the conversation into two distinct time periods (before and after) with substantially different likelihoods of the focal variable (e.g. correct ideas) appearing in each portion (Chapter 7).

We compared pivotal moments in relation to the theoretical concepts that were mobilized by each researcher. That meant we performed three comparisons: (1) conceptual change (Shirouzu) as compared to inter-animation patterns (Trausan-Matu) (2) conceptual change (Shirouzu) as compared to frequency of new ideas (Chiu) and (3) inter-animation patterns (Trausan-Matu) as compared to frequency of new ideas (Chiu). These comparisons first served to illustrate where researchers coincided with their definition of pivotal moments, even if for different reasons, and this in turn enabled discussion of how to build bridges between their underlying theoretical concepts while also solidifying their different views. Although pairs of researchers overlapped in defining pivotal moments, only one moment (of varying duration) was deemed pivotal by all three researchers. In this pivotal moment, the group of learners noticed conceptually that the solutions had the same areas, but that their shapes and production methods were different. The differential inter-animation pattern focused on "same" versus "differ", and this was also where there was a drop in new ideas in Chiu's analysis.

Multivocality changes the researcher

Shirouzu showed particular interest in understanding what other analysts had to say about his corpus, and throughout our collaboration strove to integrate their viewpoints into his own analysis, which kept evolving. This was possible because either he could reinterpret the results of others in his own framework or because he could appropriate their epistemological views on a different time scale. An example of the latter is when Shirouzu at first did not agree with Trausan-Matu that it was justifiable to use ability or character traits to explain

behavior, preferring to rather explain behavior by the unfolding of the interaction between participants. However, he came to understand that perhaps ability or character traits could have more explanatory power if learners were followed over the long run, across multiple pedagogical tasks. Our collaboration also convinced Chiu that quantitative and qualitative methods can be used in concert to obtain a more complete understanding of group interactions. Finally, although Trausan-Matu interacted intensively with the other analysts, his research seemed to be most influenced by the new type of corpus with which he was confronted, provoking modifications to the definitions of his analytical concepts (i.e. "utterance" and "adjacency pair") and thus his epistemological stance. In general, researchers in the fractions section adopted an integrative stance, actively searching for ways in which the analyses of others could become either complementary to their own or illustrate the limits of their own approach.

Lessons Learned for Productive Multivocality

The collaboration around the fractions data corpus showed how multivocal analyses help researchers to gain new insights by modifying their epistemological presuppositions about human interaction (e.g. when could it make sense to explain human interaction by a learner's individual characteristics rather than by aspects of the situation?), their assumptions about learning (e.g. how does conceptual change come about?) and their analytical methods (what are new ways of measuring individual participation in the collective?). All analysts measured the quality of the collaboration in some way (Lund, 2011) but with different indicators and units of analysis, using both qualitative and quantitative methods that were adapted to the small size of the dataset. By comparing methodological dimensions and definitions of how particular moments of interaction were pivotal for learning over essentially three years of collaboration, the analysts in this section reconsidered both their theoretical and methodological positions, thereby surpassing the initial limits of their approaches.

Case Study 2: Peer Led Team Learning for Chemistry

Section Editor: Carolyn P. Rosé, Carnegie Mellon University

We have learned through our experience on this project that multivocal approaches to analysis of collaborative learning interactions challenge our individual operationalizations of complex constructs such as social positioning, idea development, or leadership by revealing the ways in which they are each limited. Some of the most exciting insights that came from the multivocal analysis of the Peer Led Team Learning (PLTL) for Chemistry dataset were related to the realization that what might sound like very similar conceptual models and operationalizations from a high level may lead to very different codings and therefore different interpretations of the same data. These moments of insight provided the opportunity to challenge one another to think more deeply about the assumptions we were each making.

In the PLTL Chemistry section, we compared the discussion styles of two different PLTL groups (named the "Gillian group" and the "Matt group", after their leaders) as they solved a chemistry problem related to de Broglie's equation in PLTL study groups. PLTL is a collaborative learning approach that has been used on many college campuses, especially in large lecture classes in departments of chemistry. Prior work in the learning sciences community has shown that engaging in collaborative discourse contributes to deeper conceptual understanding and increased retention and transfer (Engle & Conant, 2002; Greeno, 2006; R. K. Sawyer, 2006; Scardamalia & Bereiter, 2006). However, the challenge in promoting collaboration among undergraduates in large science lecture based courses is that such courses tend to be focused on transmission of knowledge to individuals (Seymour & Hewitt, 1994). Consequently, there has been a paucity of research on students' collaborative

discourse practices in college science settings. PLTL has been designed to facilitate chemistry literacy and success for all students, including but not limited to chemistry majors, by supplementing the lecture with study group sessions that offer opportunities for active and collaborative learning (Gosser et al., 2001; Gosser & Roth, 1998; Sarquis et al., 2001; Siebert & W. J. McIntosh, 2001). Peer leaders are selected from undergraduate students who have successfully received an A in the class in an earlier semester. A peer leader is selected for each group of six to eight students who meet for two hours once per week to solve chemistry problems designed by course instructors.

Several studies have offered impressive evidence that PLTL improves learning (Gafney & Varma-Nelson, 2008; Hockings, DeAngelis, & Frey, 2008; Tien, Roth, & Kampmeier, 2002). However, prior to this study, researchers had not done a detailed investigation of the discussion practices employed by peer leaders and students, and between the students themselves, that mediate the effect. To better understand the mechanisms that make PLTL work, Sawyer, Frey, and Brown (Chapter 9, this volume-b) videotaped three PLTL sessions for each of 15 veteran peer leaders over the course of one semester. The dataset we analyzed included transcripts of two PLTL groups as they solved the same problem. Analysis proceeded in two waves, with the multi-faceted concept of leadership guiding the integration of findings from the first wave, and more of a stylistic approach to analysis of collaborative problem solving guiding the second wave.

The three analysis chapters in this section fall on three distinct places on the continuum between highly quantitative and highly qualitative. At the qualitative end, Sawyer and colleagues approached the conversations in a situated, turn-by-turn fashion. Their analysis in Chapter 10 (Sawyer, Frey, & Brown, this volume-a) includes many excerpts from the corpus in raw form, along with commentary and reflection on the substance of the interactions, including an assessment of the knowledge that was communicated and the manner in which it was communicated. At the opposite end of the spectrum, Oshima and colleagues (Oshima, Matsuzawa, Oshima, & Niihara, Chapter 12, this volume) applied a social network analysis approach to the same data. Connections are made between the evolution of the topology of the network representation over time and a theoretical framework from the Knowledge Building community. In between these two end points stands the coding and counting approach of Howley and colleagues (Howley, Mayfield, Rosé, & Strijbos, Chapter 11, this volume), which contains analyses from two different multi-dimensional coding schemes, including the Souflé analysis lead by Rosé and the CSM analysis lead by Strijbos. Both of these coding schemes consist of the same three dimensions, namely Cognitive, Relational, and Motivational, and were thus expected to reveal similar insights about the data, yet the frameworks actually brought out different insights from the data. Like the Sawyer chapter, the Howley chapter contains a number of example excerpts from the corpus. However, like the Oshima chapter, the inferences are made primarily based on quantitative measures as viewed through the lens of the theoretical frameworks that underlie the coding schemes. Only the Sawyer analysis includes an extended thick description of the two problem solving experiences. In their own way, all of the analysts investigated the ways in which participants made their reasoning public by articulating their reasoning, and commenting on and building on one another's reasoning. Each analytic approach made its own characteristic fine grained distinctions in the manner in which reasoning was articulated, shared, and integrated.

The rich contextualized turn-by-turn analysis of Sawyer and colleagues serves as a counter-point to the other analyses, which are quantitative in nature and attempt to draw conclusions from patterns found within a structure imposed on the data as an analytic lens. The qualitative and the quantitative analyses in this section of the book challenge one another's interpretations. Whereas the qualitative analysis has the benefit of contextual

knowledge and human insight, it is limited with respect to the ability to distinguish between the typical and the idiosyncratic. On the other hand, the quantitative approaches provide the machinery to not only make but also quantify this important distinction, but they are prone to misinterpretation caused by over-generalization between instances of behaviors that are treated as the same type. The role of the qualitative analysis was to challenge the treatment of the significance of individual events within the three quantitative analyses. The corresponding role for the quantitative approaches was to challenge summative conclusions drawn within the Sawyer et al. analysis.

Most of the analysts agreed that the Gillian group was more conceptually oriented and interactive whereas the Matt group was more narrowly focused on problem solving. The Oshima, Strijbos, and Sawyer analyses all make this argument using their own style of analysis. Thus, these three analyses can be seen as providing a great deal of convergent evidence that this conclusion has support in the data. The Rosé analysis presents a slightly different view, however. In both the Gillian and Matt groups the same number of reasoning statements were uttered; however, this number is a smaller percentage of moves in the Gillian group than in the Matt group. Thus, while the articulation of reasoning might be framed differently in the two groups, both groups are equally open with one another about their reasoning, and the Matt group is more singularly focused on reasoning. In the Gillian group there is more packaging around the reasoning. This packaging might be what makes the conversation hang together better and appear more highly inter-connected. And yet, the fact that the same number of reasoning statements were uttered raises questions about what the conceptual versus procedural contrast signifies. When we probe more deeply, looking at transactive contributions (i.e., those that build on or comment on a previous reasoning statement) rather than simply reasoning statements, we see that a slightly higher proportion of reasoning statements in the Matt group are transactive. These mainly took the form of comparisons between problem solving approaches. While these comparisons were written off as simply procedural by many of the analysts, the Rosé analysis calls these out as places where the students are considering each other's approaches and comparing them with their own in order to determine how best to solve the problem.

The differences between what these analyses bring out about the group discussions raise questions about what is desirable in PLTL groups, and prompt further reflection on concepts as established as group knowledge integration. All of the analysts valued students sharing their reasoning and working together to refine that reasoning. Not all of the analysts agreed with what that should look like on the surface. Through this process the analysts became aware as a community that we have work to do before we will be able to assess important qualities of collaborative problem solving that we may have previously thought we already had a handle on as a community.

Case Study 3: Multimodality in Learning About Electricity with Diagrammatic and Manipulative Resources

Section Editor: Dan Suthers, University of Hawai'i

The Electricity data corpus provided by Chen & Looi (Chapter 14, this volume) derives from a primary grade classroom in Singapore using the Group Scribbles collaborative whiteboard (Roschelle et al., 2007) and electrical components to learn about electric circuits. This data corpus is unique among those in this volume in that it mixes face-to-face interaction, collaborative physical manipulation of objects, and computer-mediated interaction. The corpus was analyzed by Looi, Song, Wen & Chen (Chapter 15, this volume) using uptake and content analysis guided by a theory of progressive inquiry, Medina (Chapter 16) using uptake

analysis with an ethnomethodological orientation towards unpacking group accomplishments, Lund & Bécu-Robinault (Chapter 17) focusing on coherence and conceptual change in translations between media and modes motivated by a theory of semiotic bundles, and Jeong (Chapter 18) using content analysis under her conception of "group understanding". The analyses focused on two major themes: what evidences understanding, and practices of multimodal interaction across various media. Understanding was analyzed via uptake structures, the coordination of multimodal acts in multiple media, and/or the contents of resulting artifacts in relation to canonical physics. Multimodality was understood in three ways: in terms of the unique affordances of each medium, conceptual coherence sustained through translations across media, and group accomplishments through simultaneous coordinated use of media.

Transcripts and Other Analytic Representations as Boundary Objects

Each analytic team created transcripts and other analytic representations as needed for their own purposes, and many analysts examined the six video records directly (synchronous viewing was made possible by Tatiana: Dyke et al., 2009). Subsequently, we tried to align the various analytic representations (including transcripts) so that we could compare results, but found it difficult to align the different units of analysis, which included participants' actions in different media; episodes defined by ideational, inscriptional, or other activities; the completion of artifacts; and translations between media/modes, among others. Discrepancies between the analytic teams' requirements for transcripts highlighted for us the purpose driven and hence theoretical nature of transcripts (Duranti, 2006; Ochs, 1979), and raised fundamental questions concerning the role shared transcripts play in a multivocal analytic collaboration. A shared transcript is a means to an end. If a shared transcript can be agreed on, it will be easier to compare analyses, but different disciplinary requirements placed on transcripts may preclude this agreement. In either case, the process of attempting to create aligned representations can lead analysts to become aware of dimensions of the data they might not otherwise have considered, and expose essential differences in viewpoints. Some of our own insights came when the group facilitator brought analyses into alignment for comparison and confronted the group with congruences and discrepancies, some of which are discussed below.

Comparing Pivotal Moments

As might be expected, definitions of "pivotal" differed across teams. For Looi, Song, Wen and Chen (Chapter 15), a contribution is pivotal if it shifts the direction of subsequent events, as evidenced by changes in content. Looi et al. were the only analysts who distinguished *manifest* pivotal moments: those that were actually taken up; and *latent* pivotal moments: those that had the potential to shift the direction but were not taken up. Perhaps more attention needs to be paid to the latter in educational research, as they may offer opportunities for interventions by practitioners. Lund and Bécu-Robinault (Chapter 17) work with Multimodal/Multimedia Reformulations (MMRs), or translations from one medium to another, as the units of analysis. An MMR is pivotal when it evidences conceptual change towards canonical physics, or progressions towards more complexity while sustaining the same level of coherence. Medina (Chapter 16) sought "pivotal sequences of interaction" rather than moments. A pivotal sequence is convergence of uptake in enacting an innovation. Jeong (Chapter 18) defined pivotal moments as "moments when changes in group understandings occurred both in terms of the development of the domain understanding and intersubjectivity," but found that in practice this is an incremental process. However, our most productive discussion came out of comparing interpretations of specific events rather than our general conceptions of pivotalness.

The Role of a Teacher Intervention

One issue surfaced by comparing analyses concerned a case where the teacher interrupted a group experiment with a two-battery, two-bulb configuration. The teacher wanted students to draw the circuits first, and then experiment to see whether they worked, and pointed out that there was "no draft" for the experiment in the Group Scribbles board. Medina, who was constructing an emic account of group accomplishments, initially saw the teacher's intervention as a disruptive move that "splintered the group's intersubjectivity and re-prioritized how they proceeded to manage their interaction". Looi, Song, Wen and Chen also marked this intervention as pivotal, but in a positive light: it "changed the direction of the group inquiry path from trying to do a new experiment to reflecting and conceptualizing their working theories of how to light a bulb and the mechanism of the circuit." In our discussion, analysts came to agree that both views were correct. The teacher disrupted the group's indigenous activity for exogenous objectives, and the group did not get to explore "two batteries, two bulbs" until later, but by imposing the activity structure of the original lesson plans the teacher led the participants to represent their understanding in a different medium that exposed one individual's conceptual weak point, prompting other students to help him. Medina reports that this exchange led him to a more dimensional understanding of the pragmatics of individual and group dynamics.

Misconception or Innovation?

Another point of contention emerged concerning whether a student we call "Bruno" had a "canonical conception" of how to connect a wire to the negative end of a battery. Based on his diagramming (see inset for one example), Lund and Bécu-Robinault concluded that Bruno did not have a complete understanding. They wrote, "he does not clearly show that the wire going to the minus pole of the battery actually touches the pole and does not just end at the bottom left of the battery". Suthers (the facilitator) found the diagram to be inconclusive, because an effective strategy for attaching a wire to a battery at its flat negative end is to press the wire flat against the battery. He returned to the video record, and found that Bruno drew the wire into the middle of the first rectangular end of the battery rather than the corner. Examining Bruno's manipulation of physical batteries, three times Bruno clearly placed the wire flat against the flat end of the battery, establishing a solid connection. In one case, Bruno pressed the batteries down on the table with the wire flat underneath, thereby accomplishing with the table what would otherwise need a third hand. This innovation made the entire battery configuration more stable, supplying the physical contingencies for a subsequent innovation (two batteries, two bulbs) enacted by the group, as detailed by Medina's analysis. Thus, the video record of the actual production of artifacts suggests that Bruno had a good understanding of how to connect the wire, enabling an innovation upon which a subsequent group accomplishment was contingent. However, Lund and Bécu-Robinault are not making a claim about whether the drawing correctly showed the actual situation in the physical environment. Rather, they are concerned with whether Bruno has shown representational competence in diagramming circuits as a physics student trained in circuit modeling would. Our dialogue surfaced the essential issue: whether Bruno's understanding should be assessed based on domain standards for abstract representations that are external to the interaction, or based on an emic display of understanding by successfully lighting the bulb in a physical configuration that led to a group innovation.

Agency and the Distribution of Activity across Modalities

Stepping away from the interpretation of specific events, we also uncovered theoretical issues indicated by how the analyses construe the objects of study. Learning has been theorized as

taking place at different granularities of *agency*, including individuals, small groups, or larger networks such as communities as the agent and locus of learning (Greeno, Collins, & Resnick, 1996; Suthers, 2006). Is the unit of agency individuals, the group acting or analyzed as a unit, or something in between, such as intertwined individual agencies from which group agencies emerge? A related question is how *activity* distributes across the available mode/media. Acts in different media can be treated as separate realms between which participants translate, or as simultaneously coordinated in a unified activity. For Jeong, the agent of interest is the group, but she does not assume that there is a singular group cognition or shared understanding. Jeong's approach of characterizing group understandings through the progression of individually produced conceptual artifacts is similar to how archeology characterizes a culture through examples of artifacts produced by individuals. Looi et al. analyze acts by individuals in different media separately, but identify shifts in these acts over time that evidence the group's progressive inquiry. Lund and Bécu-Robinault draw on a theory of semiotic bundles (Arzarello, 2004) that emphasizes coordination of multiple modes/media, but examine how translations across modes/media evidence canonical understanding ("coherence") in a manner following distributed cognition (Hutchins, 1995). The analysis is diachronic because they are concerned with conceptual change over time, and the ability to translate between representations is a key indicator of competence in the domain. Medina, influenced by Goodwin (2000), examines how simultaneously converging acts in multiple modalities/media are brought together in group accomplishments. For Medina, agency exists across the simultaneous coordinated actions of individuals, and activity is distributed across coordinated use of the modalities.

Lessons

The following lessons for achieving productive multivocality can be drawn from this experience. We found that interaction between multiple analysts with different viewpoints can drive advances in both analysts' individual and collective understanding. The potential value of collaborative data analysis has long been established (e.g., Jordan & Henderson, 1995), but there are additional opportunities as well as challenges for multivocality in multimethodological settings. Different analytic approaches make different demands on transcripts, and there are potential opportunities in the negotiation of shared transcripts as boundary objects. It is useful to attempt to map between analytic representations, or learn from the intrinsic incommensurabilities that prevent such a mapping. While abstractions such as transcripts, snapshots, and analytic structures play important roles in each analytic tradition, it may be necessary to go back to the original data record to resolve disputes. To do so, it is essential that the abstractions used by analysts index back to the data record in some shared coordinate system such as time. Not all of the benefits are found in the attempt to align and compare analyses. Some of the productivity of multivocality is found by comparing how analyses constitute the object of study, thereby making alternative theoretical conceptions explicit, such as in our discussion of the distribution of agency and activity across persons and media. Finally, a third party tasked with facilitating multivocal dialogue plays an important role in achieving the above.

Case Study 4: Knowledge Building Through Asynchronous Online Discourse

Section Editor: Chris Teplovs, Problemshift, Inc.

This dataset provided by Fujita comes from an online graduate education course that was conducted exclusively online using Knowledge Forum at the University of Toronto. The instructor organized the course into 13 separate folders or "views" that corresponded to weekly topics. The discourse data consisted of 1330 asynchronous online discussion messages

or "notes" contributed by 17 graduate student participants, the researchers and the instructor. The dataset was part of a larger designed-based research study, the goals of which were twofold: to improve the quality of online graduate education in this particular instance, and to contribute to the theoretical understanding of how students collaborate to learn deeply and build knowledge through progressive discourse.

The dataset was first shared with other analysts at the 2009 Alpine Rendez-Vous, with the goal of gaining new perspectives of collaborative learning through the application of alternate analytic approaches. Not all analytic approaches undertaken in our workshops yielded promising results, and the three chapters included in this volume represent only the more successful analyses. It took several iterations of analyses and tool development to yield the current chapters. The multiple points of contact afforded by the series of workshops at multiple Alpine Rendez-Vous and several other conferences fostered the exchange of ideas and clarification of assumptions that resulted in a deeper understanding of collaborative learning.

The three analyses differed in their purposes: Teplovs & Fujita's analysis (Chapter 21, this volume) sought to examine the relationship between social interaction and the semantics of the written contributions of students. Law & Wong's analysis (Chapter 22, this volume) was motivated by the desire to create a dashboard designed for teachers that would represent students' progress. Chiu's analysis (Chapter 23, this volume) sought to use Statistical Discourse Analysis (SDA) to identify pivotal moments in the discourse, as he did with the Japanese Fractions corpus, but here taking on the additional challenge of data from asynchronous interaction.

Analyses by Teplovs & Fujita and Law & Wong share the data provider's theoretical underpinning of knowledge building, while Chiu's analysis applied a method whose theoretical assumptions are broadly compatible with other approaches. Furthermore, all three analyses shared the goal of identifying and exploring "pivotal moments", however broadly defined, and all three analyses shared a temporal aspect of analysis even if the specific units of analysis differed. It is perhaps these shared elements that allowed Fujita to reflect on the implications of productive multivocality for design-based research in her discussion (Fujita, Chapter 24, this volume).

The hallmarks of multivocality are attractive: multiple voices, commonality, and coherence. Whereas those may be the ultimate goals, the process by which multivocality is pursued can be difficult. In this collaboration, difficulty stemmed from a variety of sources. For example, asynchronous interaction does not result in a single record of interaction that is readily accessible (such as a video recording in the case of synchronous small group interaction). The need to produce high-fidelity representations of asynchronous data that could be understood and analysed by researchers using different tools took considerable effort, and understanding what each other had accomplished as a result of their analyses was sometimes challenging. High-fidelity representations of asynchronous data, particularly those that convey information about the relationships between entities such as people and documents, often make use of network graphs. Network graphs are often difficult to interpret and care needs to be taken to explain what they show. More traditional representations, such as line graphs and bar charts of participation metrics tend to be more understandable by many researchers. Productive multivocality can be hindered by a lack of common understanding around representations.

In retrospect, it may be the case that each voice in our quartet paid little heed to other discrepant voices, but preferred to focus on aspects that resonated with existing beliefs and perspectives. This is not to say that important gains were not made: Chiu made improvements

to SDA to facilitate its use with asynchronous discourse data, Teplovs & Fujita created new representations of interactions, and Law & Wong made progress toward their goal of an analytic tool for teachers. However, theoretical stances were for the most part reified rather than revised. The openness to change, the willingness to question one's assumptions, and the commitment to engage in productive dialogue and debate waned over time.

The authors of this section made repeated overtures indicating that they believe there is merit in pursuing the integration of approaches and techniques. For example, it was suggested that the analysis using KISSME (which visualizes patterns of interaction and community structure by combining social network analysis and latent semantic analysis; Chapter 21) could be repeated using week-by-week student models and the results compared to the findings made using other analyses. This sustained collaboration has failed to materialize at least in part due to lack of resources as well as the pioneering nature of multivocal analysis that goes against existing researcher practices. The problem of limited resources is pervasive and largely insoluble. However, researchers who are new to multivocal analyses can benefit from lessons learned in this volume.

Perhaps most important is a commitment to engage in an iterative process of research amongst the multivocal analysts. This commitment requires: (1) multiple attempts at analyses and (2) carefully considering the role of the data provider. Rather than following a process by which a data set is presented to a number of analysts who may or may not collaborate with the data provider in its analysis, a more productive approach would include both the reporting back to the data provider and to other analysis the results of the first iteration of analyses as well as a commitment to at least one more round of analyses that would take into consideration feedback and reactions from the data provider and other analysts. By doing so, analysts would be more likely to pick up improvements from each other, and the workload of the data provider may also be decreased.

Case Study 5: A Data-Driven Design Cycle for 9th Grade Biology

Section Editor: Carolyn P. Rosé, Carnegie Mellon University

The unique focus of the fifth case study is using multivocality to enhance a data-driven design process by offering a multifaceted understanding of how interventions under development interact with group functioning. This raises unique challenges in sharing the task of data interpretation. While secondary data analysis is becoming more commonplace in the learning sciences, sharing pilot data is far less typical, especially pilot data from experiments gone awry. But the use of process analysis to inform iterative development of interventions for supporting collaborative learning is increasing and has great potential for impact within the field of CSCL. So within that scope, it is important to explore the potential value of multivocal analysis above and beyond a univocal process analysis approach. Do the benefits outweigh the costs in this type of setting? In this case study, four analysts offered their interpretation of what went right and what went wrong in a pilot evaluation of a new form of software-agent based support for scientific discovery learning. From this investigation we learned what we may or may not be missing in analysis of process data from prototypes by conducting the analysis from one specific theoretical and methodological lens. The discussant offers an interpretation of the multivocal process and its implications for a design-based research process (Hmelo-Silver, Chapter 30, this volume).

The study that provides the shared data for this case study is referred to as the Cell Model study, because it involved 9th grade biology student groups who were exploring how cell models work (Dyke, Howley, Kumar, & Rosé, Chapter 25, this volume). The broader project this study was part of builds on a large body of work that has shown that certain forms of

classroom interaction, termed Academically Productive Talk (APT), are beneficial for learning with understanding (Resnick, Asterhan, & Clarke, in press). This work has also shown the crucial role of the teacher in facilitating these discussions. The academically productive talk form of classroom interaction is one in which a facilitator (or a software agent) poses a question that calls for a relatively elaborated response (e.g., both a solution and a reason for the solution), and then presses the group to build on or challenge these ideas, with the purpose of keeping student reasoning at center stage and increasing student ownership of ideas. The goal of the project is to increase the extent to which these APT based practices are used within typical urban classrooms, using professional development with teachers and Computer Supported Collaborative Learning (CSCL) experiences for small groups of students as tools for reshaping the classroom culture (Rosé & Tovares, in press).

The development goal of the project is a conversational software agent that provides support for collaborative learning by mimicking practices from the APT theory of classroom discussion facilitation (Adamson, Dyke, Jang, & Rosé, under review; Michaels, O'Connor, & Resnick, 2007). Researchers conducted two complete cycles of design development, deployment, and analysis over the two-year project. The second year design drew on lessons learnt from the multivocal analyses presented in the chapters within this section, which were conducted after the first year study (Dyke, Adamson, Howley, & Rosé, in press-a). This development effort builds on an earlier history of successful deployment of intelligent conversational agents for support of small group learning. Technology for dynamic support for collaborative learning has matured both in terms of its ability to monitor collaboration through automatic collaborative learning process analysis as well as to offer context appropriate support for effective participation in groups (Kumar & Rosé, 2011). The novelty of the Cell Model study was an exploration of how one might design conversational agents that employ APT practices as scaffolding for on-line collaborative learning discussions, which were eventually successful at leading to increases in learning in the second year of the data collection effort (Adamson, Ashe, Jang, Yaron, & Rosé, 2013; Dyke et al., in press-a).

Despite the critiques of analysts (below), the project did experience some success, even in the first year. Within the context of this district-wide design study, the focus was initially mainly on teacher training. Early on, a relatively slow rate of adoption by teachers led the researchers to consider alternative means to accustom students to APT in order that they might be more responsive to the teacher's classroom scaffolding. One approach they took was to introduce APT practices to students in small group activities facilitated by conversational agents. These activities played an important enabling role in the professional development effort: students came to whole class discussions better prepared and able to engage in intensive discussion after the CSCL activities, which then elevated the teacher's adoption of APT by 1.7 standard deviations (Clarke et al., 2013).

The analysts came to the task with a variety of disparate theoretical assumptions and methodological tools. Howley, Kumar, Mayfield, Dyke, and Rosé (Chapter 26, this volume) use a visualization tool to examine patterns of linguistic codes in a three dimensional analysis framework to show how linguistic evidence of social positioning within groups pinpoints negative student experiences. Cress and Kimmerle (Chapter 27, this volume) follow with an ethnographic study that examines the collaborative setting in terms of the desired (but missing) affordances for group awareness. Stahl (Chapter 28, this volume) and Goggins & Dyke (Chapter 29, this volume) focused on roles within the interaction, and specifically how the role taken by the agent may have limited the opportunities for leadership role taking of students within the group discussions. Stahl's analysis draws on ethnomethodology, and Goggins and Dyke integrate ethnographic analysis methods and social network analysis methods.

One major discrepancy between some of the analysts and the developers was in their assumptions concerning the ideal role for a facilitator in a collaborative learning encounter. All of the analysts agreed that the intervention did not work as intended. The biggest criticism from the analysts other than the developers was that the agent dominated the conversation too much – intervening too frequently, and with turns that were too long. This view of the ideal role of the facilitator that some of the analysts brought with them into the multivocal discussion was in contrast to the theory of APT based instruction, where the instructor plays a very integral role in the classroom discussion, and where much evidence exists to support the effectiveness of this form of classroom facilitation. Debates about the ideal role of a group discussion facilitator pervaded the entire multivocal process.

At the same time, each analyst focused on different questions, sometimes much different from the focus of the intervention designers. In particular, only the analysis conducted by the designers themselves focused on the specific ways in which the behavior of the conversational agents affected the interaction between students in intended versus unintended ways. Some analysts (Stahl and Cress) ignored the experimental manipulation altogether, not seeing any of the differences between conditions as relevant to their concerns, although significant effects of the manipulation were reported in the analysis conducted by the designers. Some of the points raised by analysts were issues that the designers were aware of but chose not to address in the first iteration. This points to special care that must be taken when an analyst participates in secondary data analysis, especially as part of a design-based research process where the designers are already aware of many obvious limitations of the intervention and would benefit more from insights related to limitations they are not already aware of.

On the other side, the other analysts challenged the designers to see beyond their own research questions to the ways in which infrastructure that was the foundation for the experiment itself was flawed, especially in the way it sometimes failed to avoid clashes between multiple aspects of support that were simultaneously active during a portion of the discussion. As Hmelo-Silver pointed out in Chapter 30, in these data and analyses there are many different units of analysis discussed and explored that connect what is going on in individual utterances, larger episodes, overall interactions, and student outcomes. A valuable contribution of multivocality in this context that the combination of analyses provided insight into learning as a complex system, with interaction among different levels of the system. The feedback from the analysts to the designers was taken to heart in a redesign in terms of significantly extending the capabilities of the architecture for managing dynamic support as well as a major adjustment of the role of the agent in the conversation, which was ultimately successful. This success suggests that multivocal analysis can be valuable in challenging designers to break out of their own box and view their data more broadly. It can even lead to questioning the assumptions of their entire enterprise. In this sense, multivocality is “risky”, as that is not what designers hope to gain from recruiting other analysts to their project. Nevertheless, it can be very valuable.

Reflections on Productive Multivocality

The five data-focused collaborations that we have just summarized were each individually and to varying degrees a locus for their own advances concerning the specific matters of research and practice at hand and the development of greater understanding among members of different analytic traditions. Yet they also collectively constitute the “data” for our larger enterprise, that of developing strategies for making data-focused dialogue between analytic traditions useful, and understanding implications of these attempts at “productive multivocality” for theory and practice. In the remainder of this chapter we summarize our conclusions concerning the larger enterprise. After positioning this project relative to the

mixed methods literature, we offer a synopsis of strategies that we identified for productive multivocality that may be of use to others.

Mixed Methods

An obvious reference point for our project is "mixed methods" research (Frechtling & Sharp, 1997; Johnson & Onwuegbuzie, 2004; Tashakkori & Teddle, 2003). Mixed methods have been defined as "the class of research where the researcher mixes or combines quantitative and qualitative research techniques, methods, approaches, concepts or language into a single study." (Johnson & Onwuegbuzie, 2004, p. 17). As reflected in this quote, mixed methods has generally been conceived of as a mixture of "quantitative" and "qualitative" research. Johnson & Onwuegbuzie (2004) discuss the complementary advantages of these traditions, stating for example that qualitative methods add meaning to quantified results, while quantification adds precision to qualitative descriptions. Mixed methods can also increase generalizability of results by assessing ecological and phenomenological validity through qualitative studies while warranting causal claims through controlled experimental manipulation of variables. Achieving this complementary synergy depends on effective strategies for mixing the methods. Johnson & Onwuegbuzie (2004) elaborate on strategies for combination of quantitative and qualitative research, and offer a mixed research process model. Creswell (2003) discusses three strategies classified as (1) *sequential*, (2) *concurrent triangulation*, and (3) *concurrent nested*. For example, in a sequential strategy, qualitative methods can be used to derive and quantitative methods to test a grounded theory. Concurrent application of methods can provide stronger evidence for a conclusion through corroboration or convergence of findings. Similar strategies may be found in this volume. For example, in the Fractions case study, multiple analytic methods were applied to identify "pivotal moments" in the classroom session. Only one pivotal moment was corroborated by convergence, but the lack of convergence was also informative (Lund, Chapter 8, this volume). In the Biology case study, a deliberate effort was made to incorporate the insights of Stahl's conversation analysis into a social network analysis by Goggins and Dyke (Chapter 29, this volume), exemplifying a concurrent nested strategy in which the qualitative method is incorporated into the quantitative one.

Mixed methods have their share of critics. Issues listed by Johnson & Onwuegbuzie (2004) generally fall into difficulties with doing mixed methods and research community readiness. Due to the diverse knowledge and skill required to be sufficiently expert in multiple traditions and the sheer the amount of work to simultaneously conduct multiple analyses, it is difficult for one person to pull off. This points to the advantage of collaboration between multiple researchers, to which we return below. Other difficulties pertain to lack of acceptance of mixed methods in traditionally mono-methodological disciplines, and insufficient collective knowledge for combining methods. Although the qualitative/quantitative divide has long been questioned (Howe, 1988), some critics view mixed methods as incoherent (Yanchar & Williams, 2006). Another danger is that when an investigator working within a major paradigm mixes methods, the minor paradigm becomes a "handmaiden", not appreciated for its own value (Dourish & Button, 1998). Opportunities to challenge the assumptions of the major paradigm or exploit dialectics and synergies between two equal paradigms may be missed.

All of the claimed advantages and some of the potential disadvantages of mixed methods apply to productive multivocality, but there are some ways in which productive multivocality is not identical to mixed methods. Mixing can occur on dimensions other than the common quantitative vs. qualitative research distinction. The productive multivocality project has found multiple voices even within a single tradition, for example, as seen in the different conceptions of "leadership" that developed in two methodologically very similar analyses in

Chapter 11 (Howley, Mayfield, et al., this volume). More importantly, the objectives are different: mixed methods research is successful if the methods harmoniously work together towards a conclusion, but productive multivocality is also intended to surface conflicts, and can be considered successful when this happens as long as commonalities and essential differences are separated and well understood. From the point of view of our objectives, a limitation of the single-investigator mixed-methods approach is that there is only one agent representing the methods, and hence no true dialogue between the voices of different traditions, as the dialogue is entirely intrasubjective. This problem can be addressed by involving a committed representative of each tradition in a cooperative endeavor that yet has potential for genuine intersubjective argumentation. Our project took this approach, and elucidating argumentation resulted, for example, concerning the grounding of interpretations and causal claims in the Origami Fractions case study, the quality of Bruno's understanding in the Electricty case study, and the role of the agent in the Biology case study.

But multivocal analysis does not succeed simply by applying mixed methods distributed across multiple analysts: additional strategies are required to manage distributed agency. Other projects in the past have also attempted analysis of shared data by multiple traditions, with limited success. We encountered some of the same problems as these projects, but had the advantage of iteration over several years in which we were able to explore strategies for achieving productive multivocality. Some of these strategies are discussed below.

Strategies for Productive Multivocality

We have found the following strategies for coordinating multiple analysts to be useful, and offer them as a guide for future efforts at productive multivocality.

Analyze the same data

If each investigator takes on a different phenomenon and distinct sources of data, there may be no substantial basis for dialogue, and investigators' ad-hoc explanations might remain unchallenged. *Sharing data and comparing analyses* provides at least the possibility that alternative accounts are juxtaposed. Many efforts at research collaborations have involved this strategy (e.g., Koschmann, 2011; Stahl, 2009) and technologically oriented investigators have proposed or developed standards and metadata to enable data exchange (e.g., Harrer, Monés, & Dimitracopoulou, 2009; Reffay, Betbeder, & Chanier, 2012).

Analyze from different perspectives

Achieving epistemological multivocality requires *assigning analysts from different traditions to the same data* (although theoretical multivocality also can exist within a single tradition, as we saw in the Chemistry case study). When mixing traditions, analysts will encounter challenges in achieving agreement on what data is worth considering, and addressing differences in data needs. For example, some traditions would not find data from an experimental setting to be worth considering, or might consider it in an entirely different light than the experimenter (as happened with the Biology case study). Statistical methods based on sampling theory generally require more data (e.g., in terms of length or number of conversations) than microanalytic traditions, an issue we encountered in the Fractions case study. Issues may also arise concerning what constitute an adequate record of the phenomenon—such as what constitutes a "transcript"—as we saw in the Electricity case study. However, an important point is that these issues are not necessarily barriers to productive multivocality: they are opportunities to surface implicit assumptions of traditions and to bring them into dialogue with each other.

Push the boundaries of traditions without betraying them

A related strategy is to *push analysts outside their comfort zone, while maintaining the integrity of their traditions*. We found that advances were made when analysts were asked to deal with data of a type they had not handled previously, as was the case with Trausan-Matu in the Fractions case study. However, concerns were also expressed that analysts so pushed were taking their traditions beyond what other members of the tradition would find comfortable. (Interestingly, these concerns were sometimes expressed by persons *not* in the traditions in question.) For example, we had discussions about whether Trausan-Matu (Chapter 6, this volume) should be generalizing adjacency pairs to include mental events, whether Chiu (Chapter 7, this volume-a) was being given enough data to meet the assumptions of statistical methods, and whether Stahl (Chapter 28, this volume) is violating the ethnomethodological tradition by attempting to generalize. Future efforts should seek a balance between pushing analysts to extend the value of their methods while staying grounded in their traditions, perhaps by discussing their innovations with other members of the traditions in question.

Begin with a shared pre-theoretical analytic objective

While needed, shared data is not enough. As we found in an early iteration of the project, analysts might ask entirely different questions about the data, resulting in analyses that are difficult to juxtapose because they construe the data differently. An additional strategy that provides further points of articulation is to *identify a shared but pre-theoretical concept as the analytic objective*. For example, beginning with the third workshop in our project, we posed analysts with the objective of identifying the *pivotal moments* in the collaboration. We left what constituted a "pivotal moment" unspecified, other than that such a moment (or event, episode, etc.) should be relevant to learning or collaboration. The deliberate vagueness solves a problem: over-specification of the analytic objective might privilege one tradition over another, as traditions differ in what they either consider worth investigating or what they are capable of identifying with their analytic toolkit. Left vague, "pivotal moment" served as a projective stimulus for the researcher/tradition. The different analyses that resulted could then be compared on the interesting questions of whether they identified the "same" moments, where and why they differed, and whether the moments identified by one tradition might lead to others to refine their approach. The concept (along with the data to which it was applied) served as a boundary object (Star & Griesemer, 1989)— an entity that could be understood and interpreted by different traditions, each in their own way, but with a shared referent (the data and the identified moments) that mutually ground dialogue. Another objective that played a similar role was that of identifying "leadership" in the Chemistry case study. Yet, shared data along with a vaguely specified shared objective may still not be sufficient. We found that further strategies for comparing the analyses that result are helpful.

Bring analytic representations into alignment with each other and the original data

A straightforward yet powerful strategy is to *bring analytic representations into alignment*. It is difficult to compare results if analyses use entirely different representations and segment and describe the data in different ways. While each tradition will need to retain those representations that are essential to what it means to work in the tradition, efforts to identify where analytic representations address the same temporal, spatial and semantic spans of the original phenomenon will be rewarded with greater understanding of the relationships between approaches. Alignment need not necessarily be successful or even possible: the reward is as much in the effort to align and the discussion that results from this effort as in the aligned representations that result.

We found that this strategy can be facilitated by appropriate use of tools. For example, analyses of the Group Scribbles corpus on fractions (which was later replaced with the electricity corpus) were brought into alignment and compared using the Tatiana analytic software by Dyke and Lund at our fourth workshop (Dyke et al., 2011). It helps if the representations reference some common coordinate system and make the analytic interpretations salient: representational affordances for supporting dialogue amongst analysts are discussed in Chapter 33 (Dyke, Lund, Suthers, & Teplovs, this volume). It may be necessary to *return to the original data record* to resolve disputes (e.g., as in Chapter 19): mutual reference to the timeline of a shared data recording helps here.

Assign a facilitator/ provocateur

The natural tendency for researchers is to focus on their own analyses, produce their results, and advocate for their viewpoint in communication with others. Researchers will put less effort into carefully examining others' analyses and performing comparisons. Of course, a commitment to do so is necessary for any meaningful collaboration of persons claiming to do multivocal analysis, but we must also acknowledge and plan for peoples' natural tendency as a barrier. A facilitator can serve various roles, including assisting in doing some of the work of aligning analytic results, and finding places where analysts disagree but may not have addressed their disagreement, as occurred in the Electricity case study (Suthers, Chapter 19, this volume).

Eliminate gratuitous differences

Efforts to align analytic representations will quickly make the need to *eliminate gratuitous differences* clear. Such differences include, for example, having chosen to analyze different temporal segments of a data stream, giving different names to the same entities (e.g., contributions), including or excluding private communications or nonverbal actions, etc. There are several examples in our project, not always successfully addressed. The Fractions and Chemistry corpora were fortunate in that analysts agreed on the temporal scope of data at the outset, and generally worked from the same transcripts, so did not need to iterate for this reason (Lund, Chapter 8, this volume). Analysts of the first Group Scribbles corpus on fractions differed on whether they looked at events in private workspaces as well as the public workspace, and on whether they considered nonverbal as well as verbal events (Suthers, Chapter 19, this volume-a). These differences were eliminated for a second pass, and analysts of the Electricity corpus did not differ in these ways, but the temporal scope of data considered varied widely for the latter corpus, resulting in only a small overlap where all analysts examined the same time period. Some differences are essential to the respective traditions participating, and must be respected. For example, Stahl (Chapter 28, this volume) ignored the experimental structure of the Biology data, choosing instead to perform an uptake analysis of a single chat session. Again, productive does not necessarily mean agreement, and the process of separating nonessential from essential differences will not only help make the later more salient but may also be rewarding in itself.

Iterate

Iteration is required to successfully realize the value of many of the other strategies. Gratuitous differences may emerge only after the first attempt to bring analytic representations into alignment, so some of the analyses may need to be reworked. Iteration is also useful to take advantage of what has been learned from the entire effort. For example, we have seen an analysis from one tradition spur an analyst working in a different tradition to consider a different conception of "pivotal moment" and re-do his analysis (Lund, Chapter 8; Shirouzu, Chapter 5, this volume).

Attend to the needs of the data providers

Data providers are also providing a valuable service. It takes work to provide data to others: collaborations that share this work or otherwise provide resources for it are more likely to succeed. Analysts should also be aware that data providers may have different objectives in the activity that produces the data, and it will not be perceived as helpful to critique that activity based on criteria that are not important to them or point out problems they are already aware of. This does not preclude making such critiques, but rather is a call to respect the other perspective in doing so. These points are illustrated by our experience with the Knowledge Forum (Fujita, Chapter 24, this volume) and Biology (Hmelo-Silver, Chapter 30, this volume) case studies: see also the summaries earlier in the present chapter. Data providers are taking a risk in exposing their activity to outside analysts, not only in exposing the details of their execution but also opening up the possibility that members of other traditions may question the value of the whole endeavor. Iteration in which analysts communicate their results candidly with data providers and then revise will more likely result in new understandings that are valued by both partners.

Reflect on your practice

The final and most important strategy we will note here derives from our argument that, while methods have biases, researchers have agency in applying them as tools and are not deterministically bound to the traditions those methods come from. Methods are based on data and analytic representations and ways of manipulating those representations to derive new representations. Methods also include practices in using these tools, such as how to select questions worth asking and situations worth studying, how to map situations to data representations, and how to interpret the analytic representations. The argument has been made that methods intrinsically bring with them theoretical and epistemological commitments. While we agree that there are commitments, we believe that it is important to examine how these commitments are transmitted and which are non-negotiable, rather than accepting a methodological determinism dogmatically. But making this determination requires the final strategy.

The strategy is to remove one's methodological eyeglasses and view and *dialogue about methods as object-constituting, evidence-producing and argument-sustaining tools*. This dialogue requires careful consideration of what methods (understood as inscriptions and means of operating on inscriptions, with associated practices) intrinsically bring with them, and what teleological, epistemological and theoretical commitments are made in the practices of applying these tools to a domain. It is our expectation that this reflection will be deeper when undertaken collectively rather than individually, and our hope that such collective reflection will help the community of researchers in multidisciplinary fields such as the learning sciences identify the conceptual centers of gravity that gives their work coherence, and identify and leverage the value of distinct disciplinary orbits around these centers for improving our understanding of the phenomenon as a whole.

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